Department for
Business, Energy
& Industrial Strategy

UK Offshore Energy Strategic Environmental Assessment

Future Leasing/Licensing for Offshore Renewable Energy, Offshore Oil & Gas and Gas Storage and Associated Infrastructure

OESEA4 Environmental Report

March 2022

Any enquiries regarding this publication should be sent to us at:
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General information

Why we are consulting

This Offshore Energy Strategic Environmental Assessment (OESEA4) Environmental Report has been prepared as part of the Department for Business, Energy and Industrial Strategy's (BEIS) Offshore Energy SEA programme, in accordance with the *Environmental Assessment of Plans and Programmes Regulations 2004* (as amended) (the SEA Regulations), which apply to any relevant plan or programme which relates either solely to the whole or any part of England[1], or to England and any other part of the United Kingdom. This SEA process aims to help inform offshore energy licensing and leasing decisions by considering the environmental implications of a proposed plan/programme and the potential activities which could result from its adoption.

The BEIS draft plan/programme under consideration is broad ranging and variously covers the range of energy related activities in the UK marine environment, including: further leasing for renewable energy (offshore wind, wave and tidal technologies), further licensing for offshore oil and gas exploration and production, and further leasing/licensing for hydrocarbon gas storage and unloading, carbon dioxide transportation and storage, and the offshore production and transport of hydrogen. The geographical scope of each aspect of the draft plan/programme varies based on devolved arrangements.

In fulfilment of regulations 13 and 14 of the SEA Regulations, this Environmental Report is being subject to consultation with the relevant consultation bodies and the public. The Department will consider comments received from the consultation in their decision making regarding the draft plan/programme. Following consultation, a Post Consultation Report will be prepared and placed on the SEA webpages collating the comments and the Department's responses to them. On adoption of the plan/programme a Statement will be published detailing:

- how environmental considerations have been integrated into the plan/programme
- how the Environmental Report has been taken into account
- how opinions expressed by the consultation bodies and public consultees on the relevant documents have been taken into account
- how the results of any consultations entered into with other Member States have been taken into account (if required)
- the reasons for choosing the plan/programme as adopted, in the light of the other reasonable alternatives dealt with; and
- the measures that are to be taken to monitor for potential significant environmental effects of the implementation of the plan/programme.

[1] Including the territorial waters of the United Kingdom that are not part of Northern Ireland, Scotland or Wales, and waters in any area for the time being designated under Section 1(7) of the *Continental Shelf Act 1964*.

Consultation details

Issued: 17/03/22

Respond by: 27/05/22

Enquiries to:

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AB1 Building
Crimon Place
Aberdeen
AB10 1BJ

Tel: 01224 254015

Email: oesea@beis.gov.uk

Consultation reference: OESEA4 Environmental Report

Audiences:

Those consultation bodies defined under regulation 12(5) of *The Environmental Assessment of Plans and Programmes Regulations 2004* (as amended), as listed in Section 7.1.5 of this report, and additionally, the Joint Nature Conservation Committee, the Marine Management Organisation, Marine Scotland, and all other interested stakeholders and the public.

Territorial extent:

The territorial and offshore waters England, Wales, Scotland and Northern Ireland, but excluding the territorial and offshore waters of Scotland and Northern Ireland for the leasing of offshore renewable energy, and the territorial waters of Scotland for the storage of carbon dioxide.

How to respond

Please send responses either electronically or in writing to the following:-

By Email to: oesea@beis.gov.uk

Write to:

Offshore Energy SEA4 Consultation
AB1 Building
Crimon Place
Aberdeen
AB10 1BJ

When responding, please state whether you are responding as an individual or representing the views of an organisation.

Confidentiality and data protection

Information you provide in response to this consultation, including personal information, may be disclosed in accordance with UK legislation (the *Freedom of Information Act 2000*, the *Data Protection Act 2018* and the *Environmental Information Regulations 2004*).

If you want the information that you provide to be treated as confidential please tell us, but be aware that we cannot guarantee confidentiality in all circumstances. An automatic confidentiality disclaimer generated by your IT system will not be regarded by us as a confidentiality request.

We will process your personal data in accordance with all applicable data protection laws. See our privacy policy.

We will summarise all responses and publish a summary on the OESEA pages of GOV.UK. The summary will include a list of names or organisations that responded, but not people's personal names, addresses or other contact details.

Quality assurance

This consultation has been carried out in accordance with the government's consultation principles.

If you have any complaints about the way this consultation has been conducted, please email: beis.bru@beis.gov.uk.

Non-Technical Summary

Introduction

This Environmental Report has been prepared as part of the United Kingdom Department for Business, Energy and Industrial Strategy (BEIS) Offshore Energy Strategic Environmental Assessment (OESEA) programme and is hereafter referred to as OESEA4. This SEA process aims to help inform licensing and leasing decisions for offshore energy by considering the environmental implications of the proposed plan/programme and the potential activities which could result from their implementation.

Previous SEAs undertaken as part of this programme included UK OESEA in January 2009, UK OESEA2 in February 2011 and UK OESEA3 in July 2016, which built on a series of previous regional scale SEAs undertaken since 1999. OESEA considered the environmental implications of a draft plan/programme to enable: further seaward rounds of oil and gas licensing, including gas storage in UK waters; and further rounds of offshore wind farm leasing in the UK Renewable Energy Zone (now Exclusive Economic Zone)[2] and the territorial waters of England and Wales to a depth of 60m. During 2010, an exercise to update and extend the scope of the OESEA Environmental Report was undertaken, with OESEA2 covering further licensing/leasing for offshore energy including oil and gas, gas storage including carbon capture and storage (CCS) and marine renewables (wind, wave and tidal technologies). OESEA3 covered the same plan/programme elements of OESEA2, and provided an update to the baseline, policy context and assessment of effects.

Since OESEA3, as with previous SEAs, BEIS has maintained an active SEA research programme; identifying information gaps (some of which were outlined in previous SEA Recommendations), commissioning new research where appropriate, and promoting its wider dissemination through a series of research seminars[3]. This has also involved continued engagement with the SEA Steering Group and review of the information base for the SEA, including the environmental baseline, other relevant plans and programmes, and policy and regulation of relevance to the plan.

The purpose of the OESEA4 Environmental Report is to

- Consider the environmental implications of the BEIS draft plan/programme to enable further licensing/leasing for offshore energy (marine renewables including wind, wave, tidal stream and tidal range, oil and gas, hydrocarbon gas storage, and carbon dioxide storage, and offshore hydrogen production and transport). This includes consideration of the implications of alternatives to the plan/programme and consideration of potential interactions with other users of the sea
- Inform the UK Government's decisions on the draft plan/programme
- Provide routes for public and stakeholder participation in the process

[2] this part of the plan/programme did not include the territorial waters of Scotland and Northern Ireland.
[3] https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process#offshore-energy-sea-research-programme

This non-technical summary provides a synopsis of the OESEA4 Environmental Report, including its conclusions and recommendations.

What is the draft plan/programme?

The draft plan/programme subject to this SEA needs to be considered in the context of overall UK energy supply policy and greenhouse gas emissions reduction targets.

Evidence for human influenced climate change is now unequivocal. Over the last century anthropogenic sources of greenhouses gases (primarily carbon dioxide but also a range of others including methane) have amplified the natural greenhouse effect and are estimated to have caused approximately 1.09°C of global surface warming above pre-industrial levels (likely range of 0.95°C to 1.2°C). Associated wide ranging environmental changes have been projected, including: increased atmospheric temperatures, ocean warming and changes to ocean circulation, rising sea levels, more frequent extreme weather events and ocean acidification, with associated socio-economic and environmental effects. The evidence relating to global climate change has been comprehensively presented by, amongst others, the Intergovernmental Panel on Climate Change (IPCC), which are due to publish their Sixth Assessment Report in 2022 following a draft of their Working Group I report in 2021, which sets out the physical science base for our current understanding of climate change and its related effects. In order to limit the potential for the worst effects of climate change, global average temperature rise needs to be limited to 1.5°C. The Paris Agreement was adopted in 2015 by the parties to the United Nations Framework Convention on Climate Change, which includes the UK, and aims to hold the increase in global average temperatures well below 2˚C above pre-industrial levels, and to pursue efforts to limit this to 1.5˚C. In order to achieve such levels of temperature increase, greenhouse gas emissions need to reach net zero by 2050.

The UK Government has committed to achieving net zero greenhouse gas emissions by 2050 relative to a 1990 baseline, with the target made legally binding in 2019. The SEA will consider the contribution of the draft plan/programme towards the UK's new interim 2030 target, which is a reduction in greenhouse gas emissions by 68% against a 1990 baseline, and to the overall net zero target. The Government's Net Zero Strategy was published in October 2021 in response to the setting of the sixth Carbon Budget (for 2033-2037). It sets out policies towards that budget, Nationally Determined Contributions under the Paris Agreement (i.e. the national target of each Party towards meeting the Agreement, for the UK this being equal to interim target noted above), and a vision towards net zero being achieved by 2050. The strategy builds on earlier proposals made in the Energy White Paper: Powering our Net Zero Future and includes policies of key relevance to the draft plan/programme assessed by OESEA4. These include those on power (including the delivery of 40GW of fixed foundation offshore wind and 1GW of floating offshore wind by 2030 and a review of offshore transmission infrastructure to deliver a more coordinated approach), fuel supply and hydrogen (including the delivery of 5GW of hydrogen capacity by 2030 and a number of policies relevant to offshore oil and gas including periodic seaward licensing climate compatibility checkpoints, to help facilitate electrification of platforms, achieve zero routine flaring and venting by 2030, or sooner, and drive down upstream emissions), and, industry (including the capture, transport and storage of 20-30 million tonnes of carbon dioxide per year by 2030).

Despite the focus of the above strategy and related initiatives on a move to low carbon energy sources, it is also recognised that the oil and gas sector continues to be highly productive, and has a role in maintaining the UK's security of supply during the transition to a low carbon economy. Recognising that the oil and gas sector has to make a contribution to the net zero target, the Oil & Gas Authority updated their strategy (the OGA Strategy) such that its central obligation commits offshore oil and gas licence holders, operators and installation owners, to take appropriate steps to assist the Secretary of State in meeting the net zero target.

It should be noted that the draft plan/programme being assessed is limited in its remit to upstream elements of energy production. The end use of any electricity or hydrocarbons produced is subject to separate considerations beyond the scope of this assessment, including policies to deliver net zero across the wider economy.

The draft plan/programme covered by this SEA will contribute to the Government targets outlined above by enabling future rounds of renewable leasing for offshore wind, wave and tidal devices, and licensing/leasing for seaward oil and gas rounds and gas storage (including carbon dioxide storage), and the production of hydrogen offshore. The main objectives of the draft plan/programme are to enhance the UK economy, contribute to the achievement of carbon emission reductions and security of energy supply, but without compromising biodiversity and ecosystem function, the interests of nature and heritage conservation, human health, or material assets and other users.

The geographical limits of areas mentioned below are shown in Figures 3 and 4. The elements of the draft plan/programme are:

Renewable Energy:

Offshore Wind – to enable further offshore wind farm leasing in the relevant parts of the UK Exclusive Economic Zone and the territorial waters of England and Wales, to contribute to the UK target of up to 40GW of offshore wind generation capacity deployed by 2030 (including 1GW of floating offshore wind). The technologies covered will include fixed and tethered turbines. Tethered turbines will only be considered in waters up to 250m. The Scottish Renewable Energy Zone and the territorial sea limit of Scotland and Northern Ireland are not included in this part of the plan/programme.

Wave – future leasing in the relevant parts of the UK Exclusive Economic Zone[4] and the territorial waters of England and Wales. The Scottish Renewable Energy Zone[5] and the territorial sea limit of Scotland and Northern Ireland are not included in this part of the plan/programme. In view of the relatively early stage of technological development, a target generation capacity is not set in the draft plan/programme.

Tidal Stream – future leasing in the relevant parts of the UK Exclusive Economic Zone and the territorial and internal waters of England and Wales. The Scottish Renewable Energy Zone and the territorial sea limit of Scotland and Northern Ireland are not included in this part of the plan/programme. In view of the relatively early stage of technological development, a target generation capacity is not set in the draft plan/programme. Similarly, a minimum average tidal current velocity threshold is not proposed.

Tidal Range – future leasing in the internal and territorial waters of England and Wales. It is considered unlikely that there will be tidal range developments outside of territorial waters.

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[4] *The Exclusive Economic Zone Order 2013*
[5] *The Renewable Energy Zone (Designation of Area) (Scottish Ministers) Order 2005*

Oil & Gas:

Exploration and production – further Seaward Rounds of oil and gas licensing of the UK territorial sea and UK Continental Shelf (UKCS), subject to the outcome of periodic Climate Compatibility Checkpoints.

Hydrocarbon gas importation and storage – further licensing/leasing for unloading and underground storage of hydrocarbon gas in UK waters (territorial sea and the relevant parts of the UK Exclusive Economic Zone), including hydrocarbon gas storage in other geological formations/structures including constructed salt caverns, and the offshore unloading of hydrocarbon gas.

Carbon Dioxide:

Carbon dioxide (CO_2) transportation and storage – further licensing/leasing for underground storage of CO_2 gas in UK waters (the UK Exclusive Economic Zone and relevant territorial sea, excluding the territorial sea limit of Scotland[6]). The UK target is to have Carbon Capture Usage and Storage (CCUS) deployed in two industrial clusters by the mid-2020s, and a further two clusters by 2030, with an ambition to capture and store 20-30MtCO_2 per year by 2030. OESEA4 includes CO_2 storage in geological formations/structures including depleted reservoirs (and for enhanced oil recovery), saline aquifers and constructed salt caverns.

Hydrogen:

The offshore production and transport of hydrogen. This includes any offshore aspect of "power to gas" which uses excess renewable electricity and electrolysers to produce hydrogen (green hydrogen) and the offshore carbon dioxide transport and storage aspects of onshore hydrogen production from natural gas (blue hydrogen). An ambition of 5GW (equating to 42TWh) of low-carbon hydrogen production capacity by 2030 has been set, with the hope that 1GW capacity could be delivered by 2025. Storage of hydrogen in geological formations is not expected before 2030 but work to identify and prepare sites for storage could take place in advance of this.

What are the alternatives to the draft plan/programme?

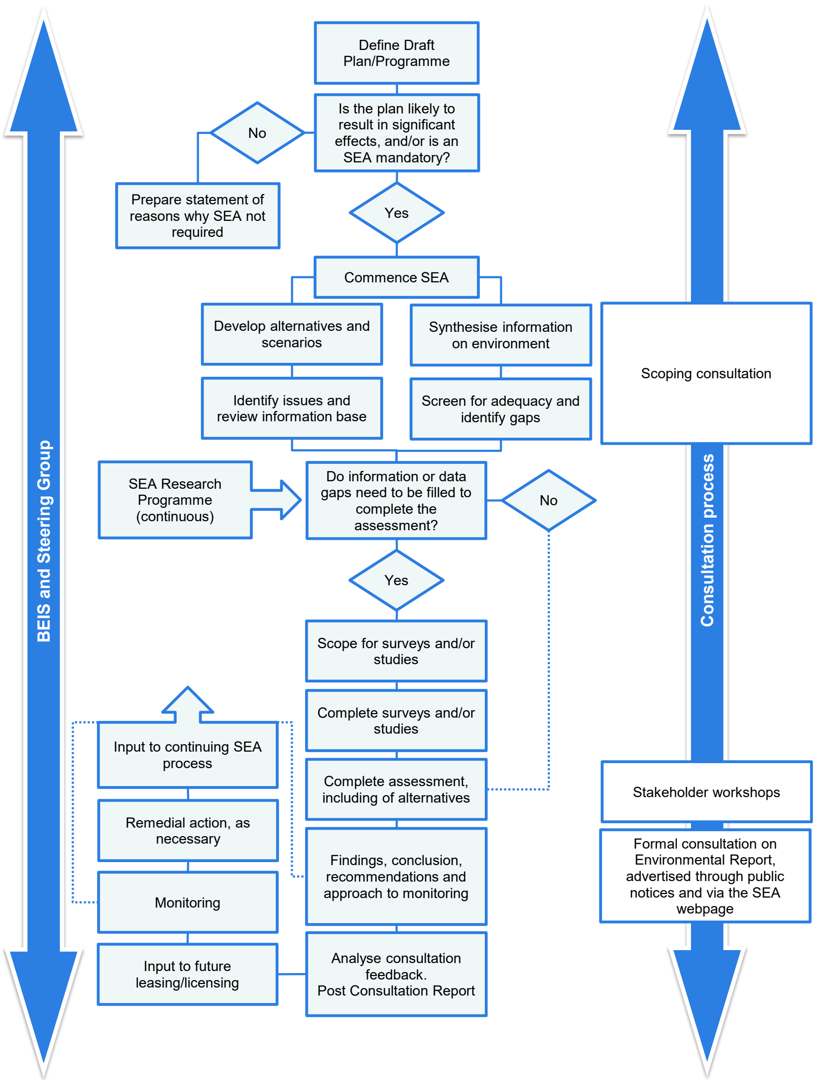
The following alternatives to the draft plan/programme have been assessed in the SEA:

1. Do not proceed further licensing and/or leasing for one or more aspects of the draft plan/programme
2. Proceed with further licensing or leasing
3. Proceed with further licensing or leasing, but restrict these spatially or temporally

[6] *The Storage of Carbon Dioxide (Licensing etc.) (Scotland) Regulations 2011, The Storage of Carbon Dioxide (Amendment of the Energy Act 2008 etc.) Regulations 2011*

The BEIS SEA process

Figure 1: Overview of the SEA process



The SEA process aims to help inform licensing and leasing decisions by considering the environmental implications of the proposed plan/programme and the potential exploration, development and energy production activities which could result from its implementation.

The BEIS offshore energy SEA process has developed over time, drawing in concepts and approaches from a variety of individuals, organisations and other SEAs as well as addressing the requirements of legislation and guidance. The process followed for this SEA and temporal sequence of events is summarised to the left, but note that certain activities such as information gathering continue throughout the process.

Formal scoping for OESEA4 with the statutory Consultation Bodies/Authorities and other stakeholders was conducted from March 2021; a Government Response to the scoping feedback is available on the SEA webpages of the gov.uk website.

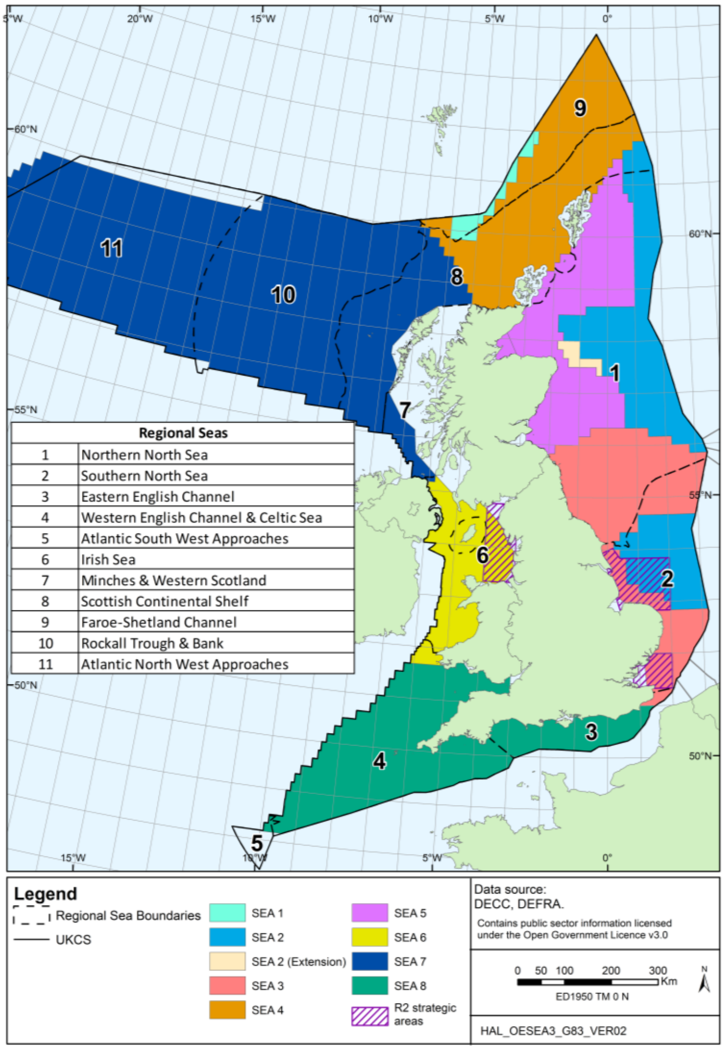
Since 1999, the Department has conducted ten SEAs of the implications of further licensing of the UK Continental Shelf (UKCS) for oil and gas exploration and production (SEAs 1-7, OESEA (incorporating SEA 8), OESEA2 and OESEA3), and an SEA for a second round (R2) of wind leasing – see the tabulation below and Figure 2 overleaf:

SEA	Area	Sectors covered	Year	Licensing/ leasing round
SEA 1	The deep water area along the UK and Faroese boundary	Oil & Gas	2001	19th Round
SEA 2	The central spine of the North Sea which contains the majority of existing UK oil and gas fields	Oil & Gas	2002	20th Round
SEA 2 extension	Outer Moray Firth	Oil & Gas	2002	20th Round

SEA	Area	Sectors covered	Year	Licensing/ leasing round
SEA 3	The remaining parts of the southern North Sea	Oil & Gas	2003	21st Round
R2	Three strategic regions off the coasts of England and Wales in relation to a second round of offshore wind leasing	Offshore wind	2003	Round 2
SEA 4	The offshore areas to the north and west of Shetland and Orkney	Oil & Gas	2004	22nd Round
SEA 5	Parts of the northern and central North Sea to the east of the Scottish mainland, Orkney and Shetland	Oil & Gas	2005	23rd Round
SEA 6	Parts of the Irish Sea	Oil & Gas	2006	24th Round
SEA 7	The offshore areas to the west of Scotland	Oil & Gas	2008	25th Round
OESEA	UK offshore waters and territorial waters of England and Wales	Oil & Gas, Offshore wind	2009	26th Round Round 3
OESEA2	UK offshore waters and territorial waters of England and Wales	Oil & Gas, Offshore wind, wave and tidal stream, gas and carbon dioxide storage	2011	27th Round
			2014	28th Round
OESEA3	UK offshore waters and territorial waters of England and Wales	Oil & Gas, Offshore wind, wave and tidal stream, gas and carbon dioxide storage	2016	29th Round 2016 Supplementary Round
			2017	30th Round
			2018	31st Round 31st Supplementary Round
			2019	32nd Round Round 4

In addition, SEA work was undertaken by the Department in 2010 for the potential exploitation of Severn Tidal Power (Severn Tidal Power Feasibility Study).

Figure 2: Spatial Coverage of Previous Offshore Energy SEAs and Regional Sea Boundaries



In addition to scoping, virtual stakeholder meetings were held February 2022 at which stakeholders from a wide variety of organisations, sectors and areas participated. The stakeholder input on the information base and other issues of relevance to the SEA is summarised in Appendix 4 of the Environmental Report.

The Environmental Report and draft plan/programme are being issued for an 8 week public consultation period. The Department will consider comments received from consultation in the decision making regarding the plan/programme. A Post Consultation Report will be prepared and placed on the SEA pages of the gov.uk website collating the comments and the Department's responses to them.

Environmental Report

The Environmental Report of OESEA4 provides relevant information for formal consultation with the statutory Consultation Bodies/Authorities and with the public regarding the implications of the draft plan/programme and its alternatives. In accordance with the SEA Regulations, the following receptors that are likely to be affected were included within the scope of the assessment.

- Biodiversity, habitats, flora and fauna
- Geology, substrates and coastal geomorphology
- Landscape/seascape
- Water environment
- Air quality
- Climate and meteorology
- Population and human health

- Other users, material assets (infrastructure, other natural resources)
- Cultural heritage, including architectural and archaeological heritage
- Conservation of sites and species
- Interrelationships of the above

Information on the environmental baseline and its likely future evolution has been grouped into these subject areas, with the assessment sections being organised by identified sources of potentially significant effect.

The key points and conclusions of the assessment are summarised in the sections below.

What areas are included in the SEA?

For offshore renewable energy this SEA considers potential leasing in the relevant areas of the UK Exclusive Economic Zone (EEZ), and also the territorial waters of England and Wales. The area covered by the Scottish Renewable Energy Zone and Northern Irish waters within the 12 nautical mile territorial sea limit are not covered by renewable energy aspects of the plan – see Figures 3 and 4 below. For gas storage and carbon dioxide storage, the SEA considers potential licensing/leasing in relevant UK territorial waters and the UK EEZ (note CCS in Scottish territorial waters is a devolved matter and so is not covered in the OESEA4 draft plan/programme). For offshore (seaward) oil and gas licensing, this SEA covers all UK waters.

Overview of the Environment

The UK has a rich marine biodiversity reflecting both the range of habitats from estuaries, through coastal waters to depths of >2400m, and its position where several biogeographical provinces overlap. Some species and habitats are naturally rare, whilst others are endangered by human activities, and actions to protect and promote biodiversity are being taken at many levels including national, European and global.

The bird fauna of the UK is western Palaearctic, that is the great majority of species are found widely over western Europe and extend to western Asia and northern Africa. There are 3 regular patterns of species occurrence: resident, summer visitors (to breed) and winter visitors. Some of the summer visitors undertake long migrations to overwinter in southern Africa or South America. The seabird community in the UK comprises a number of gull, auk, tern and skua species, while numerous waders, ducks, and geese make up seasonal and year-round assemblages in coastal wetlands. A few species are found only or predominantly in the UK. For example, Manx shearwaters where the three Pembrokeshire islands of Skomer, Skokholm and Middleholm are estimated to hold some 50%, and the Isle of Rum off western Scotland between a quarter and a third of the world’s total breeding population.

Geographical coverage of the SEA

Figure 3: Areas mentioned in the text

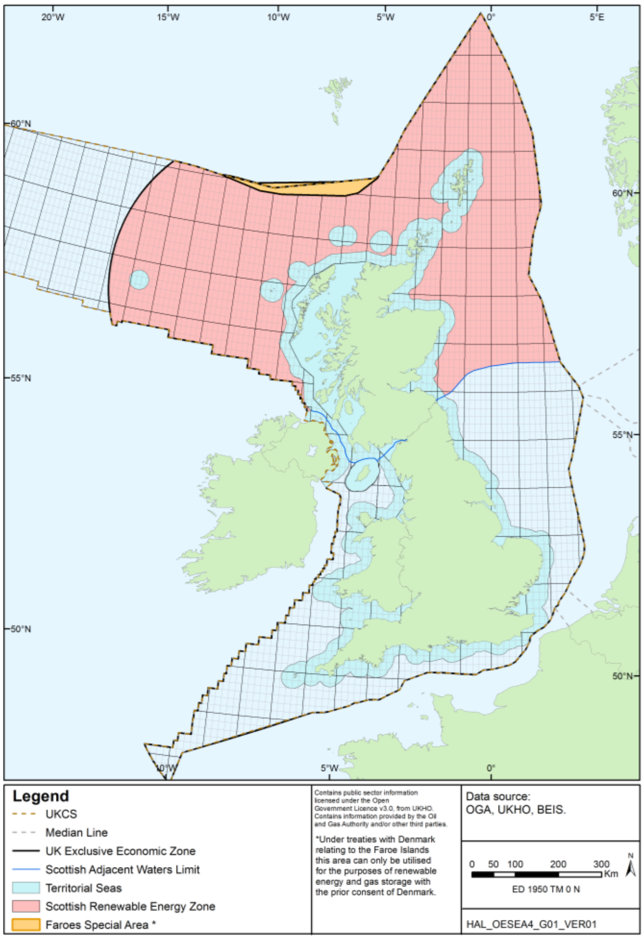
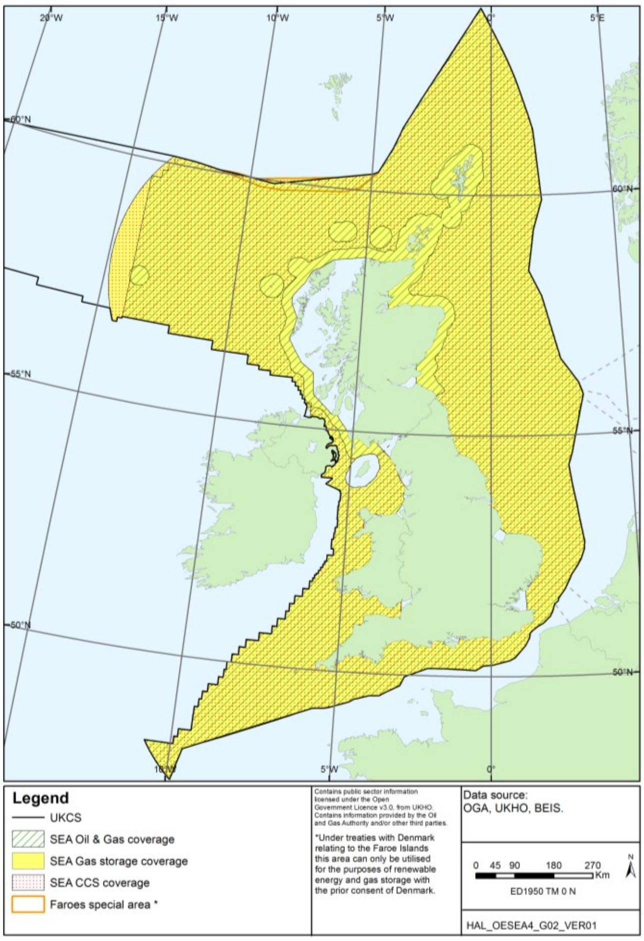


Figure 4: Coverage for oil and gas, gas storage, CCS and marine renewables



Many of the species of cetaceans found in UK waters have a worldwide distribution, although a number have restricted ranges, typically temperate to sub-Arctic or Arctic waters of the North Atlantic. British whales and dolphins include resident and migrant species (regularly moving through the area to and from feeding and breeding grounds) and vagrants (accidental visitors from the tropics or polar seas). The most abundant cetacean in UK waters is the harbour porpoise. The SCANS-III survey completed in the summer of 2016 (Hammond *et al.* 2017), provided abundance estimates for a wide range of species, including: harbour porpoise, bottlenose dolphin, Risso's dolphin, white-beaked dolphin, white-sided dolphin, common dolphin, striped dolphin, pilot whale, all beaked whale species combined, sperm whale, minke whale and fin whale. Two species of seal breed in the UK; the grey seal has a North Atlantic distribution with the UK holding over 40% of the world population; and the harbour seal, found along temperate, sub-Arctic and Arctic coasts of the northern hemisphere, with the UK population representing over 5% of the global total. Otters inhabit a variety of aquatic habitats, with some populations feeding in shallow, inshore marine areas. The most important otter populations utilising coastal habitats occur in western Scotland, Shetland, west Wales and the Wash and north Norfolk coast. Small numbers of the Nathusius' pipistrelle bat occur seasonally over UK waters on migrations between the UK and mainland Europe.

A wide range of biogeographic distribution patterns are shown by the fish in UK waters. The majority of continental shelf species have a North East Atlantic/northern Atlantic distribution, although a proportion are found globally in the tropics/subtropics and others have a circum-polar pattern of occurrence. Widely distributed species often include local stocks with distinct breeding times and locations (e.g. herring). Widespread pelagic species include herring and mackerel, particularly around the western and northern parts of the UK. Demersal species include gadoids (e.g. cod, whiting) and flatfish (e.g. plaice, dab). Demersal communities tend to be more diverse in southern areas of the UK. Diadromous fish in UK waters include sea trout, Atlantic salmon and European eel, with significant recent declines reported for both salmon and eel. A number of sharks and rays are present in UK waters, including the basking shark for which western coasts appear particularly important. Deep water fish show different distribution patterns with major differences occurring north and south of the Wyville Thomson Ridge (ca. 60°N), and a distinct species group found in the cold waters of the Faroe-Shetland Channel and Norwegian Sea. Widespread commercial shellfish species include crustaceans (e.g. *Nephrops*, brown crab), bivalve molluscs (e.g. scallops, cockles) and gastropod molluscs (e.g. whelks). Many of these species, such as *Nephrops* and scallops, are closely tied to particular seabed sediments and so occupy distinct grounds. Virtually all commercially fished species are heavily exploited although there is some evidence of recovery for some stocks.

In broad biogeographical terms, the planktonic flora and fauna of UK waters is part of the North-East Atlantic Shelves Province which extends from Brittany to mid-Norway. In addition, the deeper Faroe-Shetland Channel and areas to the north are within the Atlantic sub-Arctic Province. Each province can be subdivided according to hydrography and plankton composition.

The composition of the seabed fauna of the UK reflects the intersection of four biogeographical zones:

- Boreal Province including the North and Irish Seas
- Lusitanian-Boreal Province comprising the Celtic Sea and west coasts of Ireland and Scotland
- Arctic Deep-Sea Province, a deep water zone centred on the Norwegian Sea but extending into the Faroe-Shetland and Faroe Bank Channels
- Atlantic Deep-Sea Province, a deep water zone to the west of northeast Europe

Within each Province it is possible to distinguish a series of faunal communities inhabiting specific sediment types and depth ranges. Often these communities extend over wide areas (e.g. the fine sands of the central North Sea and the sandy muds of the Fladen Ground in the northern North Sea) and include both infauna and epifauna. In addition, there are a number of highly localised habitats and communities, including reefs of long lived horse mussels and cold water corals, where high biodiversity is accompanied by high sensitivity to human pressures. Habitat characterisation across the UKCS continues to improve, including through the efforts made in identifying, designating and monitoring MPAs. A large proportion of the seabed of the UK continental shelf and upper slope is physically disturbed by fishing and other activities.

The distribution of geological strata in the UKCS is determined by past geological and geomorphological processes. The distribution of sediments and certain topographic features is a function of the underlying geology, and millennia of aeolian, fluvial and glacial activity both in the marine and terrestrial environment. The distribution of sediments and deep geological structure of the UKCS, and the North Sea in particular, is quite well known, particularly in areas of mature oil and gas production which have been extensively explored since the 1960s. Oil and gas reserves are dependent on viable source rocks and a suitable impermeable cap-rock, and these reservoirs are responsible for the distribution of much offshore activity. Certain topographic features are notable, primarily for the quality of habitat they provide, and these are bound by geology (e.g. Haig Fras) or sediment type (e.g. north Norfolk sandbanks). There are over 100 estuaries in England and Wales of relevance to the draft plan, which can be divided into a number of broad geomorphological types. Potential areas which may be suitable for gas storage and CCS include hydrocarbon reservoirs, halite deposits and saline aquifers.

The UK lies within temperate latitudes and the climate is generally mild. Numerous easterly moving depressions meet the UK in the west leading to a gradient of relatively high wind speeds and precipitation in the exposed west and relatively low wind speeds and precipitation in the sheltered south and east. The upland nature of much of the west coast also contributes to this west-east gradient, with topography-induced enhanced precipitation, particularly in the north-west. The UK has a strong maritime influence, which has the effect of reducing the diurnal and annual temperature ranges; such effects are most notable at the coast and on islands (e.g. Orkney, Shetland). The North Atlantic Oscillation has also been linked with variations in UK sea surface temperatures, wind strength, direction and rainfall. Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Related changes include increase in sea-level, possibly more changeable and extreme weather, and alteration to meteorological and hydrographical conditions.

Whilst air quality is not monitored routinely offshore, regular air quality monitoring is carried out by local authorities in coastal areas adjacent to each Regional Sea. The air quality of all local authorities is generally within national standards set by the UK government's air quality strategy though a number of Air Quality Management Areas have been declared to deal with problem areas, primarily related to road transport. Industrialisation of the coast and certain inshore areas has led to increased levels of pollutants in these locations which decrease further offshore, though oil and gas platforms provide fixed point sources of atmospheric emissions. Shipping emissions represent a significant source of pollutants with emission control areas in operation (sulphur oxide) or approved (nitrogen oxide) in the North Sea.

The coasts and seas of the UK are intensively used for numerous activities of local, regional and national importance including coastally located power generators and process industries, port operations, shipping, oil and gas production, fishing, aggregate extraction, military practice, as a location for submarine cables and pipelines and for sailing, racing and other recreation. At a local scale, activities as diverse as saltmarsh, dune or machair grazing, seaweed harvesting or bait collection may be important. Population is also variable. General trends observed are lower population densities in coastal areas around much of the south-west of England, west and north Wales, the far north of England, and much of Scotland excluding the central belt. The highest population densities in coastal areas are around much of south-east England, part of north-east England, the Firths of Forth and Clyde, part of north-west England, south Wales and around the Severn Estuary. These areas are typically where conurbations are largest and most numerous.

Landscape, and by extension seascape, is defined by the European Landscape Convention as "an area perceived by people, whose character is the result of the action and interaction of natural and/or human factors", and can be separated into areas of sea, land and intervening coastline, and more recently is described in the Marine Policy Statement as, "landscapes with views of the coast or seas, and coasts and the adjacent marine environment with cultural, historical and archaeological links with each other." The coasts and seas of the UK have a diverse character, which has or is being defined through the existing and ongoing identification of landscape and seascape character areas which account for the key characteristics of particular areas. Such characterisation and assessment may be undertaken at the regional and more local scale. The protection of areas regarded to be of particular importance in full or part for their landscape, has to date in the UK been through designation of, for example Areas of Outstanding Natural Beauty, National Scenic Areas and National Parks, however the wider recognition of landscape in the UK is now being brought about through national and regional planning policy, including marine planning.

Cultural heritage the UK relevant to OESEA4 includes sites on the modern coast which date to some of the earliest settlements in Britain (potentially to as early as 700-900,000 years ago) and submerged sites in shelf seas which were exposed during previous glacial periods. Later submerged heritage includes a significant shipwreck record and aircraft losses which predominantly relate to previous world wars. Designated sites are relatively few in number compared to those which are recorded, and those recorded are very few against the potential resource. With the exception of shipwreck, all designated sites to date are terrestrial.

Context to the draft plan/programme

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) is an important mechanism through which Governments of the western coasts and catchments of Europe, together with the European Union, cooperate to protect the marine environment of the North-East Atlantic. The OSPAR Commission established a network of Marine Protected Areas (MPAs) following Recommendation 2003/3 on a network of marine protected areas. It aimed to complete a joint network of MPAs by 2016 that, together with the Natura 2000 network, is ecologically coherent and well managed. As part of the UK implementation of such areas, the *Marine and Coastal Access Act 2009* and the equivalent Acts of devolved administrations provide powers to designate Marine Conservation Zones (MCZs) in England, Wales and Northern Ireland, and Marine Protected Areas (MPAs) in Scotland (see Appendix 1j). The UK has nominated 366 sites to the OSPAR network, covering ~41.1% of the UK's EEZ.

OSPAR periodically publishes assessments in the form of Quality Status Reports (QSRs) of the North-East Atlantic and its sub-regions, the last QSR was published in 2010, with an intermediate assessment produced in 2017. The next QSR is due to be published in 2023.

The *Marine Strategy Regulations 2010* require the development of five elements of the marine strategy: (1) the assessment of marine waters; (2) the determination of the characteristics of good environmental status for those waters (note these are qualitatively described in Annex I to the Directive); (3) the establishment of environmental targets and indicators; (4) the establishment of a monitoring programme; (5) the publication of a programme of measures. The key objectives of the Marine Strategy Framework Directive 2008/56/EC which the Regulations originally transposed (also see Section 2.2.6) are to achieve good environmental status (GES) of marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. The Marine Strategies for the UK must contain a detailed assessment of the state of the environment, a definition of good environmental status at regional level, and the establishment of clear environmental targets and monitoring programmes. To fulfil the requirements of the Regulations, the UK has prepared documents (e.g. the Marine Strategy Parts 1, 2 and 3, and proposals for UK monitoring programmes and programmes of measures to maintain or achieve GES, including updates to these). The Regulations require that programmes of measures be established to achieve GES, and that these include spatial protection measures contributing to coherent and representative networks of marine protected areas. Analogous to the contribution to the wider OSPAR MPA network, existing and proposed Natura 2000 and MCZ/MPA sites will contribute to this.

The Marine Strategy complements measures being undertaken as part of the UK implementation of the Water Framework Directive (WFD), particularly in coastal waters where geographical scope of the Directives overlap (out to 1nm in England and Wales, and 3nm in Scotland), and also in transitional waters such as estuaries. Whilst the implementation of WFD and MSFD may be complementary in these areas in their objectives (e.g. particularly in relation to water chemical quality and some aspects of ecological quality and hydromorphological quality), for coastal waters MSFD only covers those aspects of GES not already covered by the WFD. The Regulations implementing the above Directives have been amended so that they continue to function following the UK's exit from EU (see Section 2.2.6).

Marine planning in the UK has been taking place across different timescales. All plans covering English[7], Welsh and Scottish waters have now been adopted (other than Scottish Marine Regional Plans), but the plans for Northern Ireland are still in preparation (Figure 2.1). All of the plans are consistent with the UK Marine Policy Statement, and have taken a similar approach to policies (general and sectoral) and policy wording. The Scottish National Marine Plan was adopted in 2015, and the Welsh National Marine Plan (WNMP) in 2019, with English plans adopted across the years 2014-2021. The Department of Agriculture, Environment and Rural Affairs (DAERA) continue to develop the Marine Plan for Northern Ireland, which was subject to consultation in 2018.

Marine plans in the UK have, to date, been written at a strategic level which largely consolidates and clarifies existing legal and policy arrangements, albeit with a regional focus, and in most instances do not attempt to be spatially explicit, for example by indicating defined zones for development or where development would be precluded. The plans rather identify potential resource and constraints (including through mapping), with policies that seek to balance environment, economic and social considerations in decision making and consent applications. This includes the promotion of certain activities such as offshore wind, or the safeguarding of strategic resources. As these are the first iteration of marine plans, subsequent revisions may be expected to be more spatially explicit. Planning authorities activities go beyond the documentation of the plans and have included commissioning work to improve the evidence base for marine planning and to support consenting[8].

The adopted and draft marine plans all contain policies of relevance to the draft plan/programme and OESEA4, covering both offshore hydrocarbons, renewable energy and carbon dioxide storage. The Marine Plans covering English waters provide both strict safeguarding of areas of existing oil and gas production, and also new development proposals. For offshore renewables, existing leases or agreements for lease are provided a level of safeguarding by requiring proposals to demonstrate they will not reduce the ability to construct, operate or decommission planned projects in areas held under lease. The East Marine Plans contain separate policies for wind and tidal stream but subsequent plans contain the same policies for all marine renewables. A similar policy which aims to safeguard key resource areas for carbon dioxide storage is contained in the East Marine Plans, but is not included in the other English marine plans.

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[7] https://www.gov.uk/government/news/adoption-of-marine-plans-marks-big-step-forward-for-englands-seas
[8] https://www.gov.uk/government/publications/evidence-and-the-marine-management-organisation-mmo

The WNMP plan identifies and maps the key resource areas for different offshore renewables, including wave, tidal stream, tidal range and wind, and provides accompanying supporting policies and links to safeguarding policies. These policies promote the de-risking of low carbon energy sources and support developing strategic resource areas in order to safeguard relevant resources. Note that strategic resource areas have not been identified to date. WNMP policies on offshore oil and gas recognise the continued role such resources will have during the transition to low carbon energy sources and the obligations set out in the OGA Strategy, and support the development of CCUS technologies, but are also explicit that Welsh Government policy is to avoid continued extraction of fossil fuels in intertidal areas, estuaries and coastal inlet waters that fall within the Welsh onshore licensing area (note, these areas are not included in the OESEA4 draft plan/programme).

The draft Marine Plan for Northern Ireland contains a single energy policy supporting all energy proposals (i.e. renewables and oil & gas) which improve the security and diversity of energy supply, provided that they do not unacceptably impact other activities or the offshore environment, and that restoration/decommissioning measures have, where necessary, been agreed. The draft plan does not include a specific CCUS or gas storage policy.

Overarching National Policy Statements for Energy are also relevant to plan activities, and provide planning policy in relation to nationally significant energy infrastructure projects (NSIPs), as defined in the *Planning Act 2008* – this includes almost all offshore renewable energy projects in England and Wales; however, although regulated, there is presently no planning policy for tidal lagoons.

Decision making in relation to licensing/leasing and also subsequent activities which could take place as a result of the adoption of the draft plan/programme is, therefore, split between a number of legislative and planning policy remits, including those of devolved administrations. A full list of other initiatives which have been analysed in terms of their implications for the draft plan/programme and vice versa is given in Appendix 2.

Prospectivity

The UK has extensive offshore energy resources, including of oil and gas and marine energy including wind, wave and tidal, all of which are variable over space and time. The UK also has a long maritime history and growing use of offshore areas from other users, and therefore not all areas of technical resource may be practically available at a given time.

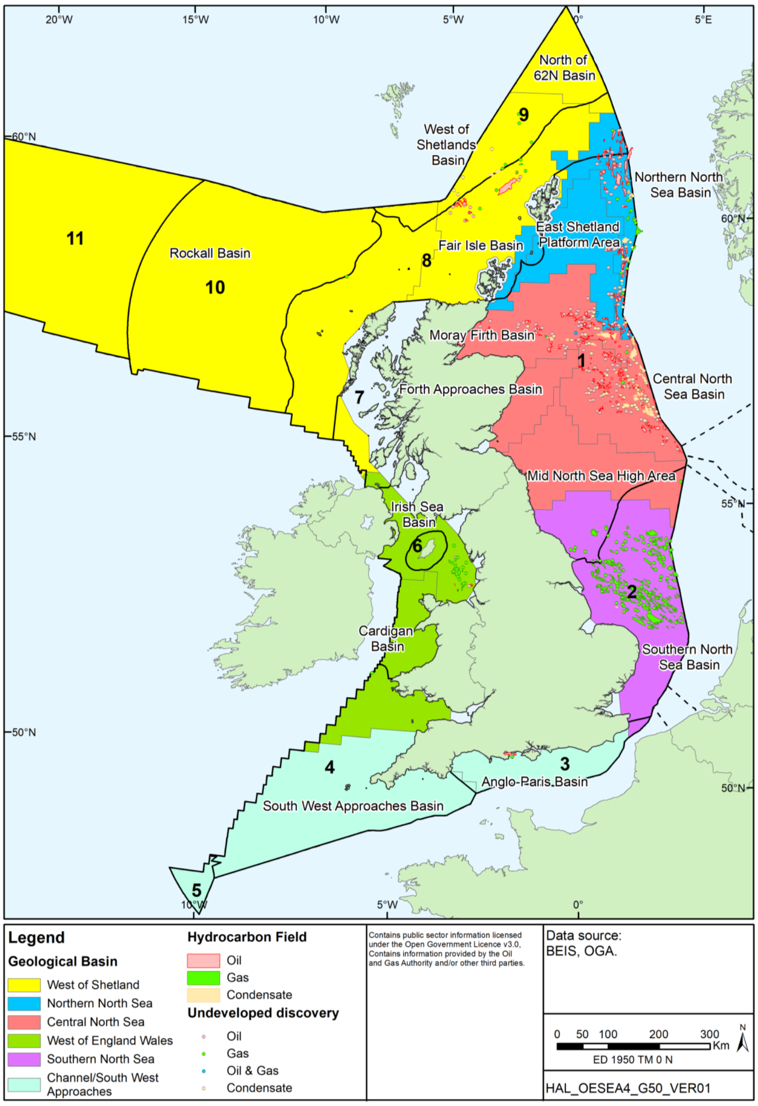
Oil and gas

For commercial hydrocarbon resources to occur, a number of factors and features have to coincide, including:

- The presence of source rocks, with an appreciable organic matter content
- Adequate depth of burial to allow the conversion of the organic matter to oil or gas through the action of temperature and pressure
- The presence of rocks with sufficient porosity to allow the accumulation of oil or gas
- Cap or seal rocks to prevent the oil or gas from escaping from the reservoir rocks

- Migration pathways to permit oil and gas formed in the source rocks to move to reservoir formations

Figure 5: Major hydrocarbon basins of the UKCS



Such conditions typically occur in sedimentary basins and not areas of igneous rock unless these overlay sedimentary rocks, as in parts of the Faroe-Shetland Channel. Offshore areas of the UK have been offered for oil and gas licensing in a series of rounds since 1964, with the 32nd Round held in 2019. Areas with hydrocarbon prospectivity have been extensively explored over this period and many fields brought into production, mainly in the North and Irish Seas, resulting in an extensive infrastructure which can be utilised by new developments. The southern North Sea and Irish Sea are largely gas provinces, with the central and northern North Sea, and West of Shetland areas being oil provinces. Whilst the major offshore hydrocarbon basins of the UK are at a mature stage of production, significant reserves remain in fields in production or development and further significant reserves are estimated to occur which are yet to be discovered.

Gas storage

The inclusion in the current draft plan/programme of gas storage is part of the strategy to increase the UK's storage capacity and maintain resilience of gas supply in cold weather periods of high demand or interruptions to imported supplies. Hydrocarbon gas storage has the potential to take place in depleted and other hydrocarbon reservoirs and other geological structures (e.g. saline aquifers), and can be expected to take place in the same areas as existing oil and gas production, or in areas of extensive halite (rock salt) deposits. Salt caverns, unlike hydrocarbon reservoirs or aquifers, are created in thick halite formations through solution mining, where some of the salt is made soluble and discharged allowing space for the storage of hydrocarbon gas. There are extensive halite deposits in the southern North Sea and eastern Irish Sea.

Carbon dioxide storage

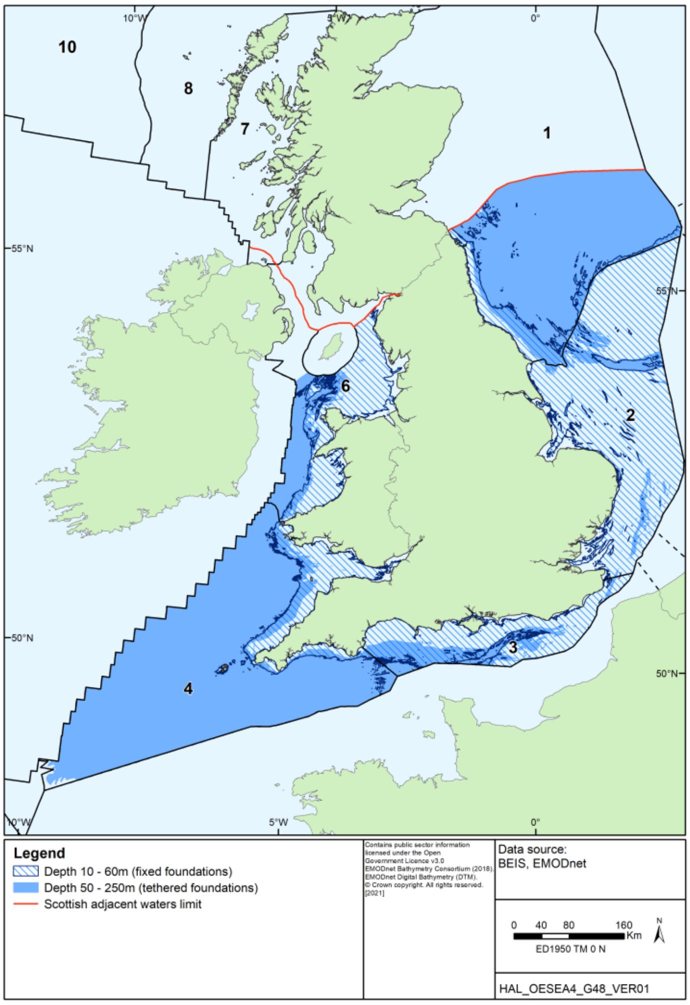
Prospective areas on the UKCS suitable for storage of carbon dioxide primarily include depleted offshore oil and gas reservoirs and saline aquifers, i.e. mainly sedimentary basins, and are therefore focussed on the southern, central and northern North Sea, and the Moray Firth Basins. Hydrocarbon reservoirs have geological characteristics suited to trapping carbon dioxide over long timescales (e.g. a suitable porosity/permeability and impervious cap rock).

Due to the maturity of most of the UKCS hydrocarbon basins, the availability of sites for carbon dioxide storage is likely to increase in the coming years and has the potential to exploit existing infrastructure. Saline aquifers can have similar characteristics to hydrocarbon reservoirs (i.e. suitably porous/permeable medium with geological constraints on migration) and may also be suited to carbon dioxide storage. The central North Sea, southern North Sea and East Irish Sea are presently most prospective due to the presence of suitable formations and proximity to areas of high carbon dioxide emissions (e.g. Thames Estuary, Humberside, Merseyside, the Firth of Forth, Teesside and Tyneside).

Offshore wind

In UK waters, offshore wind is the most developed renewable energy technology. Rounds 1 and 2 of offshore wind leasing were held in 2000 and 2003 respectively, with Round 3, held in 2009, being significantly larger in terms of the areas offered for leasing.

Figure 6: Potential offshore wind resource area



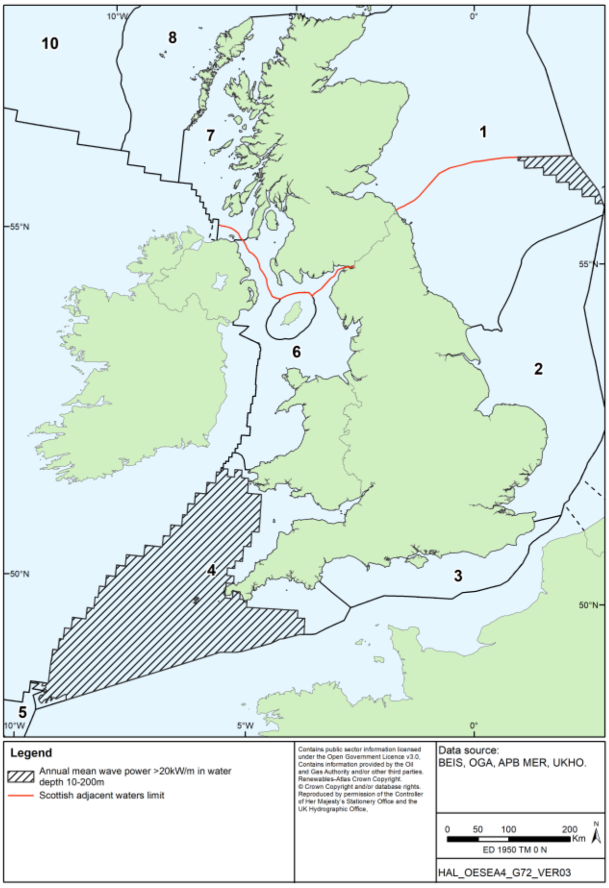
Exclusivity agreements were signed for nine of the Round 3 areas, resulting in planning applications for 17 individual wind farm projects, the majority of which (15) have now been consented. The total offshore wind capacity of all currently operational, in construction or consented wind farms in England and Wales is some 22.4GW, with a further 2.1GW in planning. When considering the UK as a whole, the capacity of operational and consented projects is 26.9GW. Further offshore leasing in the immediate term is likely to be delivered through a number of extensions to existing wind farms, Round 4 and ScotWind leasing. Away from the shelter of the coast, the total wind resource over a given year is relatively uniform across very large areas, although clearly the occurrence and strength of wind is dependent on a number of meteorological factors. At any point in time, while some areas of the UK may be calm, the wind is likely to be blowing elsewhere.

Water depth, distance from areas of high electricity demand, and the availability of connection points to the onshore transmission grid are significant factors in the preferred location of offshore wind developments. Installed or proposed wind turbine foundations have to date been dominated by fixed structures (e.g. monopiles, jackets or gravity bases). Such structures tend to be limited in the depth of waters they can be deployed effectively. For the purposes of OESEA4, it is considered that fixed foundations are likely to be deployed at depths of up to 60m. Floating wind turbines similarly have a diverse range of designs (e.g. tension leg, semi-submersible, spar-buoy), with only demonstrators having been deployment to date. For the purposes of OESEA4, it is considered that floating foundations could be deployed at depths of up to 250m.

Wave

Exploitation of wave and tidal stream energy is not yet fully commercial in UK waters, although several test and demonstrator projects have been deployed or are in development, and commercial deployment is expected in the coming years.

Figure 7: Potential wave resource



It is likely that as devices reach commercial scale and their viability is demonstrated, larger scale deployment of wave and tidal stream energy generation devices will commence. The key wave resource (for the purposes of OESEA4, >20kW/m wave crest) is broadly concentrated on the Atlantic facing coastline of the UK, and in waters relevant to the draft plan/programme, the South West peninsula and South West Wales.

Tidal stream

Tidal stream resource is geographically constrained, being localised around headlands and through straits between land masses. A number of areas in Scottish territorial waters have been leased for wave and tidal development (not considered in this SEA). Demonstration sites include the European Marine Energy Centre (Orkney) and Wave Hub (Cornwall). Areas where commercial development may take place in the near future include the Pentland Firth and Orkney waters (Scotland), Rathlin Island and Torr Head (Northern Ireland) and Anglesey (Wales). For the purposes of OESEA4, the key resource areas are considered to be those with a current speed of >1.5m/s and a water depth of >5m.

Figure 8: Tidal stream resource

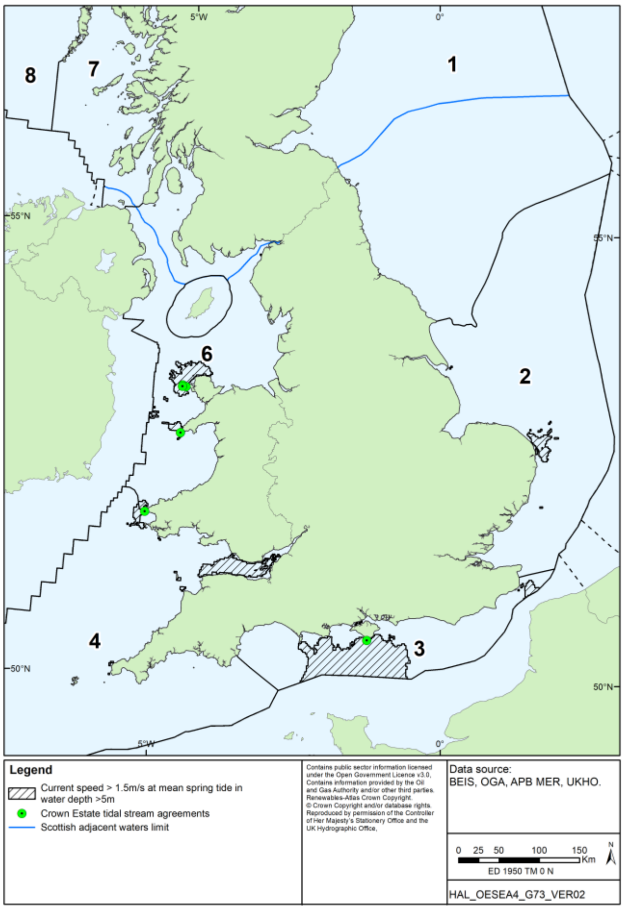
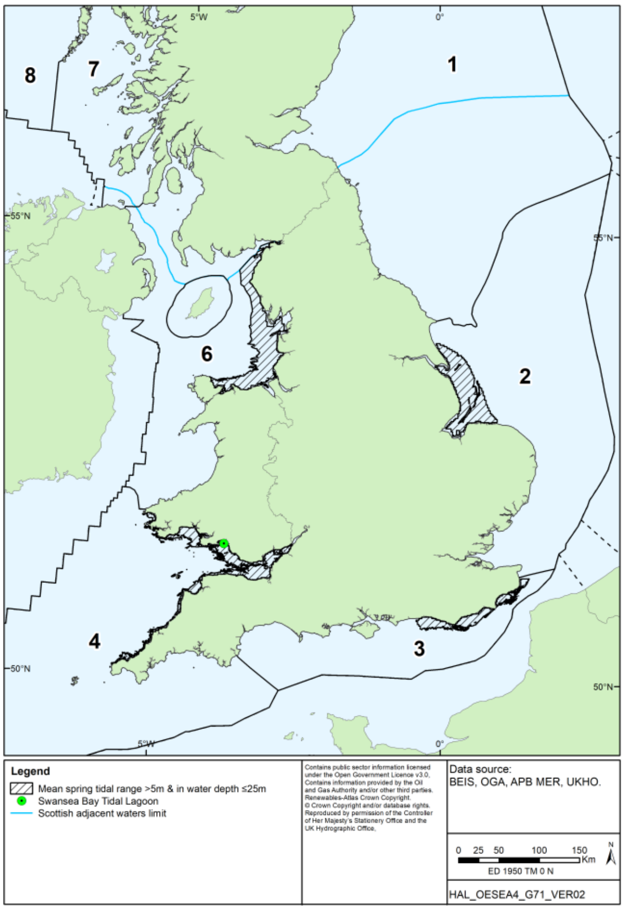


Figure 9: Tidal range resource



Tidal range

The potential future location of tidal range developments in relevant UK waters are guided by the available resource (for the purposes of OESEA4, a mean tidal range of >5m) and are generally limited by other factors such as water depth (25m as the depth limit of existing tidal range technologies and this has been used in OESEA4). The majority of the UK's tidal range resource is located in the territorial waters of England and Wales, but south west Scotland has a large area with viable resources. As a result, any proposal for the Solway in relation to tidal power would likely need to take account of the potential for effects across two legislative and planning remits which meet within this estuary. There has been much historical interest in tidal range development in the UK, particularly centred on the Severn Estuary. Despite this interest, no commercial scale tidal range developments are operating in the UK.

Hydrogen

Hydrogen is an energy carrier which could contribute to carbon dioxide emissions reductions by being generated, for example, using renewables via electrolysis of water ("green hydrogen"), or natural gas, for example by Methane Reforming (MR) combined with CCS to remove and store the carbon dioxide generated as a by-product of the process ("blue hydrogen"). Power-to-gas involves the use of excess electricity produced by renewables, which would otherwise be curtailed, to generate hydrogen, which could take place either onshore or offshore. In addition to the storage of carbon dioxide in geological formations, there is the potential to store hydrogen for later use, including in geological formation.

Overview of main sources of effect and controls in place

An evidence-based consideration is presented in the SEA, summarised below. In addition, significant use has been made of Geographical Information System (GIS) tools to collate, process, analyse and present spatial information both in the assessment and environmental baseline presented in Appendix 1 of the SEA.

The assessment for this SEA is a staged process incorporating inputs from a variety of sources:

- Baseline understanding of the relevant receptors (including other users) grouped according to the SEA Directive (see Appendix 1 *Environmental baseline* and Section 4 and the range of studies undertaken through the SEA process) together with existing environmental problems and the likely evolution of the baseline conditions.
- The likely activities, and potential sources of effect (see Box 5.1) and the existing mitigations, regulatory and other controls (see Appendix 3).
- The evolving regulatory framework.
- The evolution of technology.
- The SEA objectives (see Section 3.5).
- The evidence base regarding the relative risks and potential for significant effects from all aspects of the draft plan/programme.
- Steering Group, statutory consultee and stakeholder perspectives on important issues, information sources and gaps, and potential areas to exclude from licensing derived from scoping, stakeholder workshops and other meetings and communications – see Appendix 4.

The main stages of those activities covered by the plan are a variation on: exploration, development, operation, maintenance and decommissioning, and may be broadly summarised for the main technologies covered by the draft plan/programme as follows:

For oil and gas activity, including gas and carbon dioxide storage:

1. Exploration and appraisal: following successful licensing this involves initial exploratory drilling with well evaluation and testing typically using mobile drilling rigs, possibly preceded by seismic survey (note that purchase and reprocessing of existing seismic data is often used). For seaward oil and gas, based on previous experience, typically less than half the wells drilled reveal hydrocarbons, and of that half less than half again will yield an amount significant enough to warrant development.
2. Development: includes production facility installation (or injection facilities for carbon dioxide storage) which may be fixed or floating, and generally the installation of pipeline(s), which for major developments could come ashore but are more often “tied

back" to existing export infrastructure, and the drilling of producer and injector wells. Gas storage may require salt cavern construction, and possibly offloading facilities.

3. Production/operation: involves the production of oil and gas, chemical use, flaring, power generation, produced water management/reinjection, reservoir monitoring and maintenance, routine supply vessel trips and return of wastes to shore. Future power sources may include electrification from shore, as part of a multi-purpose interconnector or from offshore renewables. Carbon dioxide operations include the injection of CO_2 and related maintenance activity, and the monitoring of the storage site. Hydrocarbon gas storage includes both injection of gas, and then its production for use.

4. Decommissioning: including cleaning and removal of facilities, for reuse, recycling or disposal.

For renewables including offshore wind, wave and tidal technologies:

1. Site prospecting/selection including collection of site specific environmental data, and seabed information by geophysical and geotechnical survey

2. Development, including construction of foundations, barrages or lagoon walls, and possibly scour protection, turbine or device installation, cable laying including burial and cable protection, shoreline crossings and armouring, installation of gathering stations/substations and connection to the onshore national electricity transmission system

3. Generation operations, including maintenance

4. Decommissioning

These activities can interact with the natural and broader environment in a number of ways. The main potential sources of environmental effects from activities which could follow adoption of the draft plan/programme were informed through experience gathered from previous SEAs which included activity/effect matrices, which have sought to link human activities with effects on the marine environment. The list of potential effects and the plan activities to which they relate were subject to scoping and subsequent discussion with stakeholders. These sources of effect include (in no particular order):

- Physical damage to biotopes from infrastructure construction, vessel/rig anchoring etc (direct effects on the physical environment)
- Sediment modification and contamination by particulate discharges from drilling etc or resuspension of contaminated sediment
- Offshore disposal of seabed dredged material
- Physical damage to/loss of biotopes from infrastructure construction including seabed preparation, operation and maintenance, and decommissioning (direct effects on the physical environment)

- Changes/loss of habitats related to the placement of structures on the seabed and related protection materials
- Behavioural and physiological effects on marine mammals, birds and fish from noise (e.g. seismic or other geophysical surveys, construction, operation and decommissioning phase noise)
- The introduction and spread of non-native species
- Behavioural disturbance to fish, birds and marine mammals etc from physical presence of infrastructure and support activities
- Collision risks to birds, bats and water column megafauna (e.g. fish, marine mammals).
- Barriers to movement of birds, fish and marine mammals
- Changes/loss of habitats from major alteration of hydrography or sedimentation (indirect effects on the physical environment)
- Effects on prey species
- Potential for effects on flora and fauna of produced or treated water and drilling discharges
- Chemical contamination (routine) from produced or treated water, drilling and other discharges, antifouling coatings etc.
- Electromagnetic Field (EMF) effects on electrosensitive species
- Accidental events – major oil or chemical spills, or major releases of carbon dioxide (water column, seabed and air quality related effects and socio-economic consequences)
- Physical effects of anchoring and infrastructure construction (including pipelines and cables) on seabed sediments and geomorphological features (including scour), and changes to sedimentation regime and associated physical effects
- Effects of reinjection of produced water and/or drill cuttings and carbon dioxide
- Onshore disposal of returned wastes – requirement for landfill
- Post-decommissioning (legacy) effects – cuttings piles, footings, foundations, in situ cabling etc.
- Changes to sedimentation regime and associated physical effects
- Offshore disposal of seabed dredged material
- Potential effects of development on seascape including change to character (interactions between people (and their activities) and places (and the natural and cultural processes that shape them))
- Contamination by soluble and dispersed discharges saline discharges (aquifer water and halite dissolution in relation gas storage and CCS), and foundation construction
- Changes in seawater or estuarine salinity, turbidity and temperature from discharges (such as aquifer water and halite dissolution) and impoundment

- Energy removal from wet renewable devices, and offshore wind farms
- Potential air quality effects including on human health resulting from atmospheric emissions associated with plan activities, or with discharges of naturally occurring radioactive material in produced water
- Contributions to or reductions in net greenhouse gas emissions, and effects on blue carbon
- Potential for effects on human health
- Positive socio-economic effects of reducing climate change
- Interactions with fishing activities (exclusion, displacement, seismic, gear interactions, "sanctuary effects") and other users including shipping, military, potential other marine renewables and other human uses of the offshore environment
- Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc and impacts on the setting of coastal historic environmental assets and loss of access.

All the major stages of offshore oil and gas, gas storage (including carbon dioxide), offshore wind, wave and tidal installation and operation are covered by environmental regulations including the requirement for Environmental Impact Assessment at the development stage (see Appendix 3).

Assessment summary

Biodiversity, habitats, flora and fauna

In general, marine mammals show the highest sensitivity to underwater sound, particularly the intense pulses associated with seismic surveys, impact pile-driving and the use of explosives, for example, in the clearance of unexploded ordnance. The severity of potential effect is related principally to marine mammal species composition and abundance in an area, although effects on fish (including spawning aggregations), diving birds and other receptors have also been considered. The nature of effects range widely, from masking of biological communication and small behavioural reactions, to chronic disturbance, injury and mortality. For marine mammals and fish, effects will generally increase in severity with increasing exposure to noise; a distinction can be drawn between effects associated with physical injury and effects associated with behavioural disturbance.

Seismic surveys used in oil and gas exploration, and exploration related to geological storage of hydrocarbon gas and carbon dioxide, generate among the highest noise source levels of any non-military marine activity. The potential for significant effect in relation to oil & gas activities is therefore largely related to the anticipated type, extent and duration of seismic survey, and the sensitivity of the species likely to be encountered in the area. In offshore wind farm (and other renewable energy array) construction, geophysical and seabed mapping surveys still generate noise sources with the potential to cause disturbance and injury to marine mammals and potentially other receptors, however the dominant frequency and intensity of these sources is generally much less than for the type of deep geological seismic survey used for oil and gas exploration. Pile-driving of foundations, primarily related to offshore wind farms but piles can also be used in applications across all of the other technologies covered by the draft plan/programme, can generate high noise source levels and is widely recognised as a potential concern, in particular for large developments where construction may last over several years, and in areas of higher sensitivity.

In UK waters encounters with unexploded ordnance (UXO) from past military conflicts or training are frequent during the survey and installation of offshore energy developments. Most encounters are in the southern North Sea and Irish Sea, though they may be located almost anywhere across the UKCS. Clearance of UXO is generally undertaken by high-order detonation, using a charge to destroy the device, but this is a source of loud underwater noise with the potential to generate significant effects for noise sensitive receptors. Alternative “low-order” approaches (e.g. deflagration) which render the UXO safe but without causing it to explode are available, and their use is encouraged. Such low order techniques have been the subject of past and continuing SEA funded research.

There is now a good body of evidence to quantify noise levels associated with both seismic and other acoustic survey techniques, wind turbine foundation pile-driving, and to some extent UXO detonation, to understand the likely propagation of such noise within the marine environment, even in more complex coastal locations. There is less clarity about the potential effects on marine mammals (and other receptors including fish and diving birds), but progress is being made, particularly through direct observations in the field. Further support for these studies is given in this SEA, especially to fill gaps in knowledge with respect to less well studied species and sound sources.

With respect to injury, risk from an activity can be assessed using threshold criteria based on sound levels; with respect to disturbance however, establishing broadly applicable criteria based on exposure alone has proved much more difficult, because the same sound level is likely to elicit different responses depending on the individual’s behavioural context and past exposure.

In light of the available evidence, the SEA concurs with the scientific consensus judgement that underwater sound generated during acoustic survey, and in particular seismic survey, and pile-driving operations has the potential to cause injury within a limited range (tens to hundreds of metres in marine mammals) and to cause some level of disruption of normal behaviour in marine mammals and possibly some fish species at ranges of several kilometres. However, both planning and operational controls cover noise from relevant marine activities, including geophysical surveying and pile-driving. In addition, it is an offence to deliberately injure or disturb wild animals of a European Protected Species (EPS), which include all cetaceans (whales, dolphins and porpoises), particularly during the period of breeding, rearing, hibernation and migration or to cause the deterioration or destruction of their breeding sites or resting places. The SEA has considered the protections afforded to EPS under the UK Habitats Regulations and the JNCC guidance on how to minimise the risk of injury and disturbance and has concluded that current mitigation measures are sufficient in reducing the risk of injury to negligible levels whenever carefully applied by industry for all regular species that are common on the continental shelf. More uncertainty on their effectiveness exists for deep-diving species; a particular concern identified in this SEA is for beaked whales (deep water Regional Seas 9, 10, 11 in Map 1) which are known to be highly sensitive to some underwater sounds such as military sonar.

The main challenge when assessing the likelihood of significant disturbance effects stems from the need to assess these in terms of long-term population consequences while the available evidence relates to individual responses under relatively short-term conditions. Several modelling frameworks are being developed to assess population level impacts of acoustic disturbance. All frameworks rely on assumptions and on expert judgement to cope with the gaps in the data, but so far there are considerable differences in methodologies and outcomes, all of which need to be viewed with caution. The approach used by an expert group convened under the Habitats and Wild Birds Directives Marine Evidence Group led to a report with the conclusion that planned offshore construction activity up to 2020 will result in a non-trivial level of acute disturbance, but ‘this will not compromise the long-term health of the population’. However, it also raises the possibility for population size to be negatively affected if activities were to expand significantly. The report recommends the adoption of mitigation measures such as reducing noise emissions through modifications to offshore wind installation methods and careful planning to minimise the impact from temporal and spatial overlap between harbour porpoises and construction activity, recommendations which are accepted by this SEA through the review of this and other sources of information.

Given the spatial distribution of predicted activities resulting from both future oil & gas and carbon dioxide licensing, and further rounds of offshore renewables leasing, seismic activity is likely to be in the mature hydrocarbon basins, with some activity to the north and west of the UK, while in the northern, central and southern North Sea and Irish Sea, the cumulative effects of both seismic activity, other geophysical survey and piling will need to be considered. Activities may extend throughout much of the year (although seismic surveys are normally undertaken in summer when the risk of rough seas is reduced), and be audible to marine mammals over a large proportion of their regional range.

Increased anthropogenic activities in the marine environment, including all of those under consideration in this SEA, will contribute to the continued increase in ambient noise levels. Chronic exposure to increased levels of underwater sound has the potential to have long-term consequences for the health of marine species. An ambient noise indicator has been established in the Marine Strategy, however, information is still lacking as to what levels of ambient noise result in a population level effect (for all noise sensitive species).

Given the lack of definition of the survey and development programmes which may follow adoption of the draft plan/programme (in terms of duration and extent of acoustic sources, and the potential for temporal or spatial mitigation), it is only possible to make generic recommendations concerning mitigation. However, it is noted that environmental assessments will be required on a project-specific basis for all areas under the existing regulatory regime, including requirements for consideration of deliberate disturbance of cetaceans. In addition, Habitats Regulations Assessments will be required for activities which may affect marine mammal and fish populations related to SACs, and relevant diving birds related to SPAs.

Activities associated with offshore wind farm development; exploration and production of oil and gas; carbon dioxide and gas storage; wave, tidal stream and tidal range, and offshore hydrogen production and transport, can lead to physical disturbance of the seabed, with consequent effects on seabed features and habitats. In particular, scour – a localised erosion and lowering of the seabed around a fixed structure – was recognised at an early stage as a potential issue in relation to wind turbine foundations, and has been subject to considerable research and monitoring. Monitoring indicates that for most wind farms scour effects are generally small in scale and local in extent and are only likely to be of concern in areas characterised by large mobile bedforms, palaeochannels or sandbanks, although mitigation measures are available. Habitat change from the deposition of hard substrates (including rock and concrete mattresses) in sedimentary habitats, particularly associated with offshore wind farm cable protection but also as a result of oil and gas pipeline installation and decommissioning, has become a recent cause of concern, particularly for southern North Sea sandbank habitats.

The potential impacts of tidal range schemes may be significant (the scale of impact dependent on design and operation mode), with the potential loss of large areas of inter-tidal habitats and salt marshes as a result of changes in water levels and sediment transport within an estuary or river basin. The significance of potential effects of alteration or loss of intertidal habitats on birds, at a species or population level, is not clearly understood and this SEA recognises the need for further research in this area .

Seabed disturbance from installation activities could result in a loss of carbon sequestered in seabed sediments in the form of so called, blue carbon. The scale of such loss relative to the carbon dioxide reductions the draft plan/programme seeks to contribute to (particularly for renewables) is considered to be small, and also in the context of the habitat provided by the structures and its potential contribution to blue carbon sequestration, however, there is a high level of uncertainty in many aspects of blue carbon.

The SEA has considered the spatial extent of predicted disturbance effects, and the sensitivity of seabed habitats (in particular habitats listed in Annex I of the Habitats Directive) and placed these in the context of natural disturbance events and current assessment of the major sources of direct, physical pressure from human activities on seabed environments. The SEA concludes that with the currently required assessment and mitigation, physical disturbance associated with activities resulting from the proposed draft plan/programme will be negligible in scale relative to natural disturbance and the effects of demersal fishing. However, concerns with respect to the extent of habitat change from the deposition of hard substrates in sedimentary habitats, particularly associated with offshore wind farm cable protection but also from oil and gas pipeline installation and decommissioning, in southern North Sea sandbank MPAs are recognised, particularly in light of the requirements of Habitats Regulations Assessment. The potential for significant effects, in terms of regional distribution of features and habitats, or population viability, is considered to be remote.

The physical presence of offshore infrastructure and support activities may potentially cause behavioural responses in fish, birds and marine mammals, through a range of different mechanisms. Previous SEAs have considered the majority of such interactions with offshore oil and gas infrastructure, including for e.g. light attraction and collision (whether positive or negative) to be insignificant, because the total number of surface facilities is relatively small (low hundreds) and the majority are far offshore, in relatively deep water. This assessment is considered to remain valid for the potential consequences of future rounds of oil and gas licensing (including for carbon dioxide and gas storage), and also any offshore surface infrastructure associated with hydrogen production. However, the large number of individual structures in offshore wind farm developments, the presence of rotating turbines, and their potential location (e.g. in relation to coastal breeding locations for seabirds and wintering locations for waterbirds), indicate a higher potential for physical presence effects. In relation to birds, these include displacement, leading to effective habitat loss, associated with exclusion from ecologically important (e.g. feeding, breeding) areas, barrier effects and disturbance of regular movements (e.g. foraging, migration), potentially increasing flight energy demands and collision risk.

Assessments undertaken for recent southern North Sea wind farm projects (mainly Habitats Regulations Assessments) have concluded that for some species related to certain colonies (kittiwake, lesser black-backed gull), additional cumulative wind farm capacity would result in adverse effects that require compensatory measures, although the efficacy of these compensatory measures remain unknown. The collision risk assessments informing such decisions are based on a high level of precaution both in terms of project design, which is typically a worst case in terms of scale in keeping with the Rochdale Envelope approach taken to assessment[9], and in terms of assessment, significant information gaps remaining on actual levels of bird avoidance and mortality associated with wind farm operation, and with the monitoring of populations subject to multiple stressors, for example, impacts of climate change on prey availability.

Cumulative and in-combination assessments to date rely on assessments based on consented wind farm parameters that reflect the worst case noted above. To date, the difference in the number of turbines in a wind farm consent compared to that constructed can be one third to one half, such that there is also likely to be a significant difference in the estimated bird mortality between these scenarios. This could reduce the significance of effect for ongoing and future in-combination effects assessment, and result in a more realistic assessment. No legal mechanism exists to require consent variations to reflect the as-built parameters of wind farms, so at present, the reduction of this "headroom" through altering consents is at the discretion of individual operators, however, this is being remedied through changes to the National Policy Statement for renewable energy. Building on other work commissioned as part of The Crown Estate's Offshore Wind Evidence and Change programme, it is recommended that further work be undertaken to define the magnitude of the collision risk mortality headroom that exists, to determine whether agreement can be reached on the level of effect for future in-combination effects assessment, and to encourage the variation of consents to reflect the as-built parameters of projects rather than the assessed Rochdale Envelope scale.

Evidence suggests that diving birds, and in particular red-throated diver, are highly sensitive to displacement by offshore activities. A high level of displacement has been observed for red-throated diver from offshore wind farm arrays (up to 12km), though this does not appear to result in complete displacement, and the level of displacement varies between different locations. While evidence exists for displacement, evidence is lacking on any related level of mortality or population consequences. Concerns are acute in relation to certain areas around the UK which have been designated for wintering red-throated diver, with the main areas in English waters all having been subject to some wind farm development (e.g. Liverpool Bay, Greater Wash, Outer Thames). The issue primarily relates to the potential scale of cumulative habitat loss resulting from displacement (though note that displacement is not 100% and therefore habitat degradation may be more appropriate), and the potential effects on the conservation status of the species. This is despite limited to no evidence of negative population trends in these areas; surveys for red-throated diver undertaken in the Outer Thames Estuary SPA area in 2018 and a qualitative assessment of previous surveys (2002-2018), notwithstanding caveats associated with comparison of the data, suggest there has been an increase in numbers over the period. It is recommended that until further information is available on the scale of habitat loss across operational wind farms in sites designated for red-throated diver, and it is understood how this loss translates into population level effects for the species, future offshore wind leasing should avoid impinging on diver habitat as it is currently defined in site designations. It is also recommended that monitoring be undertaken to understand recent distributions and populations of the species at an SPA site scale to inform

[9] The Rochdale Envelope approach is used where some aspects of a proposed project are not well-defined when the application for consent is submitted and so flexibility is used to address the uncertainty. This tends to result in the assessment of a "worst case scenario" development.

consideration of the issue at a strategic and project level, which should be augmented by relevant wind farm monitoring reports in the area.

There is currently little information available on the interaction of birds, marine mammals and fish with surface and submerged wave and tidal devices and the SEA recommends that for the deployment of single devices and small arrays, appropriately focussed surveys of animal activity and behaviour should be undertaken to inform commercial scale deployment risk assessments and consenting.

Other potential effects considered include fouling growth (colonisation of a structure by plants and animals), effects on natural habitats (such as localised warming around seabed cables) which could facilitate colonisation by non-indigenous species, and electromagnetic fields (EMF) as a potential source of effect resulting from marine electricity transmission, particularly on electrosensitive species (e.g. fish and seals) behaviour.

Overall, the assessment of these effects concludes that based on available evidence, for most species, displacement, barrier effects and collisions are all unlikely to be significant to bird populations at a strategic level, while it is recognising that collision risk is becoming a significant consenting issue in some areas, and generally, for a few species. However, there are some important uncertainties in relation to bird distribution, including identifying important areas within UK waters where birds aggregate (i.e. for foraging, loafing), species-specific reactions to development sites, variability in migration routes and timings, and the validation of the estimated risks such as collision with monitoring data. There is also the issue of changing baselines and how this effects is dealt with in determining risk, for example, climate change and prey distribution pattern impacts on bird population sizes and distribution. Although there has recently been significant survey effort in coastal waters and studies to improve understanding of e.g. foraging areas and migration routes, and also effort in mapping higher density areas of species from available survey data, the lack of modern data on seabird and waterbird distributions in offshore areas is noted. While risks to marine life from EMFs associated with submarine power cables are not considered to constitute a major impact, significant data gaps need to be addressed with regards to the biological impacts of EMF so that a meaningful risk assessment can be conducted. Additionally, the projected increase in number of marine renewable energy developments, an understanding of potential cumulative effects will become more important.

Geology and sediments

All UK areas include a wide range of geomorphological features resulting from the underlying solid geology, past glaciations and recent processes, with sediments ranging from muds to boulders. Various wind farm, marine renewables, gas and carbon dioxide storage and oil industry activities could result in sediment disturbance or potentially, without mitigation, destruction of small scale features. The seabed mapping undertaken in advance of operations allows the identification and hence avoidance of valued features, although currently there remains poor detailed survey coverage of UK waters as a whole, and in particular at a strategic level, relatively low density and dated data relating to seabed sediment composition. Direct impacts of device footprints and cable and pipeline laying on seabed sediments and features have the greatest potential effect. However, physical disturbance associated with activities resulting from proposed oil and gas licensing and offshore wind farms, wave and tidal stream leasing will be negligible in scale relative to natural disturbance and for example the effects of demersal fishing. The potential for significant effects, in terms of regional distribution of features and habitats, and related population viability and conservation status of benthic species (see above), is considered to be low. There have been recent concerns about the nature and potential scale of hard substrate deposition associated with wind farm scour and cable protection, and to a lesser extent, oil and gas pipeline installation, due to the potential for these to change the character of the sediments in such areas, with potentially related effects on fauna, which was discussed earlier, but is also relevant to this topic. The potential impacts of tidal range schemes however may be significant, with the potential loss of large areas of intertidal habitats and salt marshes as a result of a change in water levels and sediment transport within an estuary or river basin. The level of impact will likely be dependent on the design, siting and mode of operation (e.g. two-way operation may reduce the scale of impact). For oil and gas developments, offshore wind farms, wave and tidal stream devices, and the likely nature and scale of activities associated with carbon dioxide transport and storage and offshore hydrogen production, disturbance from installation could result in a loss of carbon from seabed sediment, which provides both a store of carbon (in the form of so called, blue carbon), as well as the related sequestration associated with that area. The scale of such loss relative to the carbon dioxide reductions the draft plan/programme seeks to contribute to is considered to be small, and also when considered in the context of the habitat provided by the structures and its potential contribution to blue carbon sequestration, however, there is a high level of uncertainty in this area.

Contamination of sediments may occur from discharges of drilling wastes and spills, or in the case of the oil industry from production wastes such as produced water. The composition of planned discharges from wind farm, wave and tidal and oil industry operations is regulated, with increasingly stringent controls applied in recent years. Monitoring results indicate that sediment contamination is not a significant issue in wind farms or recent hydrocarbon developments. The geological information derived from seabed mapping, seismic survey, geotechnical surveys and the drilling of wells is regarded as a positive contribution to the understanding of the UKCS, now being augmented by post-construction monitoring and decommissioning studies.

Landscape/seascape

The maturity and proposed scale of offshore wind deployment, both in individual turbine size and the number of size of arrays, has the potential to generate the largest effect of any aspect of the draft plan/programme assessed. Early offshore wind farms were restricted to relatively nearshore locations due to the limitations of foundation technology at the time, however, as foundation technologies have allowed for deployment in deeper waters, wind farms are increasingly being proposed further from shore, reducing the visual landscape/seascape impacts of their deployment, and this includes for UK waters; offshore wind farms have, however, come to define aspects of the seascape in some areas of the UK. The most prospective areas for fixed foundation offshore wind farms in UK waters are now highly constrained at a time when the cost reduction and rapid advancement of floating wind turbine foundations will make areas further from shore and in deeper water more accessible.

The tidal range resource, including areas which have historically been or are presently subject to interest from commercial developers, are by their nature coastal/nearshore. Tidal lagoons are considered to be the most likely tidal range technology which could be deployed should the draft plan/programme be adopted, but proposals for barrages cannot be discounted entirely. Changes resulting from tidal range schemes will include the creation of lagoon or barrage walls, navigational lighting, foreshortening of seascape views and, potentially, the introduction of industrial or commercial components to the landscape/seascape. Wider changes could result to the character of estuaries associated with a tidal range scheme which are connected to its wider environmental effects, including reduced sediment loads leading to a change in water clarity, reductions in intertidal areas (and/or displacement if compensatory measures are considered) and related alteration of the fauna and flora, changes in tidal regime, and alterations to the pattern of vessel movements (e.g. if requiring traffic separation through locks). Due to the expected scale of wave and tidal stream developments arising from the draft plan/programme, significant visual effects are not expected, particularly for completely submerged devices. Any tidal range scheme would likely result in significant effects on landscape/seascape character.

In all cases, temporary interaction with the coast is likely through landfall works (e.g. where pipelines or cables are taken ashore) as part of ancillary development, with more permanent changes resulting from the construction of onshore substations, or above ground installations for pipelines, and also overhead power lines or other onshore routeing to enable the offshore aspects of projects. There are planned changes to the way in which offshore winds will be connected to the grid in future which are beyond the scope of this assessment, but the result should be fewer landfalls.

In contrast, most new seaward oil and gas developments are likely to be sub-sea facilities tied back to existing infrastructure which are well offshore and beyond sight of land. Exploration in previously underexplored areas, or redevelopment of former producing fields, could result in the addition of new fixed infrastructure depending on commercial viability of resources, however, these are more likely to be further offshore and isolated compared with wider scale renewables deployments. Gas storage and carbon dioxide storage facilities are likely to be at sufficient distance from shore in most circumstances that coastal impacts are unlikely, though prospectivity in, for instance the Irish Sea and nearshore southern North Sea, and the requirement for a larger number of fixed surface infrastructure for certain project types (e.g. where salt cavern construction is required) has the potential to generate incremental effects with other aspects of the plan and existing uses of the sea. The nature and scale of any surface facilities are likely to be comparable to that of small offshore oil and gas installations. The likely approach to pilot projects for power to gas is uncertain, however, any facilities (surface installations, shipping) associated with this process are likely to be in close proximity to the renewables devices providing the electricity for electrolysis, such that these will likely be similarly distant from the coast.

Major development of any aspect of the draft plan/programme could result in significant effects on landscape/seascape, with the potential for effects being highly site specific and requiring individual project specific consideration, for instance due to the varying number, size and layout of potential devices, alterations to which could provide a suitable level of mitigation. National policy indicates that consent for energy development, and in particular to renewable energy, should not be refused solely on the grounds of an adverse effect on seascape, including visibility of the development from within designated sites (e.g. AONBs), unless the adverse effects are considered to outweigh the benefits. For example, secondary impacts on tourism and recreation, or on internationally recognised areas such as World Heritage Sites.

Reflecting the conclusions and recommendations of previous SEAs, and the relative sensitivity of multiple receptors in coastal waters, it is recommended that new offshore wind generation capacity should be sited away from the coast, generally outside 12 nautical miles. The sensitivity of coastal areas is not uniform, and in certain cases new offshore wind farm projects may be acceptable closer to the coast, or be acceptable subject to changes in their layout and design, and in that sense this recommendation does not suggest a prescriptive restriction should be made. Project level assessment, including cumulative assessment with operational, consented and proposed developments, will be required to inform the potential impact on landscape and seascape character, and the suitability of future developments.

Water environment

The consequences of energy removal on natural marine systems are reasonably well understood for large tidal barrage schemes but are far less predictable and appreciated for smaller tidal range schemes (e.g. lagoons), wave and tidal stream devices, and also from offshore wind farms. Tidal barrages may have far reaching, large scale impacts that potentially cause permanent changes to the physical nature and associated ecology of the estuary/river basin where they are located, although the exact level of impact is dependent on operation mode, design and siting. For this reason and because individual estuary/embayments are so different, the SEA recommends that detailed site specific data gathering and assessment is required before decisions can be taken on the acceptability or otherwise of a development.

Individual and small arrays of tidal stream and wave devices are thought to have localised effects that are detectable but unlikely to be highly significant at distance from the devices. However recent modelling work has suggested potentially significant, far reaching impacts, from larger arrays of these devices depending on site location and size/layout of the array. Studies have suggested that impacts could potentially be reduced at certain sites through careful siting, although uncertainty still arises as the natural complexity of the water movements of an area are often only broadly represented in models. Current information is based on modelling with limited validation from field measurements other than for some demonstrator scale monitoring studies.

Offshore wind farm foundations interact with part of all of the water column depending on their design, e.g. floating and fixed. Turbulent wakes are generated as waters pass through offshore wind farms under tidal action which has the potential to contribute to a range of effects on hydrodynamics, including enhanced vertical and horizontal mixing and effects on stratification, changes to primary productivity and potentially related effects at higher trophic levels.

It may generally be concluded that there are limited and localised impacts from energy removal from single or pilot scale deployments of tidal stream and wave devices, and current levels of offshore wind deployment, but scaling those impacts up to commercial wave and tidal arrays and the number of wind turbines that could be required to meet the net zero target in the UK sector and adjacent north west European states, potentially has some significant issues, but there is uncertainty on the scale and nature of any potential change. Change in the biogeochemical cycles of UK waters from renewables expansion would require an understanding of the potential range of effects from wind farms, tidal stream and wave arrays and tidal range, both locally and in the far-field (and cumulatively), together with the likely range of potential impacts from climate change along realistic timescales and scenarios of deployment for such technologies.

Contamination of water may occur from discharges of drilling wastes, production wastes such as produced water (i.e. water produced along with oil and gas during the production phase), dissolution of antifouling coatings and corrosion protection anodes, accidental spills, grouting, or disturbance of previously contaminated sediments. Drilling discharges from the renewable energy and hydrocarbon industries are comprehensively regulated, with the discharge of oil-based drilling fluids effectively banned, and strict controls implemented over chemical additives used in water-based fluids. In view of the offshore locations, water depths and current regimes prevalent in areas of likely wind farm development or prospective for hydrocarbons, gas and carbon dioxide storage, significant contamination or ecological effects of drilling discharges are not expected. Other operational discharges are subject to regulatory controls, and are not considered to have significant environmental risk. Offshore renewables are generally not thought of as a significant source of marine discharges although there is evidence for substantial use of maintenance chemicals which enter the sea. In addition, the presence of numerous offshore renewables installations may increase the risk of vessel collision and associated spill risk. However, given appropriate planning and siting of developments, the increase in risk is not thought to be significant (also see Other users, material assets (infrastructure, other natural resources, below). UK regional and national monitoring programme results indicate that water column contamination and associated biological effects are not significant issues although the prevalence and potential impacts of microplastics is an area of concern and the subject of increasing research.

Air quality

Atmospheric emissions from the potential activities likely to follow implementation of the draft plan/programme could affect local air quality. Gaseous emissions contribute to regional acid gas loads and may result in local low level ozone and smog formation. The principal routine operational emissions during offshore wind, marine renewables and oil industry exploration, construction and production operations are of combustion products (including CO_2, CO, NO_X, SO_2, CH_4, and volatile organic compounds (VOCs)) from power generation and engines on rigs, production facilities, installation and support vessels, and helicopters. Exploration and installation emission sources for gas storage, carbon dioxide storage and offshore hydrogen production will be comparable to that for oil and gas activities, but operational emissions will differ and be substantially less. Fugitive emissions such as those from cement tanks (used in well operations), diesel storage and cooling/refrigeration systems can result in emissions of dust/particulates, VOCs, hydrofluorocarbon refrigerants etc. depending on the source, however regulatory controls are now in place on the use of certain refrigerants. As a proportion of UK atmospheric emissions, those directly emitted from plan related activities form a small proportion, and the distance of most point sources from shore allows for significant dispersal and so effects on coastal and terrestrial air quality are not likely to be significant. Additionally, those policies and related initiatives which have or are being put in place to meet the net zero target will also reduce air pollution in similar timescales, such that future developments that arise should the draft plan/programme be adopted, will make a much smaller contribution to air pollution than those associated with previous plans.

Emissions will also be associated with the construction of marine renewables and wind farm devices to be deployed and by the choice of construction materials, as well as operational and maintenance emissions, for example, from vessel movements. For wind farms, the "payback" time, which is how long it would take for the production of low carbon energy equivalent to that of the life cycle of the project has been estimated to be a small proportion of overall project life (in the order of 12-24 months). Such effects are not considered to be significant at the strategic level. The potential expansion of ports to facilitate renewable energy development, which is not covered by this draft plan/programme, may have implications for local air quality in these areas, some of which may already have air quality management areas. This is being addressed separately, for example through Maritime 2050 and the Clean Maritime Plan.

The likely geographic spread and timing of projected activities which may follow leasing/licensing, and the limited scale of other such sources offshore indicate that significant effects on local and regional air quality will not occur, and will likely decline in the coming years (e.g. as ships become more efficient and hybrid ships come to market). The implications of atmospheric emissions from offshore renewable developments, hydrocarbon exploration, production, gas storage (including of carbon dioxide) and offshore hydrogen production and transport activities would be assessed through the statutory EIA and consenting processes.

Climatic factors

Evidence for human influenced climate change is now unequivocal. Over the last century anthropogenic sources of greenhouses gases have amplified the natural greenhouse effect and are estimated to have caused approximately 1.09°C of global surface warming above pre-industrial levels. Consequences of this temperature rise include changes in precipitation over land and patterns of near-surface ocean salinity, alterations to mid-latitude storm tracks, the retreat of glaciers and ice mass loss from the Greenland Ice Sheet and Antarctic Ice Sheet, global heating of the upper ocean with greater upper ocean stratification, ocean acidification, reduced oxygen levels, ocean circulation changes including a weakening of the Atlantic Meridional Overturning Circulation (AMOC) and more extreme and frequent El Niño and La Niña events (medium confidence) and, an increase in global mean sea level.

Any atmospheric emissions from the potential activities following implementation of the draft plan/programme will contribute to local, regional and global concentrations of carbon dioxide and other greenhouse gases. Of those technologies covered by the draft plan/programme, offshore renewables will offset their embedded emissions from manufacture, installation, operation and maintenance by the production of renewable energy. In addition, further offshore renewables leasing as part of the draft plan/programme being assessed (including wind, wave and tidal energies) has the potential to contribute to other aspects of the draft plan, including the production of hydrogen offshore (green hydrogen) and the electrification of oil and gas installations. The transport and storage of carbon dioxide offshore is highly likely to be a critical component of delivering on the UK Government target to store 20-30 million tonnes of carbon dioxide per year by 2030 and to decarbonise parts of the energy supply sector and industry, directly and through hydrogen production (blue hydrogen). Further leasing and licensing of prospective areas for carbon dioxide storage will maintain the level of exploration, appraisal and development of such areas to deliver required storage capacity beyond 2030.

Oil and gas exploration and production on the UKCS is in long term decline. Available data indicates that imported oil and gas has a greater carbon intensity than natively produced hydrocarbons, and when taken in the context of other initiatives to reduce upstream emissions from oil and gas production including through the North Sea Transition Deal and the revised Oil & Gas Authority strategy, and the requirement by operators (e.g. through the EIA process) to demonstrate how they propose to make new development's upstream emissions (flare, vent, power generation) compatible with net zero, the gap between native and imported product carbon intensity has the potential to widen. As the UK is a net importer of oil and gas, and given that the hydrocarbon basins of the UKCS are targeting net zero emissions by 2050 in the context of the expected decline in oil and gas decline through the energy transition, continued licensing of acreage on the UKCS will maintain UK security of supply at a lower carbon intensity than equivalent imports. The difference in carbon intensity may, however, decline as other markets decarbonise their upstream activities, but there may always be a slight advantage to domestic production due to lower transport emissions. In view of the current carbon reduction policies in place, the legal requirement to achieve net zero by 2050, and continuing advice from the Climate Change Committee in relation to the UK Government's progress to date and the potential contribution of policies announced (e.g. the Net Zero Strategy), it is important that development related to the draft plan/programme is consistent with these commitments and recommendations. The SEA concluded that while domestic production of oil and gas is important for security of supply, future licensing rounds may also be subject to periodic climate compatibility checkpoints, and activities associated with licences subsequently issued must also be compatible with the interim and 2050 greenhouse gas reduction targets.

Population and human health

No adverse effects on population or human health are expected, based on the nature of the activities that could follow adoption of the draft plan/programme; the offshore locations; the low risk (based on historic frequency and severity) of major accidental events; the regulations in place to manage occupational health risks to the workforce and others, and the controls on chemical use and discharge and on other marine discharges. Potential difficulties in effecting search and rescue operations by helicopter in offshore wind farms are noted; these can be mitigated in part by the layout of turbines within a wind farm. The potential for tidal range projects to impact coastal flooding patterns will depend on their location, nature and extent and will form an important part of the consideration of any future projects during the consenting process.

The adoption of the draft plan/programme is likely to contribute to maintaining investment and activity in the renewables sector, and in particular, continued growth in the offshore wind sector, but also in other wet renewables. It will also contribute to maintaining investment in the UK offshore oil and gas industry, and to increase investment and activity in offshore gas storage, and in particular carbon dioxide storage, and the development of offshore hydrogen production and transport. This will bring positive benefits in terms of an increased proportion of low carbon energy in the UK energy mix, greater security of energy supply, and employment, including of transferrable skills from the oil and gas industry

Other users, material assets (infrastructure, other natural resources)

The waters of the UK are subject to multiple and sometimes overlapping uses, particularly in coastal and nearshore areas. The range and importance of existing and some potential uses of the sea are described in Appendix 1h of the Environmental Report, with key aspects summarised below. In addition to the formal regional scale marine spatial plans which have been adopted for most UK waters, the approach taken in this SEA has been to obtain accurate and recent information on other current and likely uses of the sea in the foreseeable future, to facilitate identification of sensitive areas and measures to reduce the scope and scale of significant adverse effects.

The UK is heavily reliant on shipping for the import and export of goods, and will remain so for the foreseeable future. Approximately 95% of the goods entering or leaving the UK are transported by ship, and substantial numbers of vessels transit UK waters *en route* to other European and more distant ports. In recognition of the vessel traffic densities and topographic constraints on various routes, the International Maritime Organisation (IMO) has established a number of traffic separation schemes and other vessel routeing measures to reduce risks of ship collision and groundings. In addition, IMO regulations have required that from 2005, an Automatic Identification System (AIS) transponder be fitted aboard all ships of >300 gross tonnage engaged on international voyages, all cargo ships of >500 gross tonnage and all passenger ships irrespective of size. AIS allows precise tracking of individual vessels but has limited coverage for smaller vessels (e.g. small commercial and fishing vessels and recreational users). Such vessels are starting to carry AIS equipment (AIS-B) and a mandatory inshore vessel monitoring system for fisheries (iVMS) will improve the understanding of smaller vessel movements. National scale AIS data have been analysed to provide information on important areas for, in particular, larger vessel navigation. In addition to collision and grounding risk considerations, most vessels typically take direct routes from place to place and new obstructions causing large route deviations would increase transit times, fuel usage and related effects (e.g. as noted in relation to air quality and climate above). Monitoring data of existing offshore wind farms pre- and post-construction suggest that regular users of the area are currently able to take altered routes and in busy areas the introduction of a traffic separation scheme can aid routeing, and navigation assessments and consultation informed by guidance provided by the Maritime and Coastguard Agency in the siting of new offshore wind farms, can contribute to the identification of major shipping routes and the avoidance of conflict. In general, areas identified for the development for offshore wind to date have considered vessel traffic and chosen sites that do not impinge on major navigation routes. The Marine Policy Statement, and now regional scale marine plans, recognise the strategic importance of shipping to the UK but also the potential for this to be compatible with other offshore activities, and a number of policies and policy maps have been produced to provide an indication of major routes and requirements placed on new developments to ensure safe navigation and shipping is not adversely affected. Additionally, navigation lighting requirements (including recent recommendations for lighting to fulfil both maritime and aviation requirements) and mandatory charting of new developments further reduces risks to shipping and navigation. Despite this, the impact on shipping by offshore energy development, and other activities, should be an ongoing marine planning concern for all marine planning authorities, and stronger policy (i.e. the creation of "clearways") where further development cannot take place should be considered, or at the least, updates to the location and nature of strategically important shipping routes should be mapped against relevant policies.

As wave and tidal developments are currently at demonstrator scale, the spatial extent of arrays of these and the implications for navigation are difficult to ascertain, although mandatory requirements on lighting, navigational aids and the charting and communication of the presence of such features to maritime users mean that they are unlikely to be any more of an issue than offshore wind developments, however, the reduction in under keel clearance for submerged devices and the visibility of devices which have limited vertical extent above the water surface will need to be carefully considered. The displacement of shipping and subsequent impact on the cost of shipping and port revenues is potentially significant, and should be taken into account when siting arrays of offshore renewable devices. The SEA concluded that wind farm (and other large footprint development) siting should be outside areas important for navigation (these are mapped in the Environmental Report) and that this would not preclude the attainment of the draft plan/programme objectives.

Military use of the coasts and seas of the UK is extensive, with all three Services (army, airforce, navy) having defined Practice and Exercise Areas, some of which are danger areas where live firing and testing may occur. Such areas are well documented and have been taken account of in the SEA. In addition, in terms of national security the potential for offshore wind farms to interfere with the reception and discrimination of military radars (air traffic control and those parts of an early warning system) is a key consideration for the siting of such developments. There are a number of other defence sensitive areas which are not necessarily mapped, but need to be taken account of at the planning stages of an individual project. Developments which jeopardise national security for example through interference with radar systems or cause unacceptable impact on training areas should not be consented unless the impacts can be appropriately mitigated or are deemed acceptable. Mitigation measures have, in part, been applied successfully for some military radar sites, however more work is needed and this is presently being addressed through the Windfarm Mitigation for UK Air Defence programme.

Fishing in the UK has a long history and is of major economic and cultural importance. In 2020, there were approximately 12,000 working fishermen in the UK (of which 80% were full time), operating over 5,549 vessels, 4,300 of which were smaller inshore boats (<10m). These vessels landed 621,900 tonnes of fish and shellfish in 2019, with a total value of £987 million. On top of this, fish processing provides over 19,000 jobs in the UK. The livelihoods of individual fishermen depend on their ability to exploit traditional fishing grounds and to adapt to changing circumstances to maximise profit. Consequently, they are vulnerable to competition within the UK industry and with foreign vessels, and to being displaced from primary grounds. To better understand the fishing activities of UK vessels, information from the UK Sea Fisheries Statistics (logbook submissions) was used to derive maps of fishing effort density, gear type and season. These show that the greatest density of fishing effort takes place in coastal waters, for both static (such as pots, traps or gillnets) and mobile gears (such as trawls and dredges). In addition, larger fishing vessels (>12m) are required to carry a Vessel Monitoring System (VMS). To inform the SEA, VMS data for UK vessels from 2019 was obtained and analysed to provide information on, and derive maps showing, important fishing areas for larger vessels and offshore areas. Data on smaller inshore vessels is lacking, and there is a programme presently underway introducing inshore VMS (iVMS) to vessels in the <12m category, and therefore more information will be available in the future to inform marine management in relation to these important fisheries. The effects of offshore developments on fishing activities depend on the scale of fishing interests in the area, the ability and willingness to fish within areas of development, the space available for displacement of fishing into other suitable areas and the management regime of fisheries in that area. To date, there has been relatively little experience of fisheries adaptation and co-location with offshore wind farms. At a strategic level, caution is required with regard to the siting of a major expansion of offshore infrastructure. Applicants for consent and relevant decision makers should ensure that they reflect relevant policies including, amongst others, those in marine plans and the Energy National Policy Statements, as these mechanisms, along with experience to date on wind farm consenting and operation, are key checks for the planning process to ensure that the activities of the fishing industry are appropriately considered; impacts on the sector need to be considered at an individual project level and cumulatively with other plans and projects. While planning policy indicates that developers and decision makers must consider displacement issues, including of fisheries, it is recognised that the cumulative and incremental effect on the fisheries sector from increasing offshore development is not well understood and is challenging to assess.

Offshore wind farms have the potential to affect civilian aerodromes and radar systems. The UK air traffic control service for aircraft flying in UK airspace has made available mapped data indicating the likelihood of interference from offshore wind turbines on its radar reception. Similarly, the Civil Aviation Authority (CAA) produces an Aerodrome Safeguarding Map and Local Planning Authorities are required to consult on relevant Planning Applications which fall within a 15km radius. Any proposals for a wind turbine within a 30km radius of an airport also require consultation with the Airport Company. In addition, the CAA has indicated the need to consult helicopter operators and offshore installation operators for developments within 9nm of a platform (e.g. an oil and gas platform or one used for CCS or gas storage) to maintain the safety of helicopter approaches, and in particular missed approach procedures and navigation in poor visibility where instrument (as opposed to visual) approaches are being made. With adequate risk assessment and consultation, the siting of wind farms within 9nm of installations can be agreed. Additionally, the CAA identify a number of helicopter main routes which relate to the oil service industry and are therefore concentrated in the northern, central and southern North Sea and Morecambe Bay. Though not having a statutory basis, the CAA recommends a 4nm corridor be kept clear of obstructions along these preferred routes. Comparable to consultation zones around platforms, further consultation may permit development and alteration to routes where possible.

Various areas of sea are used or licensed/leased for marine aggregate extraction, telecommunications and other cables, disposal of capital and other dredging wastes, offshore wind farms, surface and subsea oil and gas production and export infrastructure. These have been mapped and considered in this SEA. Potential future uses of the sea considered in

OESEA4 include gas (natural gas and carbon dioxide) storage in geological formations, aquifers or constructed salt caverns, marine renewables such as wave, tidal stream and tidal range, and offshore hydrogen production and transport. Where available, information on potentially suitable locations for these has been considered in the assessment, considering likely and potential spatial constraints on these types of development.

The implementation of the draft plan/programme will result in some associated development onshore including the installation of additional equipment at existing gas terminals for gas storage, and pipelines and associated infrastructure for the transport and storage of carbon dioxide, however, these are outside of the scope of this SEA. The considerable ancillary onshore development necessary for major expansion of offshore wind generation includes reinforcements to the national electricity transmission system (as considered by National Grid as the National Electricity Transmission System Operator) and enhancements to the capacity of the UK's port facilities. The Offshore Transmission Network Review (OTNR) is presently ongoing, which has two work streams looking at changes that can be made to the existing regime for onshore grid connections, from offshore projects, and a longer-term consideration for a new enduring regime that enables and incentivises a coordinated approach to offshore electricity transmission while seeking to minimise environment, social and economic costs. This includes a consideration of multi-purpose interconnectors to link offshore wind connections to neighbouring markets. The OTNR is separate to the draft plan/programme under consideration and is not subject to this SEA, however, it is acknowledged that the creation of a new regime for offshore grid connections has the potential to reduce the overall effects of connecting the renewables elements of the draft plan/programme to the onshore grid. The influence of wave and tidal development within the scope of OESEA4 on port and manufacturing facilities development will likely be comparable in nature, but considerably smaller in scale. than that associated with offshore wind. These will have some environmental impacts, with habitat loss/modification, noise, landscape impacts and interactions with other users among the key issues to be considered at the project planning stage, guided by National policy for ports.

Cultural heritage

The collective inventory and knowledge of maritime sites in particular is quite poor and may be subject to recording biases. Archaeology associated with human and other hominin activities either on the current seafloor of the southern North Sea, in the coastal zone of the British Isles and further inland, has the potential to date back at least as far as 500,000 years BP. Finds of flint artefacts in Suffolk and Happisburgh, Norfolk, tentatively push early human occupation of Britain back to a tentative age of approximately between 700 and 950,000 years BP. The current understanding of marine prehistoric archaeology is largely based on findspots recovered by fisheries and aggregates operations, now being augmented by interpretations of the palaeolandscapes of the continental shelf between the UK and Europe which would have been exposed and inhabitable during previous glacial phases.

The record for wreck sites is biased towards those from the post-Medieval and later periods. The strategic military importance of the sea, the importance of the seas around the UK for fishing, the importance of maritime trade routes and the treacherous nature of many nearshore waters, has lead to a large number of ship and aircraft wrecks in UK waters (e.g. the UK Hydrographic Office wrecks database contains approximately 70,000 records, and the wider wreck resource of the UKCS has been estimated to hold between 100,000 and 500,000 locations). In addition to the potential for interaction with physical heritage remains, the setting of heritage sites is also important (also refer to landscape/seascape above), which include listed buildings, scheduled monuments, and other areas such as World Heritage Sites designated in full or part due to their cultural past (e.g. the Cornwall and West Devon Mining Landscape).

Activities related to aspects of the draft plan/programme have the potential to affect underwater cultural heritage through physical disturbance of the seabed, which can result from all the technologies covered by the plan (e.g. seabed preparation for fixed structures and foundation installation, trenching of pipeline and cable routes, including inter-array cabling and in intertidal areas). Known wrecks and other obstructions are charted, but there is an accepted disparity between the number of known and likely remains on the seabed. This includes both wrecks and areas formerly used by people during previous glacial periods when sea levels were lower, and land extended across much of the North Sea. Additionally, offshore construction and operation activities, particularly of offshore wind farms, has the potential to affect the setting of heritage assets, but also the cultural associations of offshore areas.

Guidelines have been drafted in recent years to promote the consideration of marine heritage in offshore development assessment, including in survey design, and the need to take account of the setting of historic assets, and how perception of offshore historic environment may be affected by developments. National scale policies contained in the Marine Policy Statement (MPS), and now regional marine plans, emphasise the importance of non-designated sites (which can be exemplified by the contribution of knowledge to the early settlement history of Britain from the findings of work undertaken in relation to the aggregates industry), and this is now being implemented at a project level, with Development Consent Order conditions generally requiring a written scheme of archaeological investigation, in consultation with relevant bodies such as Historic England, and where relevant, subsequent post-consent monitoring and material archiving.

No further strategic level controls were identified during the SEA assessment, and it is through development and site specific surveys that cultural heritage features would be identified and mitigation measures and monitoring measures developed. The SEA acknowledges that the activities related to the draft plan/programme have the potential to disturb underwater heritage, but also that data collection from related surveys and site investigations has the potential to contribute to our understanding of the former occupation of parts of the UK’s shelf seas.

Interrelationships – Cumulative effects

The effects of activities which could result from adoption of the draft plan/programme have the potential to act incrementally with those from other offshore renewables and oil and gas (including gas storage) existing facilities or new activities, or to act cumulatively with those of other human activities (e.g. fishing and shipping). Secondary effects are indirect effects which do not occur as a direct result of the proposed activities, while synergistic effects are considered to be potential effects of hydrocarbon or renewable industry activities where the joint result of two or more effects is greater than the sum of individual effects.

Cumulative effects in the sense of overlapping "footprints" of detectable contamination or biological effect were considered to be either unlikely (accidental events), or very limited (for physical damage, emissions, discharges), since monitoring data indicates that the more stringent emissions, discharge and activity controls introduced over recent years have been effective and there is no evidence for significant cumulative effects from current activities.

The SEA recognises that there is uncertainty regarding potential cumulative effects of noise disturbance, and recommendations to address this are outlined in Section 6. Displacement, barrier effects and collision risk represent potentially significant sources of cumulative effects to birds (and potentially marine mammals) at a local or regional level but are considered unlikely to be significant to bird populations at a strategic level, while recognising potential cumulative (and in-combination) impact assessments and the determination of significant effects and appropriate mitigation or compensatory measures will be required on a project-specific basis. The SEA recommends a precautionary approach to facility siting in areas known to be of key importance to bird and marine mammal populations unless evidence indicates otherwise, and also that information on the distribution, behaviour and interactions with offshore renewable devices is in many cases limited and that additional work is required to improve current models on marine mammal and bird response/collision risk.

There is also the potential for significant adverse effects on other users of the sea (including radar coverage) and on landscape/seascape from major development of offshore wind farms, other marine renewables, and gas storage (including carbon dioxide storage, and potentially, hydrogen storage) related infrastructure at the coast and within visible distance from the coast. However, this can be mitigated to acceptable levels by appropriate site selection, in particular avoidance of areas of prime importance to other industries/users and preferential selection of sites away from the coast where offshore structures are less visually intrusive. Progress is being made on mitigating the effects on military and civilian radar from offshore wind farms, but no universal solution is yet available, and further work is required to refine solutions at the site and development specific level.

Atmospheric emissions resulting from fossil fuel use during offshore renewables facility manufacture, construction and maintenance are more than balanced by the overall net reductions in carbon dioxide emissions as a result of electricity generation from renewable energy, and reflects the need to reduce the carbon intensity of energy production. Atmospheric emissions from oil industry activities that may result from implementation of draft plan/programme, and the end use of any hydrocarbons produced, will contribute to overall global emissions of greenhouse gases. Further offshore exploration and production must now be undertaken in keeping with the OGA Strategy which has been placed in the context of the net zero target, and further licensing may also be subject to periodic climate compatibility checkpoints. The increased deployment of offshore renewables towards 2030 and beyond will, in association with carbon dioxide storage, hydrogen production, in the wider energy and greenhouse gas reduction policy context of the UK, cumulatively make a contribution to both greenhouse gas emissions reductions and air quality improvement.

Besides a minor contribution to climate change and ocean acidification, no secondary or synergistic effects were identified that were considered to be potentially significant, although the effect of multiple noise sources is an area which requires better understanding.

Interrelationships – Wider policy objectives

There is a requirement in SEA that, in considering the likely significance of effects, the degree to which the plan or programme influences other plans and programmes should be addressed, together with the promotion of sustainable development. The implementation of marine planning in the UK has set a national scale policy framework through the MPS, which in many instances formalised a number of accepted practices which together represented *de facto* marine planning in advance of the Marine and Coastal Access Act and related initiatives. Subsequent marine planning provides a regional to local scale emphasis which, in combination with the national energy policy statements (presently subject to review), helps to inform developers and decision makers including in relation to the activities covered by the draft plan/programme subject to this SEA. The SEA has in the past contributed to both an understanding of potential interactions with the environment and a wide range of other users for the draft plan/programme, and has provided this appraisal again in OESEA4, which will be of relevance to any development arising from the adoption of the draft plan/programme, and also continued marine spatial planning.

The expansion of offshore renewables, offshore hydrogen production and transport, and the transport and storage of carbon dioxide, will make positive contributions to UK Government targets of reducing greenhouse gas emissions, including both the interim target (68% reduction against a 1990 baseline by 2030) which is equal to the UK's current Nationally Determined Contribution under the Paris Agreement. The contribution of atmospheric emissions from oil and gas and gas storage activities that may result from implementation of the draft plan/programme would represent a minor fraction of existing UK, European and global emissions, however, it is recognised through a number of initiatives including the OGA Strategy and the North Sea Transition Deal, that upstream emissions from offshore oil and gas activities must be compatible with greenhouse gas reduction efforts and the net zero target. All further seaward licensing may also be subject to periodic climate compatibility checkpoints, and all future exploration and production projects following adoption of the draft plan/programme would need to be consistent with the net zero targets set by UK Government. In all cases, the reduction in greenhouse gas emissions through combustion will also contribute air quality reduction targets, for example as set out in the 25 Year Environment Plan and the UK National Air Pollution Control Programme.

Marine protected areas are part of the UK's national site network, and consist of a number of offshore Special Protection Areas (SPAs) and Special Areas of Conservation (SACs) designated under the Habitats Regulations and Offshore Habitats Regulations, and Marine Conservation Zones (MCZs) and Marine Protected Areas (MPAs) designated under the Marine and Coastal Access Act 2009. These variously protect wild birds, marine mammals, fish, and other marine fauna and flora and related habitats. A set of highly protected marine areas (HPMAs) are due to be identified and designated in 2022. These sites will prohibit extractive, destructive, and depositional uses and only allow non-damaging levels of other activities within the limits of international law. All of these sites will require careful consideration in the selection of offshore wind farm and other marine renewables sites, and development locations of all other elements of the draft plan/programme. As noted above, conclusions of adverse effects are already being made against wind farm and other projects in relation to a number of sites, species and habitats. The Environment Act 2021 requires that biodiversity net gain be secured through the planning system, with an increase in 10% in biodiversity following completion of a project compared to before development took place. This applies to consents made under the Planning Act 2008, the type of which would be required for offshore wind and large renewables projects, but does not yet apply to projects in marine areas. Amendments may be made to the Planning Act under Schedule 15 of the Environment Act allow for net gain provisions to be applied in the marine area at a future date.

In addition to the protections associated with conservation sites, frameworks for the wider improvements in the environmental and ecological/chemical status of UK water bodies are provided by the UK Marine Strategy and under the various regulations implementing retained aspects of the Water Framework Directive respectively. A number of targets have been set in relation to aspects of the marine and coastal environment through these initiatives and work is ongoing to achieve these. Any leasing/licensing decisions will need to be cognisant of these targets.

Shoreline Management Plans and other initiatives (e.g. flood risk management strategies, the flood and coastal erosion risk management strategy) which consider the potential implications of coastal and nearshore development, and the possible changes in the coast and flood risk from sea-level rise linked to climate change – the appropriateness of development in areas potentially affected by sea-level rise is also a consideration of the MPS and terrestrial policy such as the National Planning Policy Framework. While having a terrestrial focus, activities associated with the draft plan/programme have the potential to interact with the coast and therefore the objectives of the above through landfall of pipelines and cables and installation of tidal range devices, however, hydrodynamic changes associated with a broader range of renewables are also relevant.

With suitable mitigation and appropriate controls on activities which could follow adoption of the draft plan/programme, major negative effects on other policies or programmes can be avoided; this includes non-environmental topics such as navigation and air traffic control. In a number of policy areas the draft plan/programme will contribute positively to the achievement of their goals.

Transboundary effects

The OESEA4 covers a range of activities, some of which could take place in all UK waters, and others which are considered only for England and Wales. Transboundary effects are therefore possible with all neighbouring states whose waters abut the UK. These are France, Belgium, the Netherlands, Germany, Denmark, Norway, the Faroes and the Republic of Ireland. Since activities from this draft plan/programme may occur in UK waters and including adjacent to the majority of median lines, the sources of potentially significant environmental effects with the additional potential for transboundary effects include:

- Underwater noise
- Marine discharges
- Hydrodynamic changes
- Atmospheric emissions
- Impact mortality on migrating birds and bats
- Accidental events

All of the six aspects above may be able to be detected physically or chemically in the waters of neighbouring states. The scale and consequences of environmental effects in adjacent state territories due to activities resulting from adoption of the draft plan/programme will be less than those in UK waters and are considered unlikely to be significant.

Conclusions

The SEA considered the alternatives to the draft plan/programme and the potential environmental implications of the resultant activities in the context of: the objectives of the draft plan/programme, the SEA objectives, the existing regulatory and other control mechanisms, the wider policy and environmental protection objectives, the current state of the environment and its likely evolution over time, and existing environmental problems. The following summarises the conclusions that were made against each of the alternatives:

Alternative 1: Not to proceed with further licensing and/or leasing

a. **Not to undertake any further seaward oil and gas licensing rounds:** Adopting this alternative would result in a reduced level of disturbance to the seabed, fewer atmospheric emissions of greenhouse gases, air pollutants, produced water and drilling discharges. The alternative would also reduce the likelihood that the objective of the draft plan/programme to enhance security of energy supply would be achieved. The revised OGA strategy, the North Sea Transition Deal, and the periodic climate compatibility checkpoints, amongst other initiatives, are providing a framework for the UKCS to be a net zero basin by 2050. By not undertaking further seaward licensing rounds for future oil and gas exploration and production, this could result in future UK demand for oil and gas (which is projected to continue for some time under scenarios to meet net zero) being met with hydrocarbon imports which are likely to have a higher carbon intensity. There will be a range of effects from further exploration and production, however, these are subject to strict legislative control and will be subject to further assessment at a licence and project level, moreover, production from the UKCS is in long-term decline, and the scale of effect should the draft plan/programme be adopted will highly likely be of a much smaller scale than that resulting from previous plans. There will be some upstream emissions from activities related to future licensing rounds from exploration, production and decommissioning, but these are considered to be small, and in the context of an overall decline in net emissions from the sector. This alternative is, therefore, discounted.

b. **Not to licence and lease areas of the UKCS for carbon dioxide storage**: As with alternative 1a, this alternative would result in a reduced level of disturbance to the seabed, fewer atmospheric emissions of greenhouse gases, (noting that overall such schemes as a whole have the objective of storing large volumes of industrial carbon dioxide that would otherwise be emitted in to the atmosphere) air pollutants, drilling and other discharges (e.g. saline water). The offshore storage of carbon dioxide is critical to facilitating the UK Government target to store 20-30 million tonnes of carbon dioxide per year by 2030 and beyond, and therefore not leasing and licensing for carbon dioxide storage would reduce the potential to meet a key objective of the plan. This alternative is, therefore, discounted.

c. **Not to licence and lease areas of the UKCS for hydrocarbon gas storage**:

d. **Not to proceed with further renewables leasing, including rounds for offshore wind or individual leasing for wet renewables**: it is widely recognised that a significant increase in the capacity of offshore wind will be needed for the UK to meet its target of net zero emissions by 2050, with wave and tidal energy having a smaller role. While not proceeding with further leasing would result in lesser effects on a range of receptors including seabed habitats, birds, marine mammals, and other users of the sea, it would significantly affect the ability of the draft plan/programme to meet its objectives related to contributing towards greenhouse gas reduction commitments, and to enhance security of energy supply. This alternative is, therefore, discounted.

e. **Not to proceed with any leasing or licensing requirements needed for offshore hydrogen production, transport and storage offshore**: offshore hydrogen production has the potential to store energy, for example, at times of high wind farm energy output and low demand, which can then be used elsewhere as a low carbon source of energy. Proceeding with this aspect of the plan may result in additional offshore structures and shipping activities, with related effects on seabed habitats, and potentially, fish, marine mammals and other fauna, though the scale of these arising from the draft plan/programme is initially considered likely to be small. To not proceed with this aspect of the plan would reduce the opportunity for green hydrogen production and its related carbon reduction potential, and in view of the objectives of the plan, it is discounted.

Alternative 2: To proceed with a leasing and licensing programme

This alternative would meet all the objectives of the plan, however, there are a number of areas of uncertainty or high environmental sensitivity that such an alternative would not recognise at a strategic level. This alternative has, therefore, been discounted.

Alternative 3: To restrict the areas offered for leasing and licensing temporally or spatially

This alternative would meet the objectives of the plan, with the area offered restricted spatially through the exclusion of certain areas together with a number of mitigation measures to prevent, reduce and offset significant adverse impacts on the environment and other users of the sea. There will be effects across the full range of activities and receptors as outlined in the preceding assessment summary, however, it is recognised that there are areas that should not be leased or licensed at this time due to a high level of uncertainty, or that the areas are considered inappropriate for development.

The conclusion of the SEA is that alternative 3 to the draft plan/programme is the preferred option. In addition to the high level restrictions associated with this alternative, a number of recommendations are made relating to the management of spatial use and environmental risk, and where there are data gaps for which recommendations are made to prioritise future research.

National marine policy is set out at the UK level through the Marine Policy Statement, and has been regionally applied through a number of marine spatial plans in England, Wales, Scotland, and in draft form for Northern Ireland. Consultations associated with these plans involved further opportunities for coastal regulators and communities to provide input to the way the marine environment in their areas is managed. Additionally, further routes for consultation exist at the project level, for example, as part of the development consent process.

1 Introduction

1.1 Offshore Energy Strategic Environmental Assessment 4

This Environmental Report has been prepared as part of the United Kingdom Department for Business, Energy and Industrial Strategy (BEIS) Offshore Energy Strategic Environmental Assessment (OESEA) programme and is hereafter referred to as OESEA4. The SEA process aims to help inform licensing and leasing decisions by considering the environmental implications of the proposed plan/programme and the potential activities which could result from their implementation. The relevant areas for OESEA4 and a summary of the Draft Plan under consideration are described in Sections 1.5 and 2.3 respectively.

Previous SEAs undertaken as part of this programme included UK OESEA in January 2009, UK OESEA2 in February 2011 and UK OESEA3 in July 2016, which built on a series of previous regional scale SEAs undertaken since 1999. OESEA considered the environmental implications of a draft plan/programme to enable: further seaward rounds of oil and gas licensing, including gas storage in UK waters; and further rounds of offshore wind farm leasing in the UK Renewable Energy Zone (now Exclusive Economic Zone)[10] and the territorial waters of England and Wales to a depth of 60m. During 2010, an exercise to update and extend the scope of the OESEA Environmental Report was undertaken, and OESEA2 was issued for consultation covering further licensing/leasing for offshore energy including oil and gas, gas storage including carbon capture and storage (CCS) and marine renewables (wind, wave and tidal technologies). OESEA3 covered the same plan/programme elements of OESEA2, and provided an update to the assessment of effects and the baseline and policy context in which these effects were considered against.

Since OESEA3, as with previous SEAs, BEIS has maintained an active SEA research programme; identifying information gaps (some of which were outlined in previous SEA Recommendations), commissioning new research where appropriate, and promoting its wider dissemination through a series of research seminars[11]. This has also involved continued engagement with the SEA Steering Group and review of the information base for the SEA, including the environmental baseline, other relevant plans and programmes, and policy and regulation.

The aims and purpose of the OESEA4 Environmental Report are summarised in Section 1.4 below.

[10] this part of the plan/programme did not include the territorial waters of Scotland and Northern Ireland.
[11] https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process#offshore-energy-sea-research-programme

1.2 The requirement for SEA

This SEA is being conducted in accordance with the *Environmental Assessment of Plans and Programmes Regulations 2004* (as amended) (the SEA Regulations)[12], which apply to any relevant plan or programme which relates either solely to the whole or any part of England, or to England and any other part of the United Kingdom. Under regulation 5 of the SEA Regulations, a plan/programme prepared for energy must be subject to environmental assessment.

A required part of SEA is consultation with the consultation bodies/authorities (see Section 1.4.1) and public, together with such neighbouring states as may be potentially significantly affected.

1.3 Previous Offshore Energy SEAs

The SEA process aims to inform licensing and leasing decisions by considering the environmental implications of the proposed plan/programme and the potential exploration, development and energy production activities which could result from its implementation. Since 1999, in addition to OESEA, OESEA2 and OESEA3, the Department has conducted seven regional SEAs of the implications of further licensing of the UK Continental Shelf (UKCS) for oil and gas exploration and production (SEAs 1-7[13]), an SEA for a second round (R2) of wind leasing – see Table 1.1 and Figure 1.1 overleaf – and also SEA work for the potential exploitation of tidal range power in the Severn.

OESEA4 builds on the work completed for the previous SEAs. Preparatory to OESEA, the Department conducted a screening exercise for potential future rounds of offshore wind leasing to understand major constraints and issues, and whether there are any data gaps for strategic planning. A similar exercise was undertaken for other types of marine renewable energy generation, which led to the inclusion of wave, tidal stream and tidal range in OESEA2, and more detailed consideration of tidal range technologies in OESEA3. The draft plan/programme for OESEA4 (Section 2.4) includes those elements of former plans/programmes.

Table 1.1: Previous Offshore Energy SEAs

SEA	Area	Sectors covered	Year	Licensing/leasing round
SEA 1	The deep water area along the UK and Faroese boundary	Oil & Gas	2001	19th Round
SEA 2	The central spine of the North Sea which contains the majority of existing UK oil and gas fields	Oil & Gas	2002	20th Round
SEA 2 extension	Outer Moray Firth	Oil & Gas	2002	20th Round

[12] The SEA Regulations transposed the requirements of Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (commonly called the SEA Directive), and remain in force as part of retained EU law.
[13] The SEA 8 area was incorporated into OESEA.

SEA	Area	Sectors covered	Year	Licensing/leasing round
SEA 3	The remaining parts of the southern North Sea	Oil & Gas	2003	21st Round
R2	Three strategic regions off the coasts of England and Wales in relation to a second round of offshore wind leasing	Offshore wind	2003	Round 2
SEA 4	The offshore areas to the north and west of Shetland and Orkney	Oil & Gas	2004	22nd Round
SEA 5	Parts of the northern and central North Sea to the east of the Scottish mainland, Orkney and Shetland	Oil & Gas	2005	23rd Round
SEA 6	Parts of the Irish Sea	Oil & Gas	2006	24th Round
SEA 7	The offshore areas to the west of Scotland	Oil & Gas	2008	25th Round
OESEA*	UK offshore waters and territorial waters of England and Wales	Oil & Gas, Offshore wind	2009	26th Round Round 3
OESEA2	UK offshore waters and territorial waters of England and Wales	Oil & Gas, Offshore wind, wave and tidal stream, gas and carbon dioxide storage	2011	27th Round
			2014	28th Round
OESEA3	UK offshore waters and territorial waters of England and Wales	Oil & Gas, Offshore wind, wave and tidal stream, gas and carbon dioxide storage	2016	29th Round 2016 Supplementary Round
			2017	30th Round
			2018	31st Round 31st Supplementary Round
			2019	32nd Round Round 4

*Note: *incorporated the SEA 8 area*

1.4 The Environmental Report and its purpose

The purpose of the OESEA4 Environmental Report is to

- Consider the environmental implications of the BEIS draft plan/programme to enable further licensing/leasing for offshore energy (marine renewables including wind, wave, tidal stream and tidal range, oil and gas, hydrocarbon gas storage, and carbon dioxide storage). This includes consideration of the implications of alternatives to the plan/programme and consideration of potential interactions with other users of the sea
- Inform the UK Government's decisions on the draft plan/programme
- Provide routes for public and stakeholder participation in the process

The Environmental Report and the feedback from consultation will be taken into account during the finalisation of the plan/programme prior to its adoption.

1.4.1 Consultation Bodies/Authorities

Since the 2004 Regulations were made, a number of the nominated consultation bodies/authorities have been subject to organisational/name change. The following are the current statutory consultation bodies/authorities for this SEA:

- Historic England
- Natural England
- Environment Agency
- Historic Environment Scotland
- NatureScot
- Scottish Environment Protection Agency
- Cadw (Welsh Assembly Government's historic environment division)
- Natural Resources Wales
- Department of Agriculture, Environment and Rural Affairs (NI)

In addition, the Joint Nature Conservation Committee, Marine Management Organisation and Marine Scotland have also been included as consultation bodies for this SEA. The Isle of Man Government will also be consulted, as will relevant States which have the potential to be affected by the draft plan/programme.

1.5 The relevant areas

For offshore renewable energy, this SEA considers potential leasing in the relevant areas of the UK Exclusive Economic Zone (EEZ), and also the territorial waters of England and Wales. The area covered by the Scottish Renewable Energy Zone and Scottish and Northern Irish waters within the 12 nautical mile territorial sea limit are not included for this part of the plan.

For gas storage and carbon dioxide storage, this SEA considers potential licensing/leasing in relevant UK territorial waters (excluding Scottish territorial sea where CCS is a devolved matter) and the UK EEZ. The establishment of the EEZ[14] follows agreement on a number of treaties with adjacent states, and some activities may be subject to certain restrictions in the part of the EEZ known as the Faroes Special Area.

For offshore (seaward) oil and gas licensing, this SEA covers all UK waters.

The geographical coverage within which areas may be leased/licensed following adoption of the plan is shown in Figures 1.2 and 1.3. The prospectivity of these areas in relation to plan activities is discussed in Section 2.

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[14] See *The Exclusive Economic Zone Order 2013*

Figure 1.1: Spatial Coverage of Previous Offshore Energy SEAs and Regional Sea Boundaries

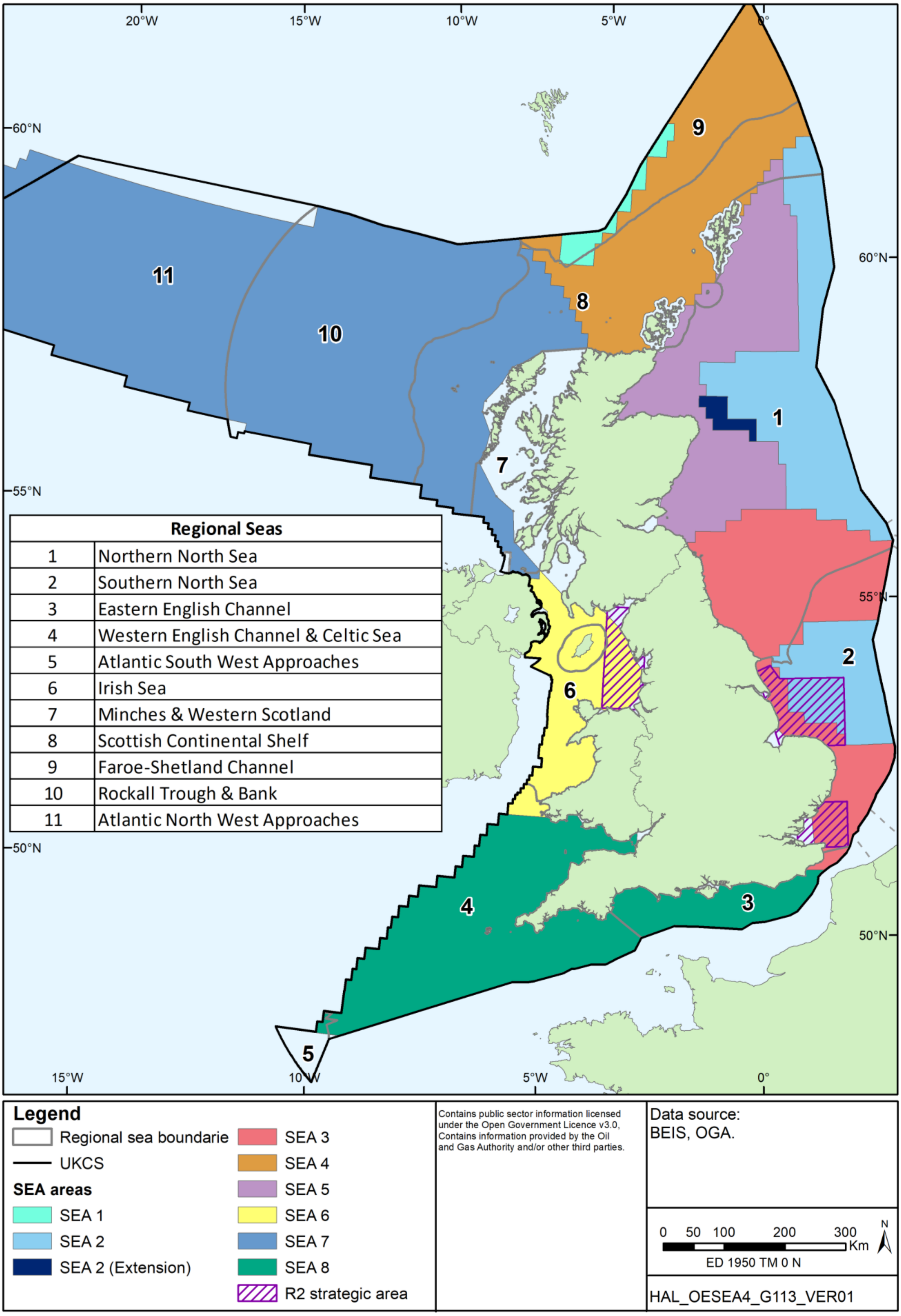


Figure 1.2: Areas mentioned in the text: the UKCS, UK Exclusive Economic Zone, Scottish Renewable Energy Zone and Territorial seas

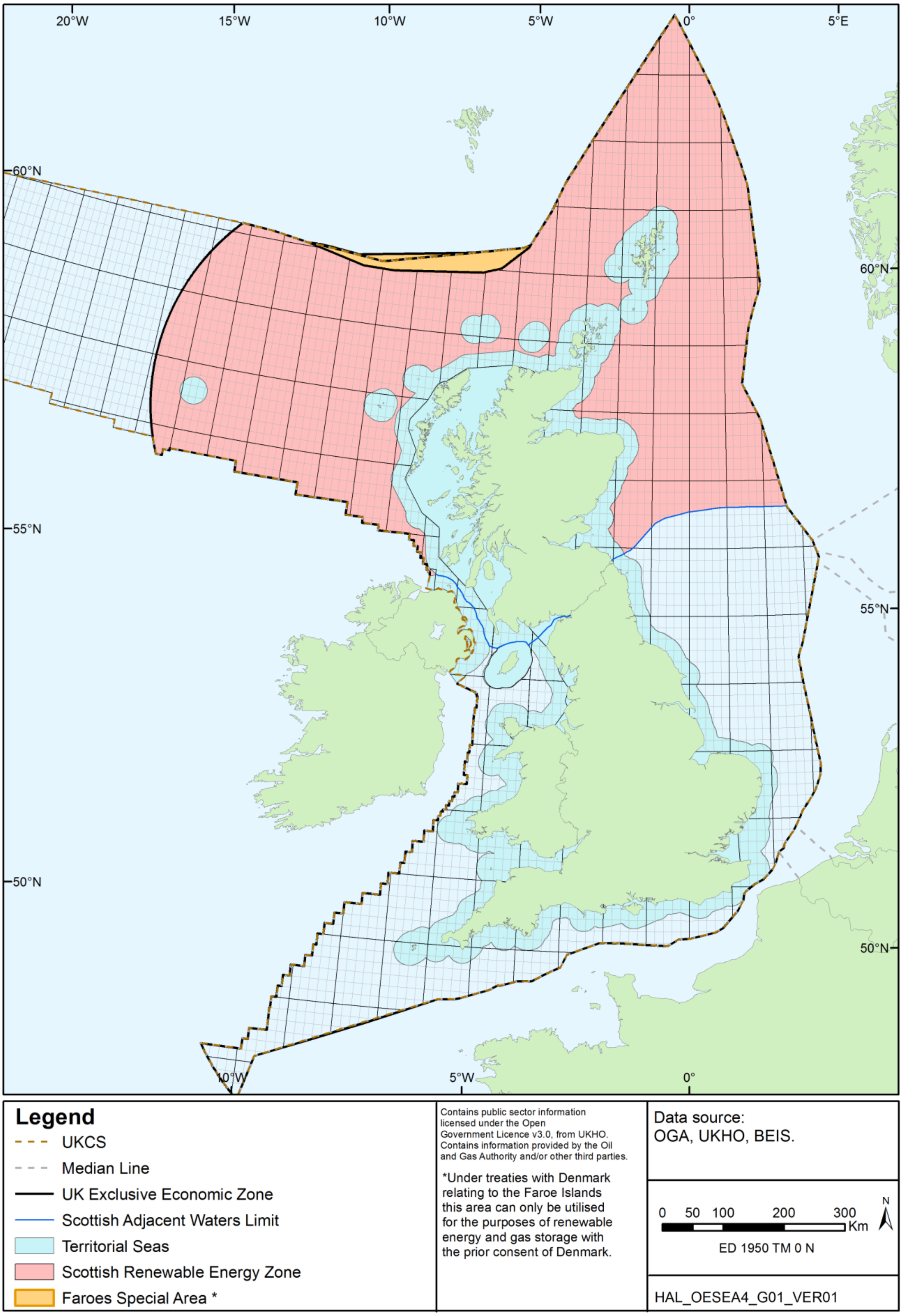


Figure 1.3 Geographical coverage of the SEA (Offshore Renewables)

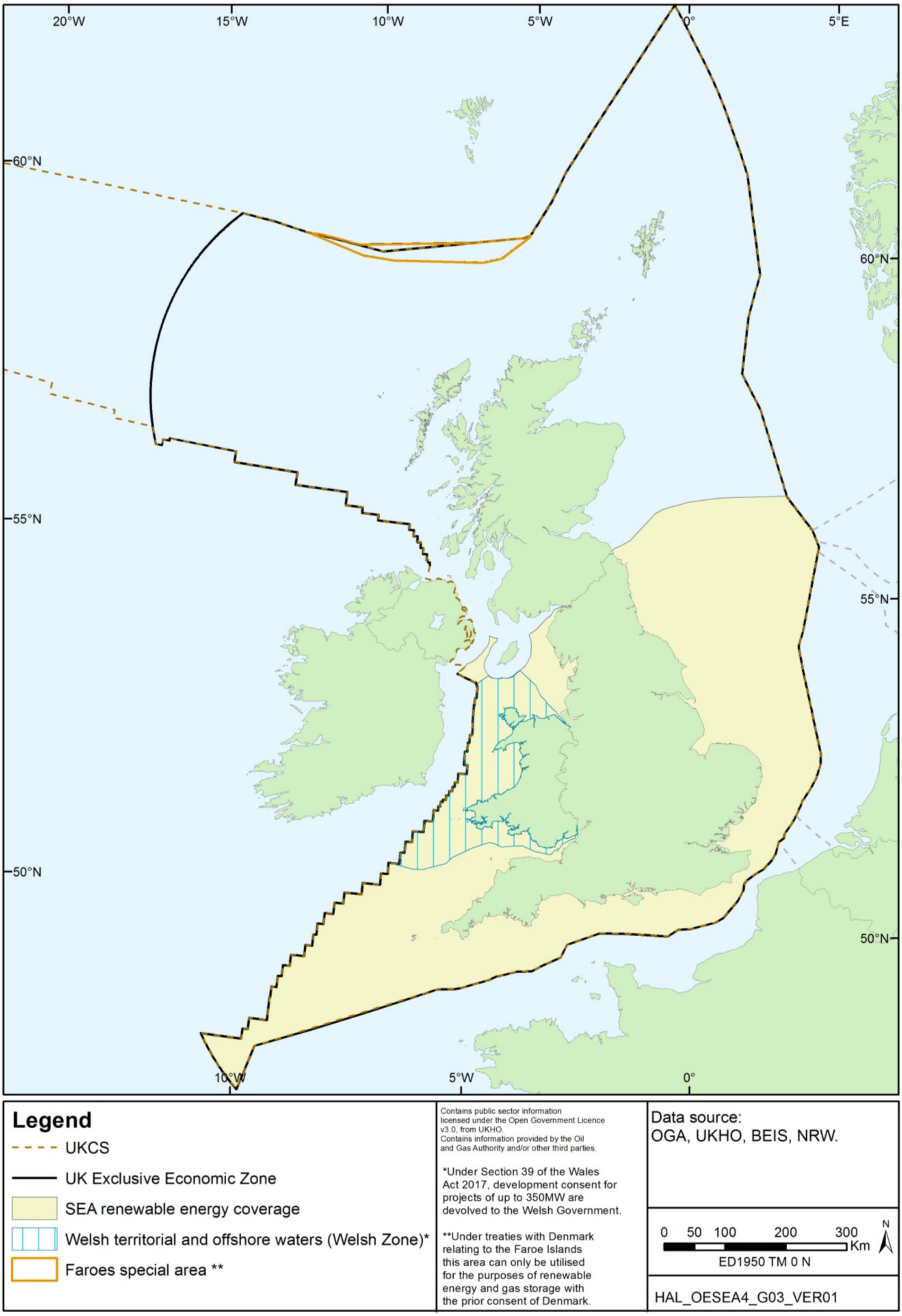
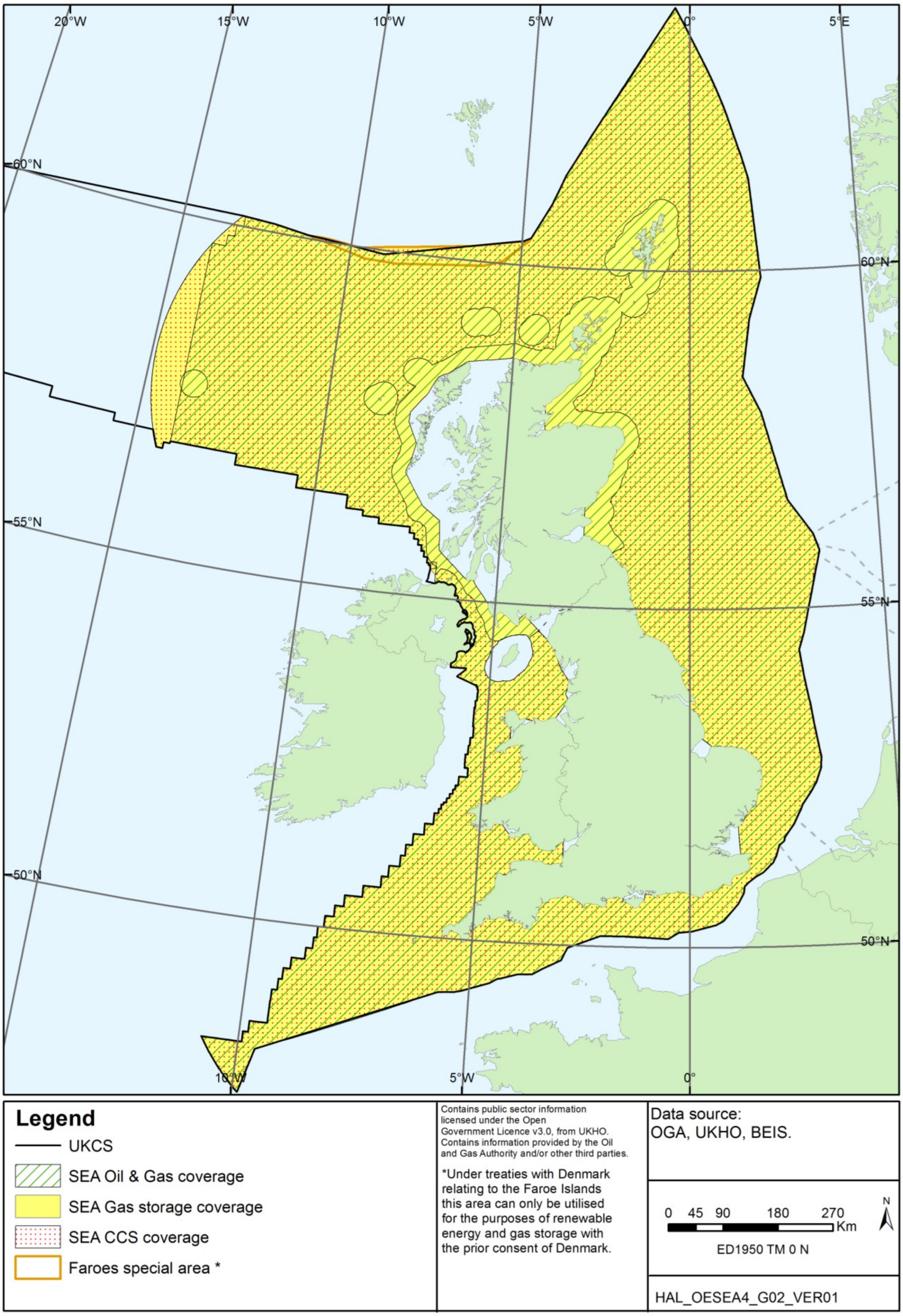


Figure 1.4 Geographical Coverage of the SEA (Oil and Gas, Gas Storage, CCS)



1.5.1 Contents of the Environmental Report

Schedule 2 of the SEA Regulations sets out the information to be included in an Environmental Report of a Strategic Environmental Assessment – see Table 1.2. Regulation 12(3) specifies that:

"...the report shall include such of the information referred to in Schedule 2 …. as may reasonably be required, taking account of:- (a) current knowledge and methods of assessment; (b) the contents and level of detail in the plan or programme; (c) the stage of the plan or programme in the decision-making process; and (d) the extent to which certain matters are more appropriately assessed at different levels in that process in order to avoid duplication of the assessment."

Table 1.2: Information to be included in Environmental Reports as required by Schedule 2 of the Environmental Assessment of Plans and Programmes Regulations 2004

1.	An outline of the contents and main objectives of the plan/programme, and of its relationship with other relevant plans/programmes.
2.	The relevant aspects of the current state of the environment and the likely evolution thereof without implementation of the plan/programme.
3.	The environmental characteristics of areas likely to be significantly affected.
4.	Any existing environmental problems which are relevant to the plan/programme including, in particular, those relating to any areas of a particular environmental importance, such as a European site (within the meaning of regulation 8 of the Conservation of Habitats and Species Regulations 2017).
5.	The environmental protection objectives, established at international, Community or national level, which are relevant to the plan/programme and the way those objectives and any environmental considerations have been taken into account during its preparation.
6.	The likely significant effects on the environment, including short, medium and long-term effects, permanent and temporary effects, positive and negative effects, and secondary, cumulative and synergistic effects, on issues such as - (a) biodiversity; (b) population; (c) human health; (d) fauna; (e) flora; (f) soil; (g) water; (h) air; (i) climatic factors; (j) material assets; (k) cultural heritage, including architectural and archaeological heritage; (l) landscape; and (m) the interrelationship between the issues referred to in sub-paragraphs (a) to (l).
7.	The measures envisaged to prevent, reduce and as fully as possible offset any significant adverse effects on the environment of implementing the plan/programme.
8.	An outline of the reasons for selecting the alternatives dealt with, and a description of how the assessment was undertaken including any difficulties (such as technical deficiencies or lack of know-how) encountered in compiling the required information.
9.	A description of the measures envisaged concerning monitoring in accordance with regulation 17.
10.	A non-technical summary of the information provided under paragraphs 1 to 9.

The criteria for determining the likely significance of effects are set out in Schedule 1 of the Regulations and are listed in Table 1.3.

Table 1.3: Criteria for determining the likely significance of effects on the environment as specified in Schedule 1 of the Environmental Assessment of Plans and Programmes Regulations 2004

1.	The characteristics of plans/programmes, having regard, in particular, to:- (a.) the degree to which the plan/programme sets a framework for projects and other activities, either with regard to the location, nature, size and operating conditions or by allocating resources; (b.) the degree to which the plan/programme influences other plans/programmes including those in a hierarchy; (c.) the relevance of the plan/programme for the integration of environmental considerations in particular with a view to promoting sustainable development; (d.) environmental problems relevant to the plan/programme; and (e.) the relevance of the plan/programme for the implementation of retained EU law on the environment (for example, plans/programmes linked to waste management or water protection).
2.	Characteristics of the effects and of the area likely to be affected, having regard, in particular, to:- (a.) the probability, duration, frequency and reversibility of the effects; (b.) the cumulative nature of the effects; (c.) the transboundary nature of the effects; (d.) the risks to human health or the environment (for example, due to accidents); (e.) the magnitude and spatial extent of the effects (geographical area and size of the population likely to be affected); (f.) the value and vulnerability of the area likely to be affected due to – (i.) special natural characteristics or cultural heritage; (ii.) exceeded environmental quality standards or limit values; or (iii.) intensive land-use; and (g.) the effects on areas or landscapes which have a recognised national, Community or international protection status.

1.6 Organisation of the Environmental Report

A large amount of information has been collated, reviewed and assessed as part of this SEA. To facilitate reader access, the following table identifies where relevant information can be found. The body of the Environmental Report comprises seven main sections plus a bibliography, glossary, appendices and a non-technical summary. Figures and tables are interspersed throughout the document.

Table 1.4: Structure of the Environmental Report

Section	Summary
Non-technical summary	A standalone summary in non-technical language of the SEA, its findings and conclusions.
1. Introduction	Describes the background to the draft plan/programme and the regulatory context and purpose of the SEA and the ER.
2. Overview of the draft plan/programme	Provides details of the background to the proposed plan/programme, the plan/programme itself, its objectives and relationships to other initiatives. Alternatives to the plan/programme are also described.
3. SEA approach	Describes the scope and methodology of the SEA.
4. Environmental Information	Describes the environmental characteristics of the relevant areas, identifies relevant existing environmental problems, the likely evolution of the environmental baseline and SEA objectives.
5. Consideration of the potential effects of the draft plan/programme	Provides details of the assessment method, a consideration of the results of the assessment and identifies mitigation and enhancement measures to prevent, reduce or offset any significant adverse effects identified during the assessment process.

Section	Summary
6. Recommendations and monitoring	Provides an overall conclusion on the likely implications of the proposed licensing/leasing and alternatives, together with recommendations for mitigation and monitoring, and identification of relevant gaps in understanding.
7. Next steps	Describes the consultation phase for the Environmental Report and proposed plan/programme, the process underpinning the adoption of the plan/programme and the final SEA statement.
	References
	Glossary and abbreviations
Appendix 1: Environmental Baseline	Underpins Section 4 and contains a series of sub-appendices (A1a to A1j) describing the key characteristics in relation to biodiversity, habitats, flora and fauna; geology, substrates and coastal geomorphology; landscape/seascape; water environment; air quality; climate and meteorology; population and human health; other users, material assets (infrastructure, other natural resources); cultural heritage and conservation of sites and species in relation to UK waters as a whole and for each of the draft Regional Seas (see Figure 1.1 for Regional Seas boundaries).
Appendix 2: Other Initiatives	Describes other initiatives, plans and programmes of relevance to the proposed plan/programme, the implications of these for the proposed plan/programme and vice versa.
Appendix 3: Regulatory and other controls	Summarises the key environmental legislation and controls applying to the activities encompassed by the draft plan/programme.
Appendix 4: SEA Stakeholder Workshops	Contains summaries of the range of workshops (assessment, regional stakeholder and sector) which contributed to the SEA process and information base.

1.7 The study team

This report was prepared by independent consultants, Hartley Anderson Limited, in conjunction with BEIS. Contributions/input to the assessment process from the SEA Steering Group, studies commissioned for the BEIS SEA process and the participants in the SEA workshops are reflected in the Environmental Report.

1.8 Public consultation

The Environmental Report and draft plan/programme will be issued for formal consultation as required by the SEA Regulations. The SEA consultation process has been designed to be in keeping with the Cabinet Office guidance[15] on Consultation Principles for engaging stakeholders when developing policy and legislation.

15 https://www.gov.uk/government/publications/consultation-principles-guidance

2 Overview of the draft plan/programme

2.1 Introduction

The SEA Regulations require that the Environmental Report includes:

"an outline of the contents and main objectives of the plan or programme, and of its relationship with other relevant plans and programmes" and that consideration is given to the degree to which the *"plan or programme influences other plans and programmes including those in a hierarchy"*

"The environmental protection objectives, established at international, Community or national level, which are relevant to the plan or programme and the way those objectives and any environmental considerations have been taken into account during its preparation".

A list of the International and UK initiatives, including plans/programmes, together with their objectives which have been analysed in terms of their implications for the draft plan/programme and vice versa is given in Appendix 2.

2.2 Energy policy context

2.2.1 Net Zero and the Net Zero Strategy

The UK Government has committed to achieving net zero greenhouse gas (GHG) emissions by 2050 relative to a 1990 baseline, with the target made legally binding through the *Climate Change Act 2008 (2050 Target Amendment) Order 2019*. While the foundations are in place to meet net zero, according to the Climate Change Committee, the ability for the UK to achieve this target will require additional policy (CCC 2020a). The CCC (2019) recognise that the potential to reach this target is not evenly distributed across the UK, and recommended that Wales achieve a 95% reduction by 2050, and Scotland a 100% reduction by 2045. The SEA will consider the contribution of the plan/programme towards the UK's new interim 2030 target (reduction in greenhouse gas emissions by 68% against a 1990 baseline[16]) and to the overall net zero target.

The Government's Net Zero Strategy: Build Back Greener, was published in October 2021 in response to the setting of the sixth Carbon Budget, pursuant to Section 14 of the *Climate Change Act 2008*. The strategy sets out policies in response to accepting the carbon budget as recommended by the CCC (2020b), Nationally Determined Contributions under the Paris

[16] https://www.gov.uk/government/news/uk-sets-ambitious-new-climate-target-ahead-of-un-summit and https://www.gov.uk/government/publications/the-uks-nationally-determined-contribution-communication-to-the-unfccc, also note the setting of the 6th carbon budget (*The Carbon Budget Order 2021*) which targets an emissions reduction of 78% on 1990 levels by 2035.

Agreement[17], and a vision towards net zero being achieved by 2050. Key policies in the Strategy relevant to the draft plan/programme include:

Power: the delivery of 40GW of fixed foundation offshore wind and "moving towards" 1GW of floating offshore wind by 2030, with the latter backed by £380 million in funding. There is a commitment to produce all electricity from low carbon sources by 2035, subject to security of supply, with deployment of renewables, including wind, supported through Contracts for Difference (CfD); the frequency of auctions related to CfD was subject to review and will now take place annually[18], and will be key to delivering the levels of generation required by 2030. The Offshore Transmission Network Review (OTNR) aims to help coordinate offshore grid connections, with recent proposals made as part of a consultation for a regime that takes a more strategic approach to offshore transmission that is considered holistically with the onshore network to deliver greater coordination and reduce cumulative effects[19].

Fuel supply and hydrogen: the delivery of 5GW of hydrogen production capacity by 2030 (indirectly relevant to the draft plan/programme, for example, by requiring carbon dioxide transport and storage offshore to facilitate blue hydrogen production), as set out in *The Hydrogen Strategy*[20], to be augmented by a Hydrogen Sector Development Action plan in early 2022.

Building on the North Sea Transition Deal (see 2.2.2 below), a new periodic climate compatibility checkpoint for future oil & gas licensing on the UK Continental Shelf may be introduced and the sector will be regulated in a way that minimises greenhouse gases through the revised Oil and Gas Authority strategy (see 2.2.3 below). The consultation on the design of the compatibility checkpoint[21] set out the scope of the checkpoint (i.e. that it covers only new licensing and may cover one or more licensing rounds) and its implementation, and proposes a number of tests that would inform the outcome of the checkpoint. The Government will work with stakeholders to address barriers to electrification of oil and gas production through £1 million of additional funding from 2021 to 2022, and will work with regulators to review supporting infrastructure through the OTNR. Additionally, as part of a separate Scottish Sectoral Marine Plan for Offshore Wind for Innovation and Targeted Oil and Gas Decarbonisation (INTOG)[22], a number of areas of search have been identified, and subject to consultation, for future offshore wind leasing specifically to help decarbonise the offshore oil and gas production. Routine flaring and venting will continue to be driven down, going beyond the World Bank's "Zero routine flaring by 2030" initiative (to which the UK is a signatory), with new OGA guidance[23] setting an expectation that all facilities should have zero routine flaring and venting by 2030 or sooner, with industry taking action through its Methane Action Plan.

Industry: Deliver four carbon capture usage and storage (CCUS) clusters, capturing 20-30 $MtCO_2$ across the economy, including 6 $MtCO_2$ of industrial emissions, per year by 2030, and 9 $MtCO_2$ per year by 2035; pipeline and non-pipeline transport (e.g. shipping) may be required.

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17 https://www.gov.uk/government/publications/the-uks-nationally-determined-contribution-communication-to-the-unfccc
18 https://www.gov.uk/government/news/government-hits-accelerator-on-low-cost-renewable-power
19 https://www.gov.uk/government/consultations/offshore-transmission-network-review-proposals-for-an-enduring-regime
20 https://www.gov.uk/government/publications/uk-hydrogen-strategy
21 https://www.gov.uk/government/consultations/designing-a-climate-compatibility-checkpoint-for-future-oil-and-gas-licensing-in-the-uk-continental-shelf
22 https://marine.gov.scot/data/sectoral-marine-plan-offshore-wind-innovation-and-targeted-oil-and-gas-decarbonisation-intog
23 https://www.ogauthority.co.uk/news-publications/publications/2021/flaring-and-venting-guidance/

In line with this ambition, the HyNet and East Coast Clusters have been confirmed as being Track-1 clusters following the CCUS cluster sequencing process, with the Scottish cluster kept as a reserve cluster. Developed alongside hydrogen, CCUS will be part of creating transformative "SuperPlaces" in areas such as the Humber and North East, North West, and Southern England as well as in Scotland and Wales. The clusters could access support under the Government's CCUS programme which includes the £1 billion CCS Infrastructure Fund, the Industrial Decarbonisation and Hydrogen Revenue Support (IDHRS) scheme and the £240 million Net Zero Hydrogen Fund. Most recently, BEIS has proposed an Industrial Hydrogen Accelerator competition to support projects over the full technology chain, from hydrogen generation and delivery infrastructure through to industrial end-use[24].

An evaluation of the Net Zero Strategy by the CCC (2021a) indicated that it is comprehensive and represents a significant step forward in UK climate policy which is achievable though will require quick implementation to be a success. The CCC indicate that the commitments of the Strategy match those of the Sixth Carbon Budget's Balanced Pathway to Net Zero scenario (CCC 2020b) for the period 2025-2035, including targets for offshore wind, low-carbon hydrogen, and carbon capture and storage. This includes that funding mechanisms are apparently set at levels required to achieve a balanced mix of solutions across these and other sectors. The CCC Pathway and the Net Zero Strategy also differ on emissions (in the order of 5-6MtCO_2e) associated with the fuel supply sector. This mainly reflects the difference between the Pathway and the emissions reductions targets in the North Sea Transition Deal. While the commitments are consistent with a pathway towards meeting the sixth carbon budget, the CCC (2021a) note that the effect of each policy on emissions has not been quantified.

2.2.2 The Energy White Paper: Powering our Net Zero Future

The 2020 Energy White Paper, Powering our Net Zero Future[25], was published in December 2020 and sets out the contribution that the energy sector could make to delivering emissions reductions consistent with the net zero by 2050 target, and the role that the Government and related regulatory bodies will take to assist relevant sectors to achieve this. The Energy White Paper built upon the Government's, Ten Point Plan for a Green Industrial Revolution (November 2020), which includes a number of policy elements relevant to the draft plan/programme being assessed in OESEA4, including on offshore wind and CCUS. The White Paper does not make any recommendation or prediction on the energy mix needed to deliver net zero (outside of the support to 2030 for certain technologies such as offshore wind). It is expected that the market will deliver the lowest cost route to net zero, and a number of modelling exercises illustrate how this might be achieved (also refer to CCC 2020c).

The aspects of the White paper most relevant to the draft plan/programme are summarised below.

Offshore renewables

In keeping with earlier UK Government announcements is the delivery of up to 40GW of offshore wind by 2030, supported through further Contract for Difference (CfD) auctions. The fourth round of CfD opened in December 2021[26] and is due to make available up to £285 million for projects bidding in the auction. No capacity cap has been set for offshore wind, which has been assigned the majority of the available funding in the auction (£200 million).

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[24] https://www.gov.uk/government/publications/industrial-hydrogen-accelerator-programme
[25] https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
[26] https://www.gov.uk/government/collections/contracts-for-difference-cfd-allocation-round-4

Other less well established offshore renewables including floating offshore wind and tidal stream will also have funding allocated. A call for evidence[27] was announced in August 2020 covering the scope for innovation in marine energy (including tidal stream, tidal lagoons and barrages, floating offshore wind, and wave energy), building on a related consultation on changes to the CfD scheme[28]. In response to the call for evidence, 1GW of floating wind will be supported by 2030, and the UK Government will work with The Crown Estate and Crown Estate Scotland to address leasing issues, protecting the marine environment, and ensuring the UK captures the economic benefits of deploying the technology. Additionally, £20 million per year will be ringfenced for tidal stream energy projects as part of the fourth allocation round[29].

A Ministerial Delivery Group will be established to bring together relevant Government departments to oversee the expansion of renewables, including tackling barriers to further offshore wind deployment, including radar interference, impacts on the marine environment, and appropriate network infrastructure. It will also focus on reducing consenting delays and ensuring that planning guidelines and environmental regulations are fit for purpose. Existing cross-government mechanisms will be used, such as the Offshore Wind Enabling Actions programme, a £4.3 million initiative run jointly by Defra and BEIS, and funded by HM Treasury.

The Offshore Wind Sector Deal will be used to ensure that domestic deployment creates jobs and raises skills levels across the country, and to support overseas trade and investment opportunities for UK-based companies. Developers who are awarded a CfD will be required to honour their supply chain plans. £160 million will be provided to support the development of major portside infrastructure hubs. This investment, and the 40GW target, will support the industry's target to achieve 60% UK content by 2030.

Offshore wind farms have, to date, been connected to the onshore grid via project-specific export cabling. The Offshore Transmission Network Review was launched in July 2020 in recognition that the current regime has encouraged such connections, and the impact this can have on coastal communities. The review will consider such impacts and how the wider UK would benefit from a more strategic approach, seek the appropriate balance between environmental, social and economic costs, and the potential of hybrid, multi-purpose interconnectors. Those with projects already in development will be encouraged, where early opportunities for coordination exist, to consider becoming pathfinder projects that will help inform the design of the enduring regime.

CCUS

The deployment of CCUS projects in the energy sector will play a key role in the decarbonisation of the electricity system, and support will be provided for the construction of at least one power plant using CCUS, to be operational by 2030. A business model will be introduced based on the existing CfD framework, adapted so that price signals incentivise power CCUS. It is considered that the current 300MW minimum threshold for carbon capture readiness creates a market distortion by disincentivising the deployment of larger gas plants which tend to be more efficient. A call for evidence on the removal of the 300MW threshold

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[27] https://www.gov.uk/government/consultations/potential-of-marine-energy-projects-in-great-britain-call-for-evidence
[28] https://www.gov.uk/government/consultations/contracts-for-difference-cfd-proposed-amendments-to-the-scheme-2020
[29] https://www.gov.uk/government/news/uk-government-announces-biggest-investment-into-britains-tidal-power

and the inclusion of low-carbon hydrogen as an additional decarbonisation technology took place between July and September 2021[30].

In addition to energy, CCUS is key to decarbonising industry, and industrial centres can benefit from utilising shared infrastructure, such as the transportation and storage networks for captured carbon dioxide, and hydrogen production and distribution. £1 billion will be invested to facilitate the deployment of CCUS in two industrial clusters by the mid-2020s (selected projects are the East Coast Cluster and HyNet North West, with the Scottish cluster identified as a reserve), and a further two clusters by 2030. This will support the ambition to capture 20-30MtCO_2 per year by2030. CCUS is not yet a viable investment for the majority of industrial sectors, and a business model is therefore being designed and implemented to provide revenue support, and to improve confidence for investing in carbon capture solutions. The industrial carbon capture business model will be funded through the IDHRS scheme, announced in the Net Zero Strategy.

The UK will continue to rely on natural gas for some years during the transition to net zero. A consultation is to be undertaken to update the Gas Act 1986 to ensure gas supplies are decarbonised while encouraging investment and maintaining security of supply. This will reduce emissions and help build the networks needed to accommodate hydrogen (see below) and CCUS. This will include a review of gas quality standards to enable the widest range of gasses to be used to decarbonise energy.

Hydrogen

The White Paper committed to a *Hydrogen Strategy*, which was published in August 2021[31]. Around 95% of global hydrogen production is currently fossil-fuel based, and a switch to clean hydrogen is required together with a major increase in production capacity. Current production is ~27TWh/year, and the CCC (2019) suggest a ten-fold increase by 2050 may be required, with the option to go further depending on the scale of hydrogen use in heat, transport and power. A variety of production technologies will be required, but will likely include methane reformation with CCUS, biomass gasification with CCUS and electrolysis of water using renewable or nuclear generated electricity. An ambition of 5GW (equating to 42TWh) of low-carbon hydrogen production capacity by 2030 has been set, with the hope that 1GW capacity could be delivered by 2025. Cost, technology, policy and regulatory, infrastructure and demand challenges will need to be overcome to deploy hydrogen at scale. A number of commitments are made in the *Hydrogen Strategy* to enable growth in the sector including, the launch of a £240m Net Zero Hydrogen Fund in early 2022, development of a UK standard for low carbon hydrogen by early 2022, finalising the Hydrogen Business Model enabling the first contracts to be allocated from 2023 (all subject to consultations August to October 2021), a £60 million Low Carbon Hydrogen Supply 2 competition[32], and, further detail on a production strategy and “twin track” approach (i.e. production of both blue hydrogen with CCS and green hydrogen) by early 2022.

Oil & Gas

The UK is not self-sufficient in crude oil, and although much of the crude oil produced from the North Sea basin is exported[33], the UK imports quantities of suitable crude oils to meet

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[30] https://www.gov.uk/government/consultations/decarbonisation-readiness-call-for-evidence-on-the-expansion-of-the-2009-carbon-capture-readiness-requirements
[31] https://www.gov.uk/government/publications/uk-hydrogen-strategy
[32] https://www.gov.uk/government/publications/low-carbon-hydrogen-supply-2-competition
[33] https://www.gov.uk/government/statistics/petroleum-chapter-3-digest-of-united-kingdom-energy-statistics-dukes

domestic refinery demand. Domestic gas production met 46% of the UK gas supply in 2019, the vast majority from North Sea offshore production, with a smaller proportion from onshore production. UK demand for oil and gas is expected to continue for several decades.

The sector is already under significant pressure from investors and the public to respond to the net zero challenge, and Government support will be in the context of delivering the net zero target. There is potential for the sector to play an important part in the energy transition and retain vital skills across key regional hubs around the country, supporting CCUS and hydrogen. Working with the regulators, greenhouse gas emissions from all offshore oil and gas operations will be driven down to make the UK continental shelf a net zero basin by 2050: the oil and gas sector will need to reduce its emissions from offshore production and operations to 0.5MtCO_2e by 2050, from 19MtCO_2e today, and methane will be a particular focus. The UK will commit to the World Bank's 'Zero Routine Flaring by 2030' initiative[34] and will work with regulators towards eliminating routine flaring as soon as possible in advance of this date. The Oil & Gas Authority (OGA) will take a more robust stance to push for reductions in flaring and venting through its consents, field development process and project stewardship role. Regulatory and policy barriers to the use of clean electricity, such as from offshore wind, to power offshore oil and gas facilities will be tackled to assist the reduction in upstream emissions. The sector will also be challenged to address embodied emissions from the consumption of their products, or from supply chain activities.

The UK Government will work with the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED) and OGA in the delivery of a net zero basin without imposing significant regulatory barriers. OPRED will increase its focus on the reduction of greenhouse gas emissions from offshore oil and gas operations and will put in place a regulatory framework to support emerging decarbonisation technologies. The OGA's former Maximising Economic Recovery (MER) Strategy has been refreshed and renamed the OGA Strategy[35] (see Section 2.2.3). The Strategy's central obligation, and supporting obligations have been modified to be consistent with the delivery of the Government's net zero target.

The OGA is clear that Net Zero is compatible with MER and part of a proper and wide consideration of what Maximising Economic Recovery means. The Energy White Paper refers to the government's review of the UK's offshore oil and gas licensing regime. This review concluded that licensing for oil and gas should continue but with the introduction of periodic Climate Compatibility Checkpoints[36]. These assessments will be based on a range of information including the UK's energy demand and sources of supply and will provide advice on how proceeding with future licensing would impact on the UK's climate and energy goals. The Energy White Paper indicated that a North Sea Transition Deal would be agreed with the industry, and be focused on the economic opportunities of net zero and providing support for the people and communities most affected by the move away from oil and gas production. The North Sea Transition Deal was released on 24th March 2021 and includes the following commitments:

- the sector setting early targets to reduce emissions by 10% by 2025 and 25% by 2027, with emissions cut by 50% by 2030

34 The UK endorsed the World Bank's 'Zero Routine Flaring by 2030' on 17 December 2020
35 https://www.ogauthority.co.uk/news-publications/publications/2020/the-oga-strategy/
36 https://www.gov.uk/government/news/north-sea-deal-to-protect-jobs-in-green-energy-transition

- joint government and oil and gas sector investment of up to £16 billion by 2030 to reduce carbon emissions, including up to £3 billion to replace fossil fuel-based power supplies on oil and gas platforms with renewable energy, up to £3 billion on CCUS, and up to £10 billion for hydrogen production

- by 2030, the sector will voluntarily commit to ensuring that 50% of its offshore decommissioning and new energy technology projects will be provided by local businesses

- support to the coordination of local growth and job opportunities with other sectors, such as CCUS and offshore wind

As part of decommissioning within the sector, the potential to use existing infrastructure in CCUS transport and storage will be considered. A review of the possible re-use of oil and gas assets for CCUS[37] identified those with greatest potential, and UK Government will work with industry and regulators to provide clarity on the regulations for re-purposing assets and to develop technical guidance on how this can be done safely and securely.

Other areas of relevance to the draft plan/programme

The White Paper indicates that a review of the existing energy National Policy Statements (NPS) will be undertaken, with the aim of designating the updated NPSs by the end of 2021, and consultation on the review concluded in November 2021[38]. The review will ensure the NPSs reflect the policies of the Energy White Paper, and that they will provide the framework required to deliver the infrastructure needed for net zero. It is noted that this review and update will not prevent the use of the existing NPSs to make decisions under the *Planning Act 2008*, in the period before the new NPSs are formally designated by Parliament.

A UK Emissions Trading Scheme (UK ETS) has been established to replace the UK's participation in the EU ETS and is a market-based cap and trade measure[39]. A consultation will take place in due course on how to align the cap with an appropriate net zero trajectory, such that the system will significantly contribute to the 2050 target. It is indicated in the Net Zero Strategy that the cap will be introduced by January 2024.

2.2.3 Oil and Gas Authority Strategy

Despite the focus of the above strategies on a move to low carbon energy sources, the Industrial Strategy also recognises that the oil and gas sector continues to be highly productive, and also has a role in maintaining the UK's security of supply during the transition to a low carbon economy. Pursuant to Section 9G of the *Petroleum Act 1998*, an updated OGA Strategy was laid before Parliament on 16th December 2020 and came into force on 11th February 2021. The OGA Strategy (building on the earlier Maximising Economic Recovery (MER) UK Strategy) takes account of the UK Government's Net Zero commitment, with alterations made to the central obligation, and supporting obligations, which commit "relevant

[37] https://www.gov.uk/government/consultations/carbon-capture-usage-and-storage-ccus-projects-re-use-of-oil-and-gas-assets
[38] https://www.gov.uk/government/consultations/planning-for-new-energy-infrastructure-review-of-energy-national-policy-statements
[39] The UK ETS was introduced on 1st January 2021 https://www.gov.uk/government/publications/participating-in-the-uk-ets

persons"[40] to, "take appropriate steps to assist the Secretary of State in meeting the net zero target, including by reducing as far as reasonable in the circumstances greenhouse gas emissions from sources such as flaring and venting and power generation, and supporting carbon capture and storage projects." Downstream of offshore activities, gas production has been recognised as a potential contributor to a hydrogen economy (e.g. through methane reforming) and the wider net zero target when combined with carbon capture and storage[41].

2.2.4 Industrial Decarbonisation Strategy

The UK's Industrial Decarbonisation Strategy[42] was published in March 2021 and aims to show how the UK can have a successful industrial sector, aligned with the net zero target, and without pushing emissions and business abroad. The strategy covers a range of established industrial sectors and emerging industries such as low carbon hydrogen CCUS. It provides an indicative roadmap to net zero for UK industry and outlines how government will act to support this.

2.2.5 Marine management context

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) is an important mechanism through which Governments of the western coasts and catchments of Europe, together with the European Union, cooperate to protect the marine environment of the North-East Atlantic. The OSPAR Commission established a network of Marine Protected Areas (MPAs) following Recommendation 2003/3 on a network of marine protected areas. It aimed to complete a joint network of MPAs by 2016 that, together with the Natura 2000 network, is ecologically coherent and well managed. As part of the UK implementation of such areas, the *Marine and Coastal Access Act 2009* and the equivalent Acts of devolved administrations provide powers to designate Marine Conservation Zones (MCZs) in England, Wales and Northern Ireland, and Marine Protected Areas (MPAs) in Scotland (see Appendix 1j). The UK has nominated 366 sites to the OSPAR network, covering ~41.1% of the UK's EEZ.

OSPAR periodically publishes assessments in the form of Quality Status Reports (QSRs) of the North-East Atlantic and its sub-regions, the last QSR was published in 2010, with an intermediate assessment produced in 2017. The next QSR is due to be published in 2023.

The *Marine Strategy Regulations 2010* require the development of five elements of the marine strategy: (1) the assessment of marine waters; (2) the determination of the characteristics of good environmental status for those waters (note these are qualitatively described in Annex I to the Directive); (3) the establishment of environmental targets and indicators; (4) the establishment of a monitoring programme; (5) the publication of a programme of measures. The key objectives of the Marine Strategy Framework Directive 2008/56/EC which the Regulations originally transposed (also see Section 2.2.6) are to achieve good environmental status (GES) of marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. The Marine Strategies for the UK must contain a detailed assessment of the state of the environment, a definition of good environmental

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[40] Defined under Section 9A (1)(b) of the *Petroleum Act 1998* (as amended), i.e. the holder of a petroleum licence; an operator under a petroleum licence; the owner of upstream petroleum infrastructure, persons planning and carrying out the commissioning of upstream petroleum infrastructure, or owners of relevant offshore installations
[41] For example, see: https://www.gov.uk/government/news/pm-commits-350-million-to-fuel-green-recovery and https://www.ogauthority.co.uk/news-publications/news/2020/offshore-energy-integration-can-deliver-30-of-uk-s-net-zero-target/
[42] https://www.gov.uk/government/publications/industrial-decarbonisation-strategy

status at regional level, and the establishment of clear environmental targets and monitoring programmes. To fulfil the requirements of the Regulations, the UK has prepared documents (e.g. the Marine Strategy Parts 1, 2 and 3, and proposals for UK monitoring programmes and programmes of measures to maintain or achieve GES, including updates to these). The Regulations require that programmes of measures be established to achieve GES, and that these include spatial protection measures contributing to coherent and representative networks of marine protected areas. Analogous to the contribution to the wider OSPAR MPA network, existing and proposed Natura 2000 and MCZ/MPA sites will contribute to this.

The Marine Strategy complements measures being undertaken as part of the UK implementation of the Water Framework Directive (WFD), particularly in coastal waters where geographical scope of the Directives overlap (out to 1nm in England and Wales, and 3nm in Scotland), and also in transitional waters such as estuaries. Whilst the implementation of WFD and MSFD may be complementary in these areas in their objectives (e.g. particularly in relation to water chemical quality and some aspects of ecological quality and hydromorphological quality), for coastal waters MSFD only covers those aspects of GES not already covered by the WFD. The Regulations implementing the above Directives have been amended so that they continue to function following the UK's exit from EU (see Section 2.2.6).

Marine planning in the UK has been taking place across different timescales. All plans covering English[43], Welsh and Scottish waters have now been adopted (other than Scottish Marine Regional Plans), but the plans for Northern Ireland are still in preparation (Figure 2.1). All of the plans are consistent with the UK Marine Policy Statement, and have taken a similar approach to policies (general and sectoral) and policy wording. The Scottish National Marine Plan was adopted in 2015, and the Welsh National Marine Plan (WNMP) in 2019, with English plans adopted across the years 2014-2021. The Department of Agriculture, Environment and Rural Affairs (DAERA) continue to develop the Marine Plan for Northern Ireland, which was subject to consultation in 2018.

Marine plans in the UK have, to date, been written at a strategic level which largely consolidates and clarifies existing legal and policy arrangements, albeit with a regional focus, and in most instances do not attempt to be spatially explicit, for example by indicating defined zones for development or where development would be precluded. The plans rather identify potential resource and constraints (including through mapping), with policies that seek to balance environment, economic and social considerations in decision making and consent applications. This includes the promotion of certain activities such as offshore wind, or the safeguarding of strategic resources. As these are the first iteration of marine plans, subsequent revisions may be expected to be more spatially explicit. Planning authorities activities go beyond the documentation of the plans and have included commissioning work to improve the evidence base for marine planning and to support consenting[44].

The adopted and draft marine plans all contain policies of relevance to the draft plan/programme and OESEA4, covering both offshore hydrocarbons, renewable energy and carbon dioxide storage. The Marine Plans covering English waters provide both strict safeguarding of areas of existing oil and gas production, and also new development proposals. For offshore renewables, existing leases or agreements for lease are provided a level of safeguarding by requiring proposals to demonstrate they will not reduce the ability to construct, operate or decommission planned projects in areas held under lease. The East Marine Plans

[43] https://www.gov.uk/government/news/adoption-of-marine-plans-marks-big-step-forward-for-englands-seas
[44] https://www.gov.uk/government/publications/evidence-and-the-marine-management-organisation-mmo

contain separate policies for wind and tidal stream, however, subsequent plans contain the same policies for all marine renewables. A similar policy which aims to safeguard key resource areas for carbon dioxide storage is contained in the East Marine Plans, but is not included in the other English marine plans.

The WNMP plan identifies and maps the key resource areas for different offshore renewables, including wave, tidal stream, tidal range and wind, and provides accompanying supporting policies and links to safeguarding policies. These policies promote the de-risking of low carbon energy sources and support developing strategic resource areas in order to safeguard relevant resources. Note that strategic resource areas have not been identified to date. WNMP policies on offshore oil and gas recognise the continued role such resources will have during the transition to low carbon energy sources and the obligations set out in the OGA Strategy, and support the development of CCS technologies, but are also explicit that Welsh Government policy is to avoid continued extraction of fossil fuels in intertidal areas, estuaries and coastal inlet waters that fall within the Welsh onshore licensing area (note, these areas are not included in the OESEA4 draft plan/programme).

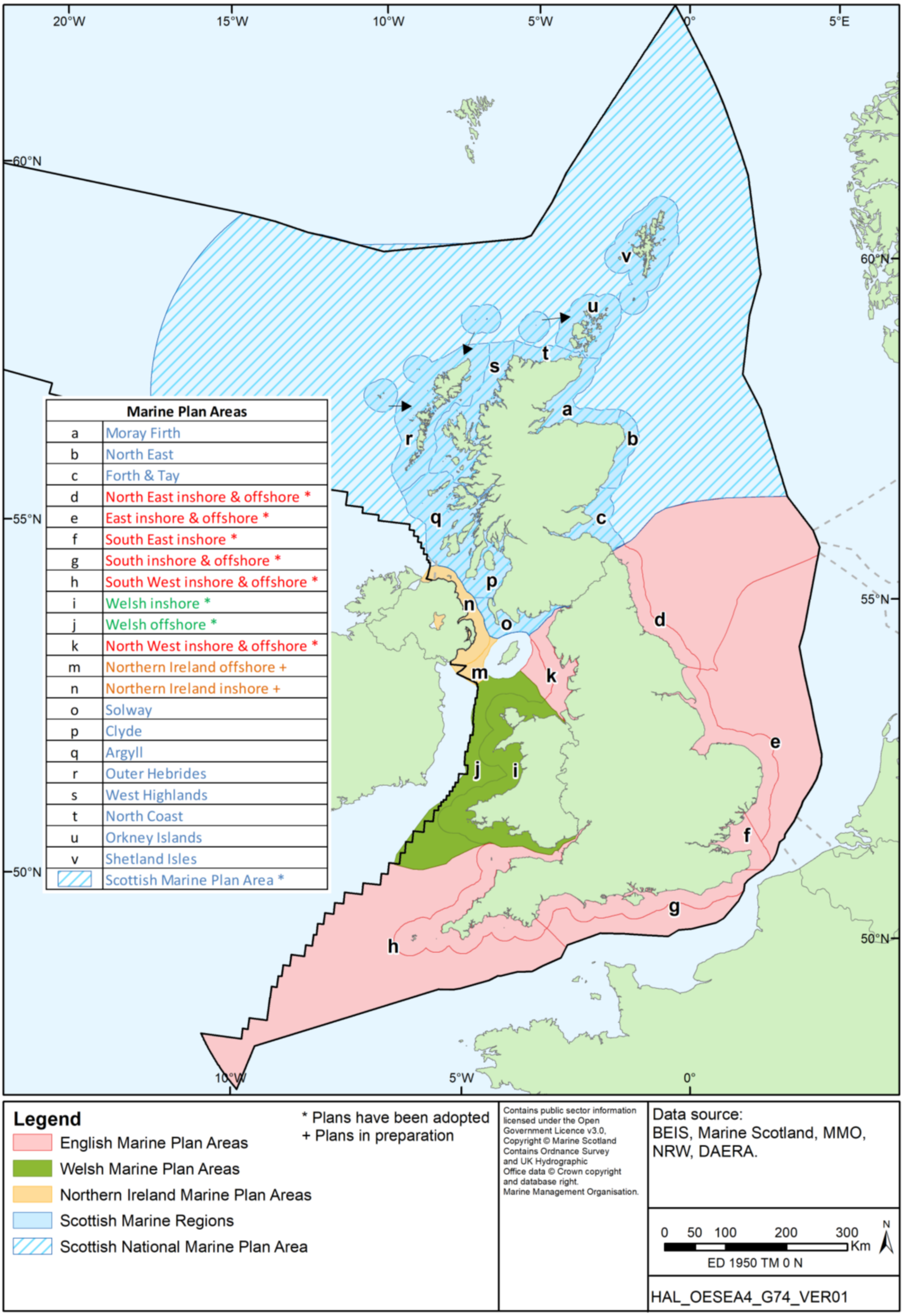
The draft Marine Plan for Northern Ireland contains a single energy policy supporting all energy proposals (i.e. renewables and oil & gas) which improve the security and diversity of energy supply, provided that they do not unacceptably impact other activities or the offshore environment generally, and that restoration/decommissioning measures have, where necessary, been agreed. The draft plan does not include a specific CCUS or gas storage policy.

2.2.6 The UK’s withdrawal from the EU

Following the UK’s exit from the European Union, the UK Government has confirmed that it is firmly committed to maintaining high environment and climate standards.

Sections 2-7 of the *European Union (Withdrawal) Act 2018*, confirm that the body of EU law transposed into UK legislation at the time that the UK exited the EU was retained, such that it continues to have effect in domestic law. The SEA will consider the implications of any relevant legislative and related policy changes which take place during its preparation that are associated with the UK’s exit from the EU.

Figure 2.1: Geographical Coverage of the SEA in relation to UK Marine Spatial Planning Boundaries



2.3 The draft plan/programme

The BEIS draft plan/programme under consideration is broad ranging and variously covers the range of energy related activities in the UK marine environment. The geographical limits of areas mentioned below are graphically represented in Figure 1.2-Figure 1.4. There are a number of reasonable alternatives to the draft plan/programme assessed in the SEA, these are outlined in Section 3.8 including the reasons for their selection. The elements of the draft plan/programme are:

Renewable Energy:

Offshore Wind – to enable further offshore wind farm leasing in the relevant parts of the UK Exclusive Economic Zone and the territorial waters of England and Wales, to contribute to the UK target of up to 40GW of offshore wind generation capacity deployed by 2030 (including 1GW of floating offshore wind). The technologies covered will include fixed and tethered turbines. Tethered turbines will only be considered in waters up to 250m. The Scottish Renewable Energy Zone and the territorial sea limit of Scotland and Northern Ireland are not included in this part of the plan/programme.

Wave – future leasing in the relevant parts of the UK Exclusive Economic Zone[45] and the territorial waters of England and Wales. The Scottish Renewable Energy Zone[46] and the territorial sea limit of Scotland and Northern Ireland are not included in this part of the plan/programme. In view of the relatively early stage of technological development, a target generation capacity is not set in the draft plan/programme.

Tidal Stream – future leasing in the relevant parts of the UK Exclusive Economic Zone and the territorial and internal waters of England and Wales. The Scottish Renewable Energy Zone and the territorial sea limit of Scotland and Northern Ireland are not included in this part of the plan/programme. In view of the relatively early stage of technological development, a target generation capacity is not set in the draft plan/programme. Similarly, a minimum average tidal current velocity threshold is not proposed.

Tidal Range – future leasing in the internal and territorial waters of England and Wales. It is considered unlikely that there will be tidal range developments outside of territorial waters.

Oil & Gas:

Exploration and production – further Seaward Rounds of oil and gas licensing of the UK territorial sea and UK Continental Shelf (UKCS), subject to the outcome of periodic Climate Compatibility Checkpoints.

Hydrocarbon gas importation and storage – further licensing/leasing for unloading and underground storage of hydrocarbon gas in UK waters (territorial sea and the relevant parts of the UK Exclusive Economic Zone), including hydrocarbon gas storage in other geological formations/structures including constructed salt caverns, and the offshore unloading of hydrocarbon gas.

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[45] *The Exclusive Economic Zone Order 2013*
[46] *The Renewable Energy Zone (Designation of Area) (Scottish Ministers) Order 2005*

Carbon Dioxide:

Carbon dioxide (CO_2) transportation and storage – further licensing/leasing for underground storage of CO_2 gas in UK waters (the UK Exclusive Economic Zone and relevant territorial sea, excluding the territorial sea limit of Scotland[47]). The UK target is to have CCUS deployed in two industrial clusters by the mid-2020s, and a further two clusters by 2030, with an ambition to capture and store 20-30MtCO_2 per year by 2030. OESEA4 includes CO_2 storage in geological formations/structures including depleted reservoirs (and for enhanced oil recovery), saline aquifers and constructed salt caverns.

Hydrogen:

The offshore production and transport of hydrogen. This includes any offshore aspect of "power to gas" which uses excess renewable electricity and electrolysers to produce hydrogen (green hydrogen) and the offshore carbon dioxide transport and storage aspects of onshore hydrogen production from natural gas (blue hydrogen). An ambition of 5GW (equating to 42TWh) of low-carbon hydrogen production capacity by 2030 has been set, with the hope that 1GW capacity could be delivered by 2025. Storage of hydrogen in geological formations is not expected before 2030 but work to identify and prepare sites for storage could take place in advance of this.

2.4 Context to Licensing and Leasing

Decision making in relation to licensing/leasing and also subsequent activities which could take place as a result of the adoption of the draft plan/programme, is split between a number of legislative and planning policy remits and related decision makers. The following summarises the current licensing and leasing arrangements for offshore energy in UK waters, and for the purposes of this SEA, only those aspects applicable to the geographical coverage of each aspect of the plan (see Figure 1.2, Figure 1.3 and Figure 1.4) are relevant.

2.4.1 Offshore Renewables: Wind

Under *The Crown Estate Act 1961*, The Crown Estate is entrusted to manage assets on behalf of the Crown including most of the UK seabed out to 12nm, over half of the foreshore, as well as certain sovereign rights in respect of areas beyond the territorial sea. Such sovereign rights are vested in the Crown by the virtue of the designation of the EEZ, formerly covered by the Renewable Energy Zone (REZ) under the *Energy Act 2004*, which covered an area from 12nm out to 200nm (now the UK EEZ and the Scottish Renewable Energy Zone) in which rights under Part V of the UN Convention on the Law of the Sea may be exercised to exploit water or wind energy.

A licence from The Crown Estate is required for the placement of structures or cables on the seabed, this includes offshore wind farms and their ancillary cables and other marine facilities. The Crown Estate grants rights in the form of an Agreement for Lease or Option Agreement. An Agreement for Lease generally grants a developer an option over an area of seabed. Exercise of the option by the developer will be conditional on it satisfying certain conditions. If the conditions are satisfied and the developer exercises the option, The Crown Estate will be obliged to grant a Lease of the seabed to the developer. The conditions to be satisfied before

[47] *The Storage of Carbon Dioxide (Licensing etc.) (Scotland) Regulations 2011, The Storage of Carbon Dioxide (Amendment of the Energy Act 2008 etc.) Regulations 2011*

the developer may exercise the option will include the obtaining by the developer of all statutory consents for the proposed development. If the developer is unable to satisfy all the conditions within a certain time provided for in the Agreement for Lease, the option will lapse. During the option period the developer will be permitted to undertake surveys and deploy anemometry equipment etc. However, the developer is not permitted to commence construction of its development until and unless a Lease is granted. Potential offshore wind farm developers also require statutory consents from a number of Government departments before development can take place.

Under the *Planning Act 2008*, the Planning Inspectorate (PINS) assumed responsibility for consent applications for offshore electricity generating stations with a capacity of more than 100MW (or 350MW in Wales[48]). Such applications to PINS are under the Planning Act (which replaces the provisions of the Electricity Act 1989) for these developments. While PINS deals with the acceptance and examination of the application and provides a recommendation on whether consent should be granted, the ultimate decision maker in these cases is the Secretary of State.

The *Marine and Coastal Access Act 2009* (as amended) provided for the creation of the Marine Management Organisation (MMO). The MMO took over the processing of offshore renewable energy generating station applications under section 36 of the *Electricity Act 1989* (i.e. those not considered to be nationally significant, with a capacity of more than 1MW but less than 100MW) in English territorial and offshore waters (i.e. that part of the UK EEZ relevant to this plan/programme). A single Marine Licence is required for activities formerly covered by the *Coast Protection Act 1949* and the *Food and Environment Protection Act 1985* (FEPA).

While the Secretary of State is responsible for consenting offshore wind farm projects of more than 100MW (England) or 350MW (Wales), the leasing of areas for offshore wind is the responsibility of The Crown Estate. The draft plan/programme to be assessed in OESEA4 includes future leasing for offshore wind, but is not geographically constrained by any area in relevant English or Welsh waters that The Crown Estate propose to include in any leasing round (for example, the proposed projects for Round 4). Therefore, OESEA4 is a connected but separate process to offshore wind leasing. The work undertaken by The Crown Estate to identify the Round 4 bidding areas will, however, be considered as inputs to this SEA.

2.4.2 Offshore Renewables: Wave and Tidal

The leasing and consenting processes for wave and tidal stream renewable energy generating developments are as described above for offshore wind, though tidal range developments consenting requirements may differ from those of offshore wind to reflect the likelihood of their being land-connected and being more akin to large terrestrial infrastructure development. The Crown Estate has not, to date, carried out any wave or tidal stream energy leasing rounds for English and Welsh waters but has offered leases for test devices or small arrays. The vast majority of wave and tidal demonstration to date has taken place in Scottish waters which are not in the remit of this SEA. No leases for tidal range proposals have yet been granted.

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[48] Section 39 of the *Wales Act 2017*. Note that applications for developments of national significance in Wales are made to the Planning Inspectorate Wales, with the planning procedure being similar to that for projects in England.

2.4.3 Offshore Oil and Gas Exploration and Production

The exclusive rights to search and bore for and get petroleum in Great Britain, the territorial sea adjacent to the United Kingdom and on the UKCS are vested in the Crown and the *Petroleum Act 1998* (as amended) gives the Oil & Gas Authority (OGA)[49] the power to grant licences to explore for and exploit these resources. The main type of offshore Licence is the Seaward Production Licence. Offshore licensing for oil and gas exploration and production commenced in 1964 and has progressed through a series of Seaward Licensing Rounds. A Seaward Production Licence may cover the whole or part of a specified Block or a group of Blocks. A Licence grants exclusive rights to the holders "to search and bore for, and get, petroleum" in the area covered by the Licence but does not constitute any form of approval for activities to take place in the Blocks, nor does it confer any exemption from other legal or regulatory requirements.

Offshore licensing takes place under an "Innovate" licence, with amendments to Model Clauses for offshore licensing made to implement this under the *Petroleum and Offshore Gas Storage and Unloading Licensing (Amendment) Regulations 2017*. The Innovate licence is made up of three terms covering exploration (Initial Term), appraisal and field development planning (Second Term), and development and production (Third Term). The lengths of the first two terms are flexible but have a maximum duration of 9 and 6 years respectively. The Third Term is granted for 18 years but may be extended if production continues beyond this period. The Innovate licence has three Phases in its the Initial Term, covering:

- Phase A: geotechnical studies and geophysical data reprocessing (note that the acquisition of new seismic could take place in this phase for the purpose of defining a 3D survey as part of Phase B, but normally this phase will not involve activities in the field)
- Phase B: acquisition of new seismic data and other geophysical data
- Phase C: exploration and appraisal drilling

Applicants may propose the Phase combination in their submission to the OGA. Phase A and Phase B are optional and may not be appropriate in certain circumstances, but every application must propose a Phase C, except where the applicant does not think any exploration is needed (e.g. in the development of an existing discovery or field re-development) and proposes to go straight to development (i.e. 'straight to Second Term'). The duration of the Initial Term and the Phases within it are agreed between the OGA and the applicant. Applicants may choose to spend up to four years on a single Phase in the Initial Term but cannot take more than nine years to progress to the Second Term. Failure to complete the work agreed in a Phase, or to commit to the next Phase means the licence ceases, unless the term has been extended by the OGA.

Applicants for licences are required to provide the OGA with a number of submissions in support of their applications, including submissions to enable the Competent Authority[50] to

[49] Note that while certain licensing and related regulatory functions were passed to the OGA (a government company wholly owned by the Secretary of State for BEIS) on 1st October 2016, environmental regulatory functions are retained by BEIS, and are administered by the Offshore Petroleum Regulator for Environment and Decommissioning (OPRED).

[50] BEIS and the Health and Safety Executive (HSE)

assess their safety and environmental competence and capability. Seaward licensing rounds are progressed by the OGA with approximately one round taking place each year.

The power cables from shore or the integration of offshore wind turbines and oil and gas installations are likely to be features of new developments and modifications to existing developments in the coming years as means to reduce upstream emissions from oil and gas production.

2.4.4 Offshore Natural Gas Transportation and Storage

The *Energy Act 2008* (as amended) made provision for the designation of Gas Importation and Storage Zones (now encapsulated and superseded by the Exclusive Economic Zone) and creates a licensing framework for the unloading and storage of combustible gas offshore. The Act prohibits the carrying out of the activities below except in accordance with an Energy Act licence:

- use of a controlled place for the unloading of gas to an installation or pipeline
- use of a controlled place for the storage of gas
- conversion of any natural feature in a controlled place for the purpose of storing gas
- recovery of gas stored in a controlled place
- exploration of a controlled place with a view to gas storage
- establishment or maintenance in a controlled place of an installation for the purposes of the above activities

A “controlled place” is a place in, under or over waters within the UK territorial sea, or within any area extending beyond the territorial sea within the Exclusive Economic Area. Carrying on such an activity without a licence, and in certain cases the breach of the conditions of a licence is a criminal offence, and the Licensing Authority for gas storage licensing is the OGA. Operators will also need to obtain a grant of the appropriate rights (a lease) from The Crown Estate or Crown Estate Scotland.

The *Energy Act 2008* also makes provision with respect to the interaction between activities regulated under the *Petroleum Act 1998* and gas storage activities (e.g. that operations to recover gas from a storage site are not regarded to be the result of boring for and getting petroleum within the meaning of the Petroleum Act). Analogous to offshore oil and gas licensing, the environmental management capacity and track record of applicants is considered by BEIS, through written submissions and interviews, before licences are awarded by the OGA.

2.4.5 Offshore Carbon Dioxide Transport and Storage

The *Energy Act 2008* (as amended) provides for a similar licensing regime governing the offshore storage of carbon dioxide and makes it an offence to carry out storage activities without a licence. The regime applies to storage in the offshore area comprising both the UK territorial sea (excluding Scotland), and any area extending beyond the territorial sea within the Exclusive Economic Zone (EEZ). Licences specifically cover:

- Storage of carbon dioxide with a view to its permanent disposal

- Conversion of a natural feature (for example, a saline aquifer) for such storage
- Exploration for a carbon dioxide storage site
- Establishment or maintenance of an installation for any of those purposes

The licensing authority is the OGA except in the case of the territorial sea adjacent to Scotland for which Scottish Ministers are the licensing authority. In keeping with other offshore licensing arrangements for oil and gas, and gas storage, BEIS retain environmental regulatory functions for carbon dioxide transport and storage projects in relevant UK waters. The *Energy Act 2008* also indicates that the use of the seabed or areas under the seabed for these activities would also require a lease from The Crown Estate or Crown Estate Scotland. The licensing arrangements for carbon dioxide storage for the area indicated above is contained within the *Storage of Carbon Dioxide (Licensing etc.) Regulations 2010* (as amended) for England and Wales, and the *Storage of Carbon Dioxide (Licensing etc.) (Scotland) Regulations 2011* (as amended).

To date, Licences have been awarded in an *ad hoc* manner following applications from prospective developers. While this is likely to continue, a targeted licensing round could be undertaken within the next five years.

2.4.6 Offshore Pipelines

The activities listed above may require a subsea pipeline for the purpose of exporting oil and gas, and for the transfer of gas or carbon dioxide to underground storage. In order to place and use/modify a pipeline on the continental shelf a Pipeline Works Authorisation (PWA) or PWA variation is required (as per Part III of the *Petroleum Act 1998*) for both gas, carbon dioxide transport and offshore petroleum production activities, the consent for which is granted by the OGA. Where a pipeline falls within the territorial sea limit (i.e. within 12nm of the coast) a lease will also be required for that section of the pipeline from The Crown Estate, or Crown Estate Scotland. Any works which precede the installation of any pipeline (e.g. deposits of rock prior to a PWA being in place), are covered by marine licences under the *Marine and Coastal Access Act 2009*. Any onshore part of a pipeline (that landward of mean low spring tides) is subject to the terrestrial planning regime, including the *Planning Act 2008*, where appropriate, and is not a subject of this SEA.

2.5 Prospectivity and likely nature and scale of draft plan/programme related activity

Though activities for the whole UKCS (for reserved matters) will be considered in the OESEA4 Environmental Report, the potential for areas to be leased/licensed for plan level activities to take place in any given area is spatially controlled to some extent by prospectivity, whether it be the conditions in which hydrocarbons have accumulated over geological time, the presence of geological structures capable of trapping gas or carbon dioxide in the long term, or the location of the best wind, tidal or wave energy resource. The following sections outline the prospective conditions for each of the plan elements, which are followed by a series of maps illustrating prospectivity against existing or proposed projects which are part of former or ongoing licensing/leasing of these activities.

It is likely that in the coming years there will be a greater level of energy integration both offshore and onshore, such that oil and gas production, renewable energy generation, electricity transmission and carbon dioxide storage cannot be considered in isolation. For example, offshore natural gas from the UKCS may be used with carbon capture and carbon dioxide storage in an offshore storage site as part of a process to generate hydrogen as a low carbon energy carrier. Such integration will be required in order to meet the 2050 net zero commitment.

2.5.1 Offshore Wind

In UK waters, offshore wind is the most developed renewable energy technology. Rounds 1 and 2 of offshore wind leasing were held in 2000 and 2003 respectively, with Round 3, held in 2009, being significantly larger in terms of the areas offered for leasing. Exclusivity agreements were signed for nine of the Round 3 areas, resulting in planning applications for 17 individual wind farm projects, the majority of which (15) have now been consented. The total offshore wind capacity of all currently operational (see Figure 2.2), in construction or consented wind farms in England and Wales is some 22.4GW, with a further 2.1GW in planning[51]. When considering the UK as a whole, the capacity of operational and consented projects is 26.9GW.

Further offshore leasing in the immediate term is likely to be delivered through a number of extensions to existing wind farms, seven of which were taken forward following the outcome of a plan level Habitats Regulations Assessment (HRA)[52]. These extensions amount to a further potential 2.85GW of capacity. The combination of the above operational, consented, in-planning and pre-planning capacities indicates sufficient potential to reach the 2030 target of 40GW of fixed foundation installed capacity, subject to approval of all related projects (see Figure 2.4). Note that based on projects associated with Round 3 wind farm leasing, the average number of years between a planning application and receiving consent is two years (range 1-5 years), though the time to construction and operation is an average of 6 years (range 3-8). Similarly, approximately 0.9GW of UK floating offshore wind capacity is operational, in-planning or at a pre-planning/concept stage, and could make a substantial contribution to the 1GW target by 2030. The growth in offshore wind to date and potential growth based on all known projects, their indicative capacities and timelines, is shown in Figure 2.6 – with projects at pre-planning and in-planning stages used here for illustrative purposes and it is acknowledged these are subject to ongoing consenting processes.

The Crown Estate is also progressing Round 4[53] wind leasing, which along with The Scottish Government's sectoral plan for offshore wind[54] (and related leasing via Crown Estate Scotland (ScotWind)[55]) have the potential to deliver some 8GW and 10GW of additional capacity respectively. Six potential Round 4 projects with a combined capacity of 7.98GW were announced by The Crown Estate in February 2021 following a competitive tendering process (Figure 2.3). These projects will be subject to HRA prior to any Agreements for Lease being granted. It is expected that this will be concluded in spring 2022. The Crown Estate also announced proposals in November 2021 for leasing of floating wind in the Celtic Sea of up to

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[51] Correct at June 2021: https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract
[52] https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2019-28-gw-of-offshore-wind-extension-projects-to-progress-following-completion-of-plan-level-habitats-regulations-assessment/
[53] https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/offshore-wind-leasing-round-4/
[54] https://www.gov.scot/publications/sectoral-marine-plan-offshore-wind-energy/
[55] https://www.crownestatescotland.com/our-projects/scotwind

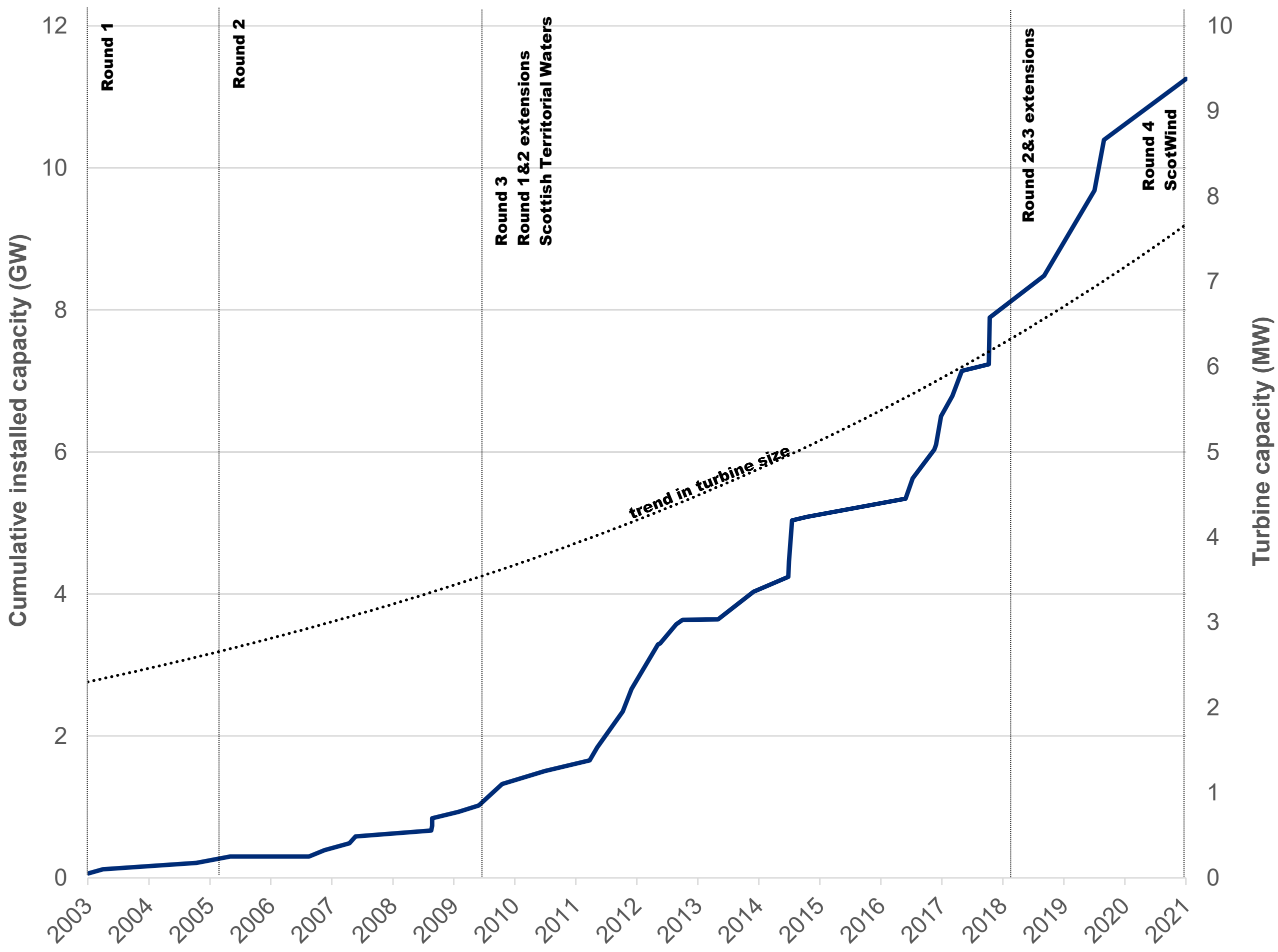
4GW, with projects expected to be installed from 2030[56]. Crown Estate Scotland announced the awards for the ScotWind auction in January 2022, with option agreements offered to 17 projects with a total combined capacity of almost 25GW. While this capacity figure may not be realised in full, it is significantly larger than the anticipated 10GW of capacity.

The CCC (2020b) have suggested the need for 95GW of offshore wind to be installed to meet the UK's net zero commitment by 2050 under their Balanced Net Zero Pathway (also see National Grid 2020). The 2050 figure noted by CCC (2020b) would require a further ~35.2GW of capacity to that already producing, in-planning, pre-planning and that envisaged to potentially be delivered as part of the most recent leasing rounds (Figure 2.4). In view of current project timescales, assuming those presently consented projects are constructed approximately by the middle of the 2020s and a 25 year average project lifespan, all the currently operational and consented capacity (~26GW) would also need to be renewed (e.g. through new projects or repowering) to meet the 2050 target.

Away from the shelter of the coast, the total wind resource over a given year is relatively uniform across very large areas (Figure 2.3), although clearly the occurrence and strength of wind is dependent on a number of meteorological factors. At any point in time, while some areas of the UK may be calm, the wind is likely to be blowing elsewhere. Water depth, distance from areas of high electricity demand, and the availability of connection points to the onshore transmission grid are significant factors in the preferred location of offshore wind developments.

[56] https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/the-crown-estate-develops-proposals-for-floating-wind-in-celtic-sea-outlining-4gw-opportunity/

Figure 2.2: Trend in cumulative operational UK offshore wind installed capacity, 2003-2020



Source: BEIS renewable energy planning database. Notes: data correct at December 2021. Excludes Beatrice demonstrator which ceased producing electricity in 2015 and is subject to decommissioning planning, and Blyth which was decommissioned in 2019.

Round 4 of offshore wind leasing was focussed on fixed foundations in water depths of up to 60m, however, leases for commercial scale developments could be issued in deeper areas for floating wind technologies within the timescale of the SEA. Therefore, for the purposes of this SEA, it is anticipated that wind turbines could be deployed in water depths of up to 250m in relevant UK waters (Figure 2.5). On 24th March 2021, The Crown Estate announced[57] a new leasing opportunity for early commercial-scale floating wind projects in the Celtic Sea. The leasing process will focus on projects of circa 300MW in scale, and would contribute to the Government's ambition for 1GW of floating wind generation by 2030. Note that is in addition to the 396MW in leases already offered through The Crown Estate's Test and Demonstration leasing opportunity (Erebus, Whitecross, Llŷr 1 and Llŷr 2 projects). The Crown Estate subsequently announced proposals in November 2021 for leasing of floating wind in the Celtic Sea of up to 4GW, with projects expected to be installed from 2030.

[57] https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/the-crown-estate-to-create-new-floating-wind-leasing-opportunity-in-the-celtic-sea/

Figure 2.3: Average annual wind speed, current wind farm status and lease bidding areas (correct at November 2021)

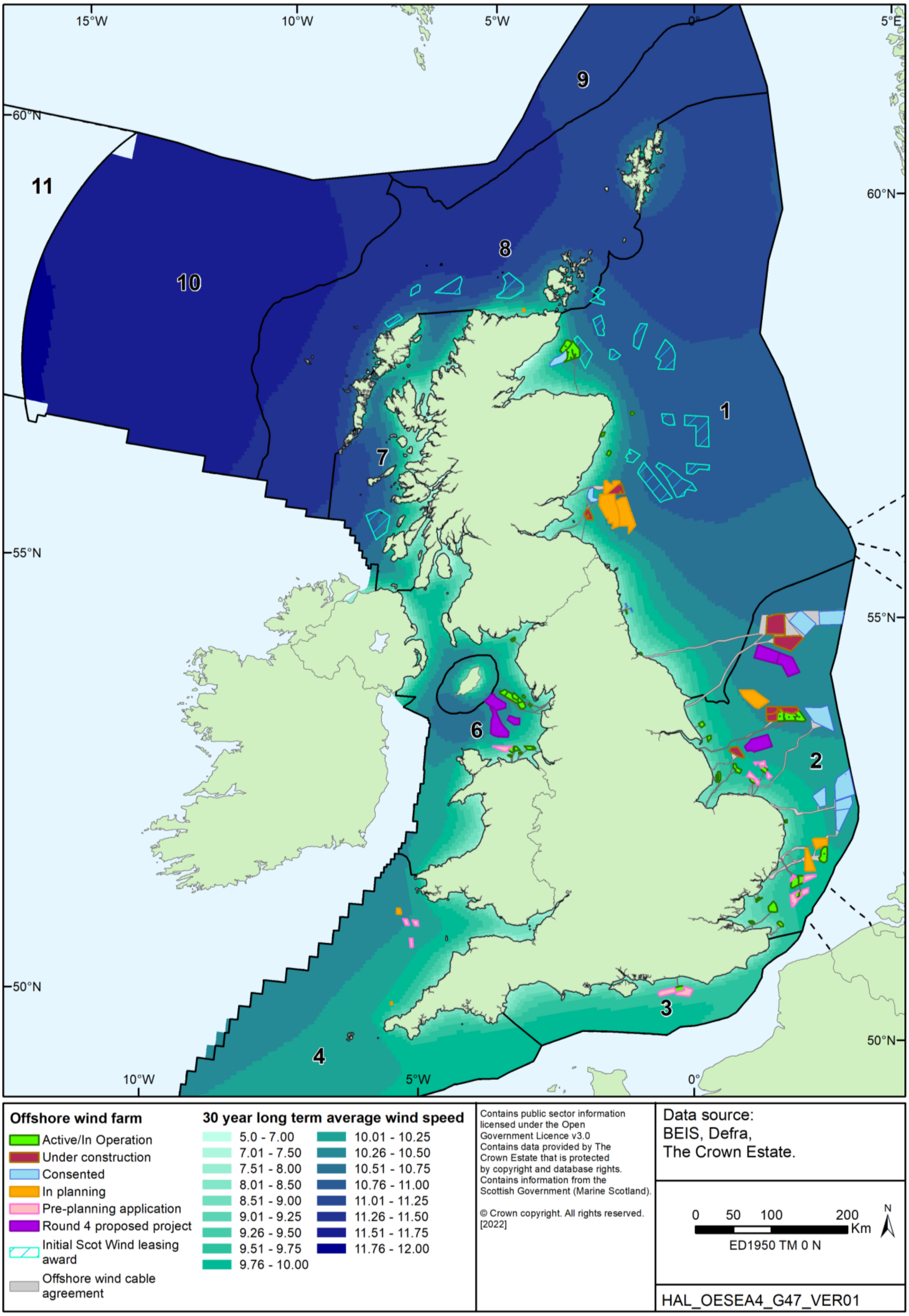
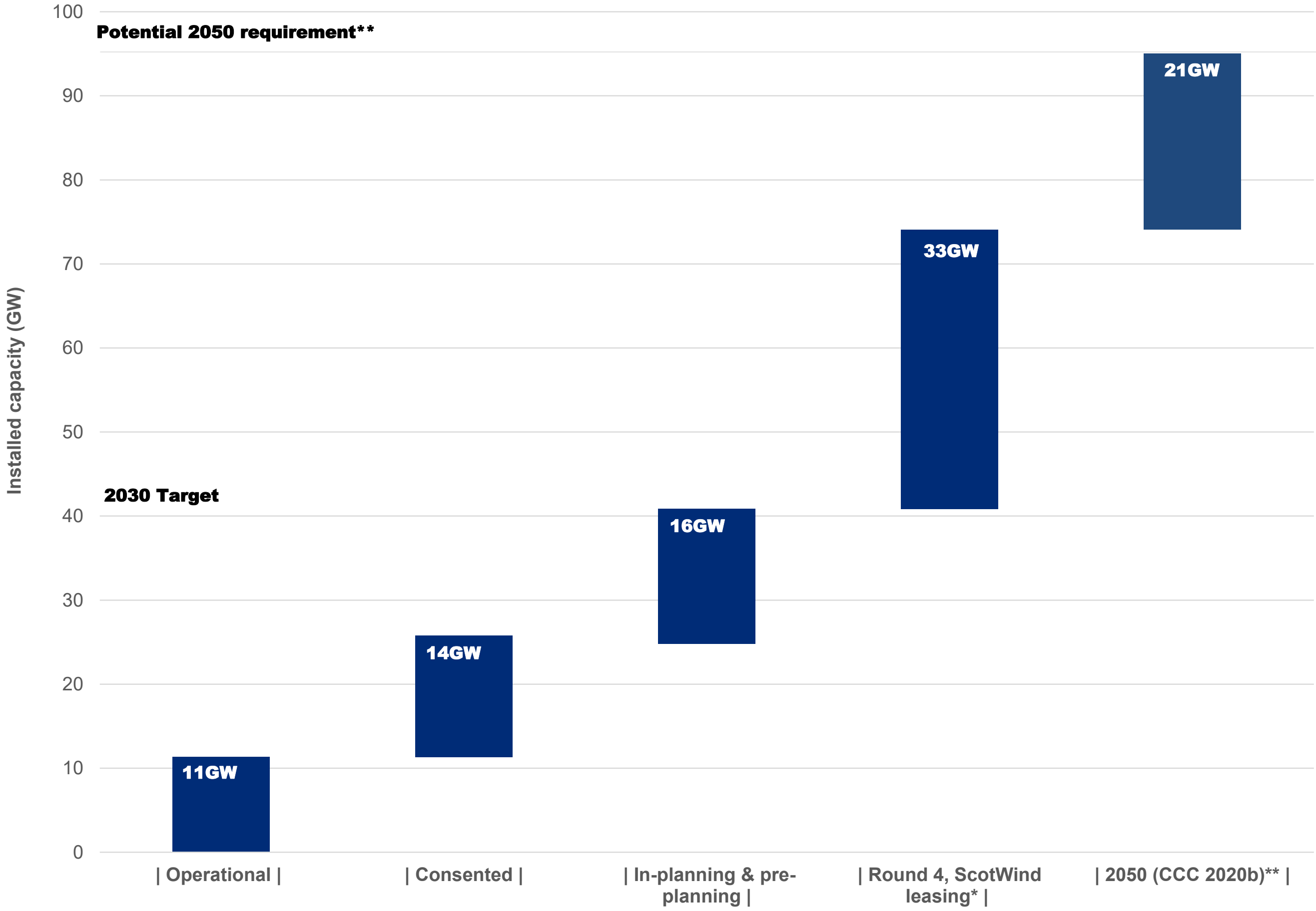


Figure 2.4: Current, planned and potential offshore wind installed capacity



Notes: Includes capacity for all UK waters. *Assumes that the capacity anticipated from projects related to Round 4, ScotWind and in the Celtic Sea are fully realised, **The CCC (2020b) figure of 95GW is based on their "balanced pathway" scenario to reach net zero emissions for the UK by 2050, which is used in the above figure. The scenario makes a number of assumptions about the mix of the low carbon technologies that will be required to meet the net zero commitment in the energy sector and wider economy and is used here to reflect the potential scale of deployment required beyond 2030, and following Round 4/ScotWind. National Grid (2021) project installed offshore wind capacities of between 95GW and 113GW for two of their Future Energy Scenarios 2020 ("consumer transformation" and "system transformation") as part of an energy mix that would meet the net zero target by 2050. This diagram does not consider potential decommissioning or repowering of arrays and offshore transmission assets that may be needed to meet installed capacities related to any target.

At present, operational offshore wind farms in the UK use turbines with capacities of approximately 3.6MW to 9.5MW. The largest capacity turbines currently commercially available include the 14MW GE Renewables Haliade-X, 14MW Siemens Gamesa 14-222 and the 15MW Vestas V236, the scale of which are expected to be deployed at Round 3 locations yet to be constructed (e.g. Dogger Bank A and B, and Sofia). There is an expectation that turbines of 12-16MW will be deployed in the 2020s, and that those of 20-24MW may be available by 2040 (Everoze 2020). Increasing the size of turbines reduces the number of turbines required to achieve the same array capacity and tends to improve their load factor.

The main stages of offshore wind development are:

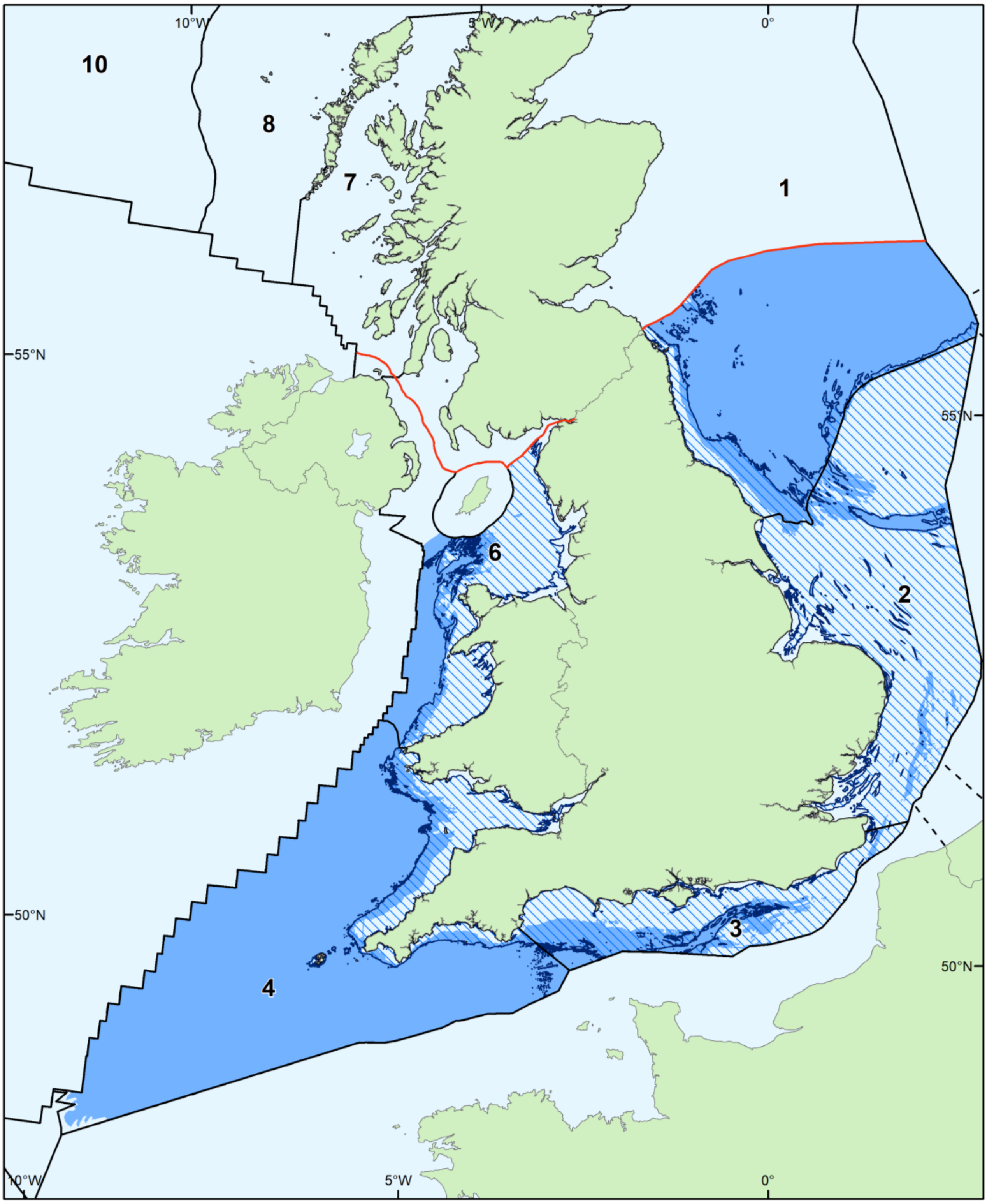
- Site prospecting/selection: including collection of site-specific resource and constraint data, and seabed information by geophysical and geotechnical survey.
- Development: includes selection and construction of foundations (which could be pile driven, gravity base, floating tethered) possibly scour protection, device installation,

cable laying including shoreline and other cable/pipeline crossings and protection, installation of gathering stations/substations and connection to the onshore national electricity transmission system.

- Generation operations, including maintenance.
- Decommissioning, including removal of facilities, for reuse, recycling or disposal.

In view of the above, the potential location and scale of the UK offshore fixed wind capacity required to meet the 40GW target by 2030 (and beyond) with Round 4 and ScotWind, can be reasonably accounted for. Similarly, much of the 1GW of floating wind capacity could be met by existing proposals, provided that all meet the relevant environmental and economic tests. There remains a considerable resource area across the UKCS, in particular for floating offshore wind, a proportion of which will be required to maintain deployment at levels projected to be required to meet the net zero commitment (e.g. by the CCC or National Grid). An overall spatial consideration of the resource areas against a number of current potential constraints to future offshore wind deployment is provided in Section 5.15.

Figure 2.5: Primary offshore wind resource areas considered in OESEA4



Legend

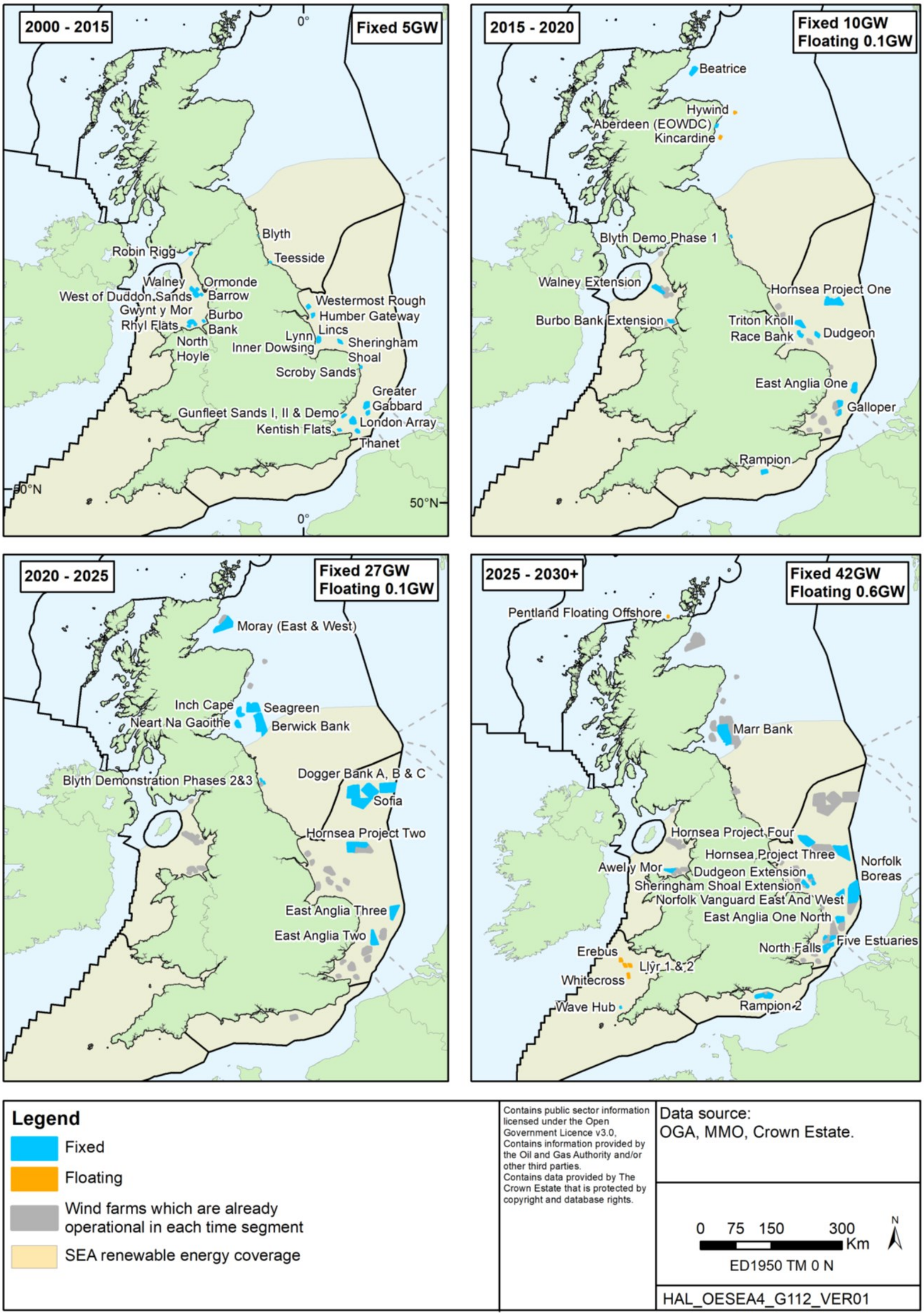
- Depth 10 - 60m (fixed foundations)
- Depth 50 - 250m (tethered foundations)
- Scottish adjacent waters limit

Data source:
BEIS, EMODnet

0 40 80 160 Km
N
ED1950 TM 0 N

HAL_OESEA4_G48_VER01

Figure 2.6: UK Wind farm construction to 2020 and indicative construction to 2030



Notes: projects at a pre-planning and in-planning stage are used here for illustrative purposes only as these are subject to ongoing consenting processes. Future construction timescales are indicative and based on the National Grid TEC Register and the RenewableUK Offshore Wind Project Timelines document

2.5.2 Other Renewables

Exploitation of wave and tidal stream energy is not yet fully commercial in UK waters, although several test and demonstrator projects have been deployed or are in development, and commercial deployment is expected in the coming years. It is likely that as devices reach commercial scale and their viability is demonstrated, larger scale deployment of wave and tidal stream energy generation devices will commence.

The wave resource is broadly concentrated on the Atlantic facing coastline of the UK (Figure 2.7 and Figure 2.8), and in waters relevant to the draft plan/programme, the South West peninsula and SW Wales. The tidal stream resource is more geographically constrained, being localised around headlands, in some estuaries and through straits between land masses (Figure 2.8).

In English and Welsh waters, lease areas for wave and tidal demonstration have been issued almost exclusively on the west coast, off Anglesey (the West Anglesey Demonstration Zone), the Llyn Peninsula (Bardsey Sound), Pembrokeshire (South Pembrokeshire wave demonstration zone), and Cornwall (Wave Hub), the only exceptions being the Perpetuus Tidal Energy Centre off the Isle of Wight, and Torr Head (Northern Ireland). Although not within the scope of this SEA, a number of areas in Scottish territorial waters have also been leased for wave and tidal stream development (Figure 2.7 and Figure 2.8).

The potential future location of tidal range developments in relevant UK waters are guided by the available resource (for the purposes of OESEA4, a mean tidal range of >5m) and are generally limited by other factors such as water depth (e.g. TCE 2013 suggest 25m as the depth limit of existing tidal range technologies and this has been used in OESEA4, see Figure 2.9). The majority of the UK's tidal range resource is located in the territorial waters of England and Wales, but south west Scotland has a large area with viable resources. As a result, any proposal for the Solway in relation to tidal power would likely need to take account of the potential for effects across two legislative and planning remits which meet within this estuary.

The Hendry Review[58] assessed the strategic case for tidal lagoons, and reported in January 2017. The review made over 30 recommendations and concluded that tidal lagoons would help deliver security of supply; assist in delivering decarbonisation commitments, and would bring supply chain opportunities for the UK. The review also indicated that a small pathfinder project (<500MW, e.g. the Swansea Bay tidal lagoon proposal) should be commissioned and be operational for a reasonable period (to allow in-depth monitoring to be carried out and research to be conducted to address issues) before a financial decision is reached on a larger-scale project. While recognising the potential of tidal lagoon technology to deliver low carbon energy, following further economic analysis the Swansea Bay project was not considered to represent value for money when compared with other low carbon sources of energy (e.g. offshore wind), and support for the project by the UK Government (e.g. through a contract-for-difference) was not taken forward. It is uncertain whether this, or other tidal range projects (e.g. including former proposals including Tidal Lagoon Cardiff, Tidal Lagoon Newport and the West Somerset Tidal Lagoon) will be developed. The Welsh Government launched the Welsh Tidal Lagoon Challenge in March 2021. This was to understand the level of interest in progressing tidal lagoon projects in Wales, and to engage with interested organisations before it formulated a preferred approach to a competition and support package, but details of how this might proceed are not yet available.

[58] https://hendryreview.wordpress.com/

On the basis of the above information, it is considered possible that a number of tidal lagoon projects could be proposed in the coming years, potentially of a scale in the order of between 1,000-3,200MW, though larger schemes may be possible, including the potential for barrage, fence or other tidal range technology types.

The main stages of other marine renewables development are:

5. Site prospecting/selection: including collection of site-specific resource and constraint data, and seabed information by geophysical and geotechnical survey
6. Development: includes selection and construction of foundations, device installation, cable laying including shoreline and potentially other cable/pipeline crossings and armouring, installation of gathering stations/substations and connection to the onshore national electricity transmission system
7. Generation operations, including maintenance
8. Decommissioning

While a number of leases/agreements for lease have been made with The Crown Estate for wave and tidal projects in waters relevant to the plan/programme, there remain significant cost challenges to such projects, and the Energy White Paper indicates that the role of wave and tidal energy will be considered further following further evaluation of commercial and technical evidence. These technologies remain at a relatively early stage in their commercialisation, however, for the purposes of OESEA4 it has not been ruled out that these technologies could contribute to low carbon energy production in the near-term.

Figure 2.7: Annual mean wave power, current wave leasing areas and status, and potential resource areas

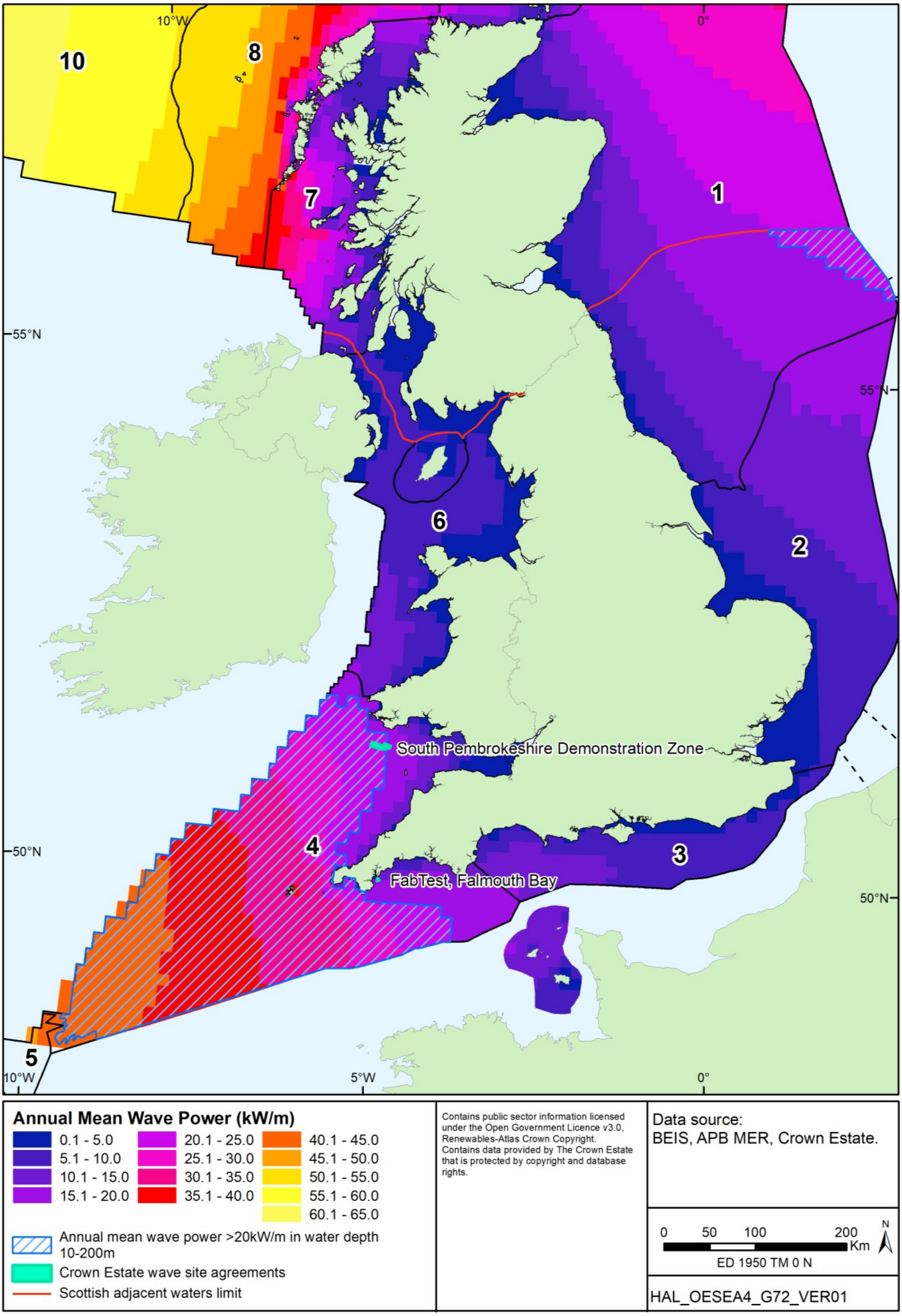


Figure 2.8: Annual mean tidal power, current tidal stream leasing areas and status, and potential resource areas

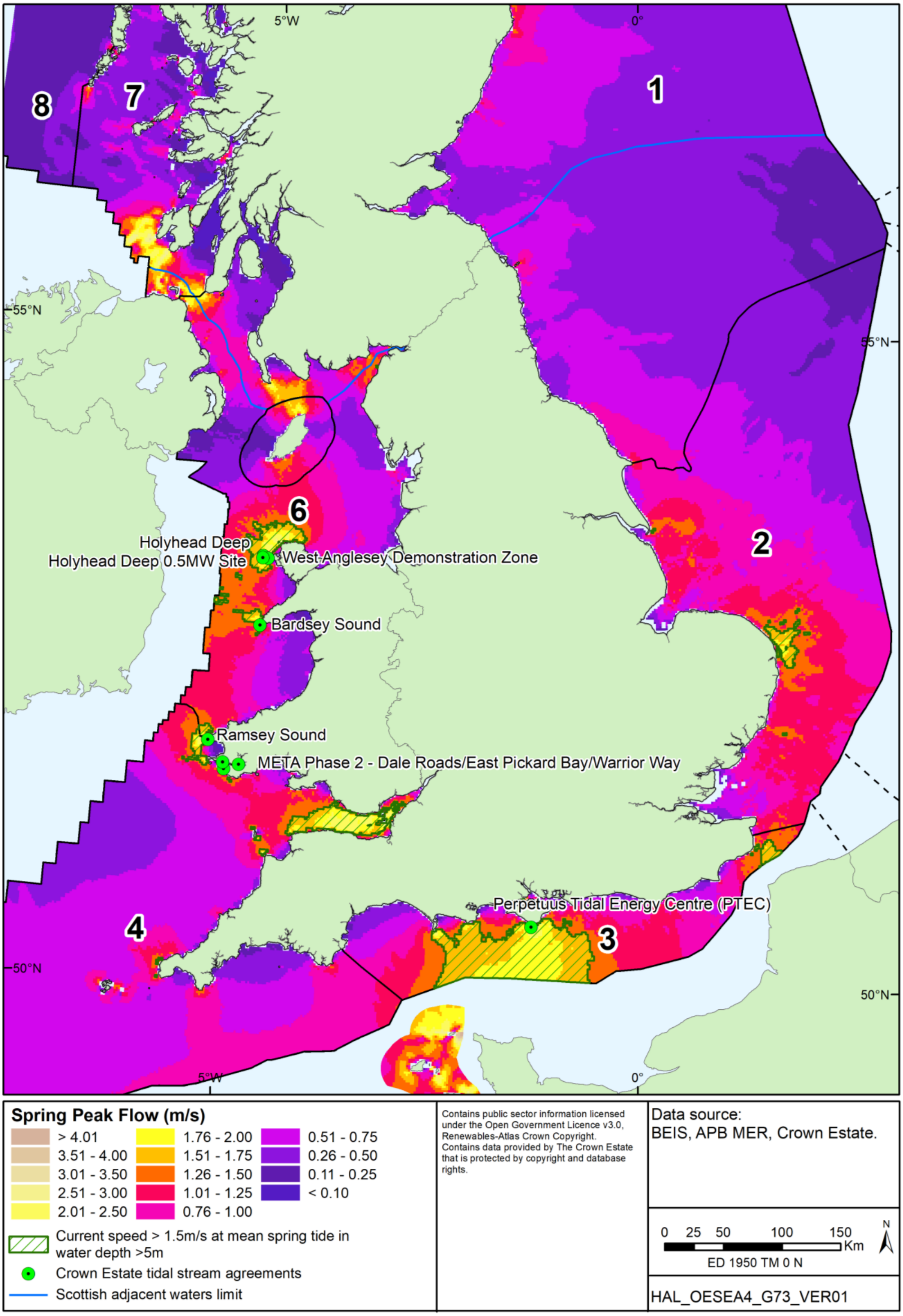
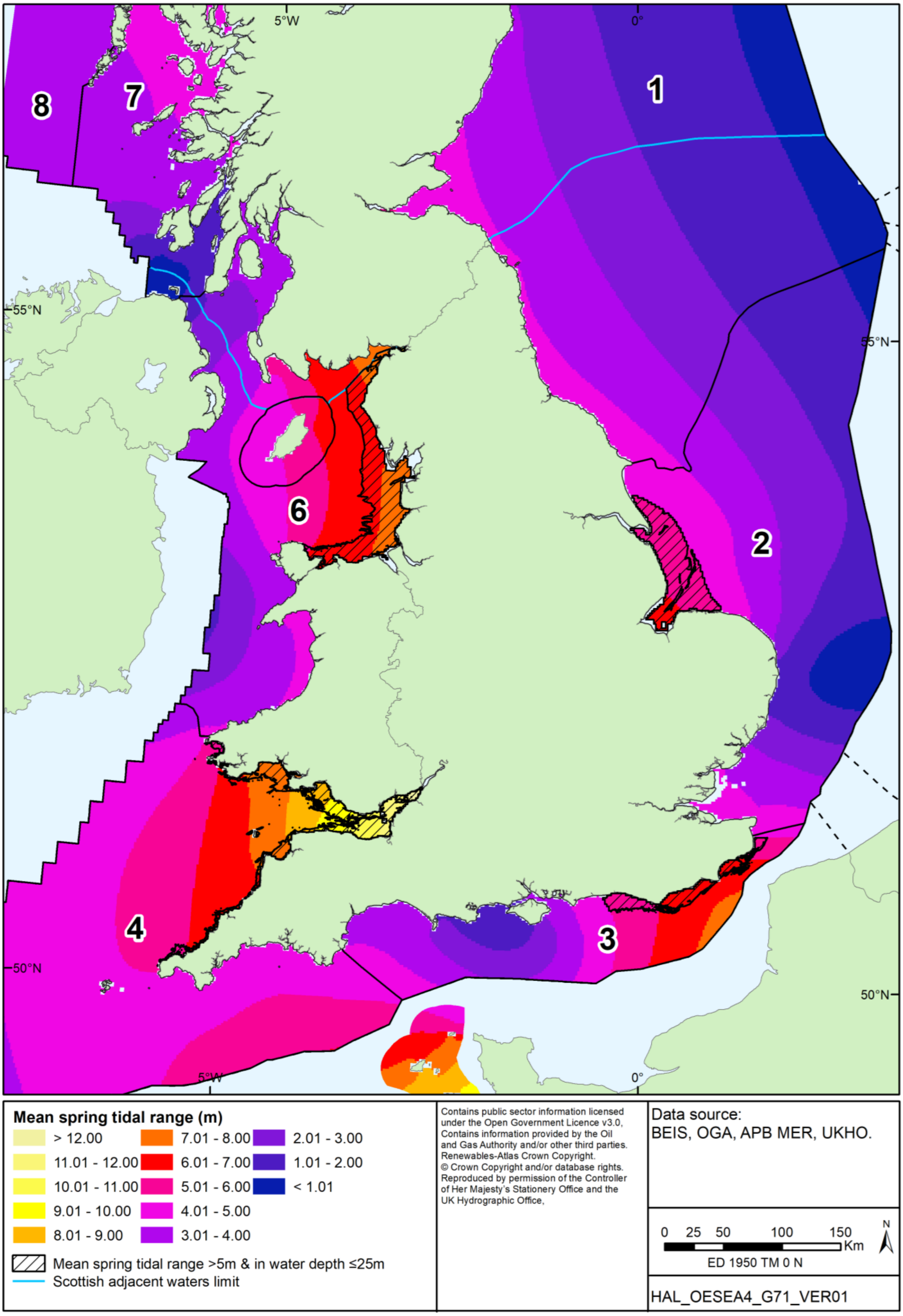


Figure 2.9: Mean spring tidal range and potential resource areas



2.5.3 Oil & Gas

For commercial hydrocarbon resources to occur, a number of factors and features have to coincide, including:

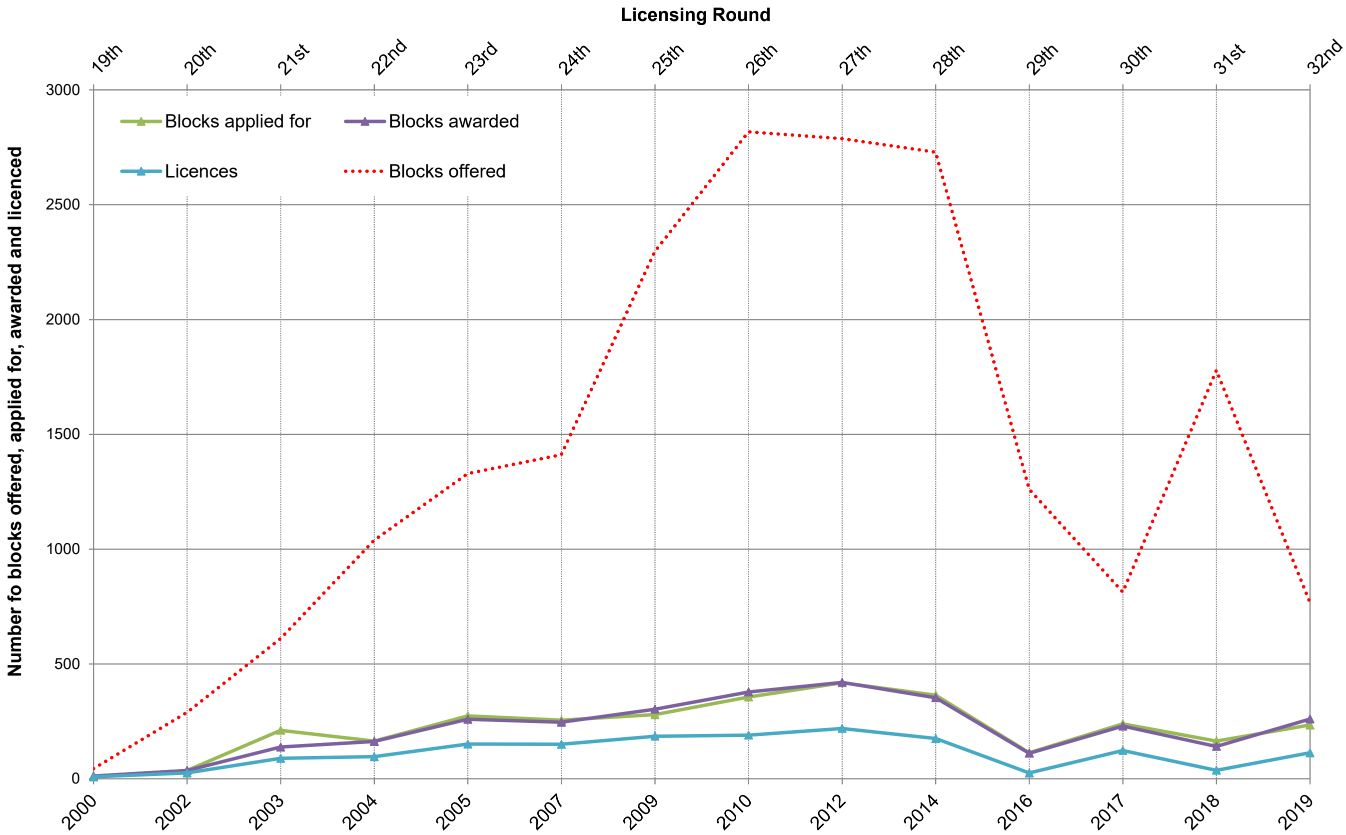
- The presence of source rocks, with an appreciable organic matter content
- Adequate depth of burial to allow the conversion of the organic matter to oil or gas through the action of temperature and pressure
- The presence of rocks with sufficient porosity to allow the accumulation of oil or gas
- Cap or seal rocks to prevent the oil or gas from escaping from the reservoir rocks
- Migration pathways to permit oil and gas formed in the source rocks to move to reservoir formations

Such conditions typically occur in sedimentary basins and not areas of igneous rock unless these overlay sedimentary rocks as in parts of the Faroe-Shetland Channel. Offshore areas of the UK have been offered for oil and gas licensing in a series of rounds since 1964. Areas with hydrocarbon prospectivity have been extensively explored over this period and many fields brought into production, mainly in the North and Irish Seas, resulting in an extensive infrastructure which can be utilised by new developments (Figure 2.12). The principal regions of historical and ongoing interest on the UKCS are the southern North Sea and Irish Sea, which are largely gas provinces, and the central and northern North Sea, and West of Shetland, which are mainly oil provinces, with some shore based production of offshore fields in the Anglo-Paris Basin; these areas encompass a number of basins and sub-basins and a number of others (e.g. the Mid North Sea High, Rockall Basin, Cardigan Basin and South West Approaches Basin) have proved to date to have low prospectivity and/or have been less well explored (see Figure 2.13 for a map of the major hydrocarbon basins of the UKCS). The variability of prospectivity of these basins is set out in Appendix A1b, though at a high level, the most prospective areas remain those which have been subject to historical production, including the mature North Sea basins. There is a consensus view that the great majority of large fields in shelf depth waters (<200m) have been found. Deeper water areas are either not prospective or are increasingly well explored and understood, however, the possibility of future major commercial finds cannot be discounted.

The number of exploration and development wells drilled on the UKCS shows a general decline over time, aligned with a decline in domestic gas and oil production. Recent UKCS oil and gas licensing Rounds (31st and 32nd Rounds) have maintained interest in exploration, including of mature hydrocarbon areas. Recent licensing rounds have been undertaken on an annual basis, covering mature areas, less well explored areas, and possible areas for redevelopment. While a high number of blocks tend to be offered in each round, relatively few are applied for, with approximately 80-90% of those offered resulting in a licence. Though several hundred blocks have been licensed in previous rounds (Figure 2.10), exploration drilling tends to involve relatively few wells per year (Figure 2.11), and of those only a few may result in a commercial discovery, and of these, less again may result in development. In terms of timescales of development, projects involving tie-backs to existing infrastructure have the potential to be completed within three years from the time of a discovery, with a timescale of five-ten years being more likely for a more complex development requiring new export routes.

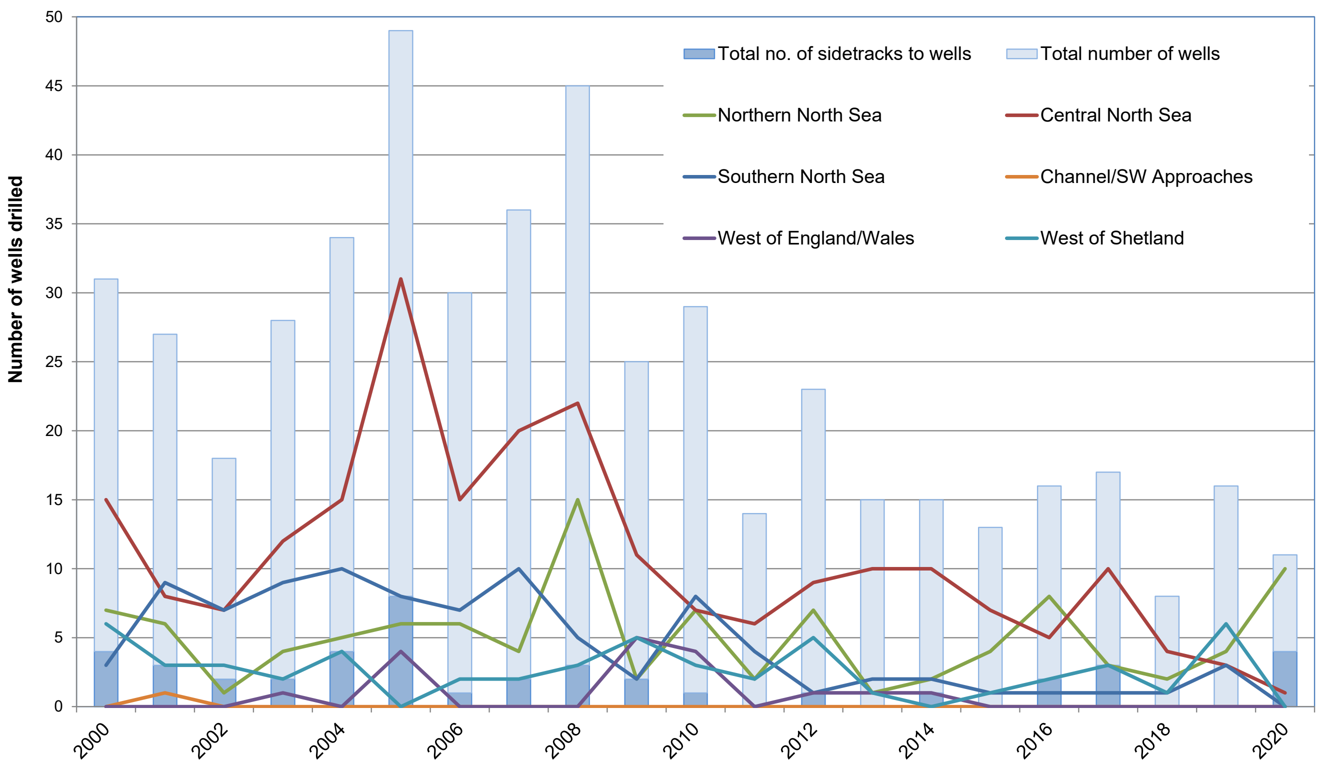
For context, the scale of former licensing rounds and the number of exploration wells drilled on the offshore UKCS over the last 20 years is shown in Figure 2.10 and Figure 2.11 respectively.

Figure 2.10: Trends in number of blocks offered during each round and those applied for/licensed, 2000-2019



Notes: does not include supplementary rounds or out of round offers

Figure 2.11: Trends in exploration drilling in different areas of the UKCS, 2000-2020



In addition to exploration and production, the speed and scale of decommissioning planning has increased considerably in recent years, and there is an expectation that activities involving the removal of offshore assets will increase over the coming decade. The map of current offshore licences and infrastructure in Figure 2.12 indicates the current status of decommissioning based on those fields and facilities which have been decommissioned, or are likely to be decommissioned soon (e.g. Decommissioning Plan has been submitted).

It was recognised in the *Industrial Strategy* that the oil and gas sector has a role in maintaining the UK's security of supply during the transition to a low carbon economy. Noting the UK is a net importer of oil and gas, maximising domestic production maintains security of supply during the transition towards net zero, moreover, non-fossil use of hydrocarbons is likely to be required for some time. The continued demand for oil and gas has been incorporated into the CCC (2020b) projections for net zero, and the demand for oil and gas based on the Balanced Pathway are charted in Figure 2.14 along with OGA's presently projected domestic supply over the same period[59]. While both sets of values are estimates, demand exceeds supply in all years, indicating the potential for domestically produced hydrocarbons to contribute to projected demand and security of supply throughout this period. Following the Government review of the UK's offshore oil and gas licensing regime, it was concluded that licensing for oil and gas should continue but with the introduction of periodic Climate Compatibility Checkpoints. The OGA anticipate that regular licensing rounds will still take place, however, at the time of writing the final format of the Climate Compatibility Checkpoint is not known.

As noted in Section 2.2.3, the current OGA Strategy, and its legislative underpinnings, commit offshore operators to take steps towards reducing their upstream emissions consistent with the UK commitment to achieving net zero greenhouse gas emissions by 2050, and with the North Sea Transition Deal outlined in Section 2.2.2. Upstream emissions are dominated by the combustion of diesel and gas, and flaring (13.7MtCO_2 in 2019, equivalent to ~3.8% of UK CO_2 emissions for the same year) which are used to meet offshore installation power demands and safety requirements. OGA (2020) note a number of decarbonisation options associated with the integration of energy systems which largely rely on the electrification of offshore installations, for example, from integration with offshore wind farms. OGA (2020) indicate the potential for a combination of the above integration of wind and hydrocarbon producing facilities, with bi-directional cables allowing for export and import. The technical feasibility of supporting power generation on platforms using offshore wind has already been demonstrated (e.g. at Beatrice in the Moray Firth), and the cost reduction of offshore wind combined with developments in floating wind turbines may now make them more attractive for deeper-water locations[60]. The Scottish Government has announced an Innovation and Targeted Oil and Gas (INTOG) leasing round, whereby developers may apply for rights to build offshore wind farms to power oil and has installations, within a number of areas identified by Marine Scotland as part of a sectoral plan[61].

[59] https://www.ogauthority.co.uk/data-centre/data-downloads-and-publications/production-projections/
[60] e.g. https://www.equinor.com/en/what-we-do/hywind-tampen.html
[61] https://marine.gov.scot/data/sectoral-marine-plan-offshore-wind-innovation-and-targeted-oil-and-gas-decarbonisation-intog

Figure 2.12: Current offshore oil and gas fields, infrastructure, onshore terminals, and licensed Blocks

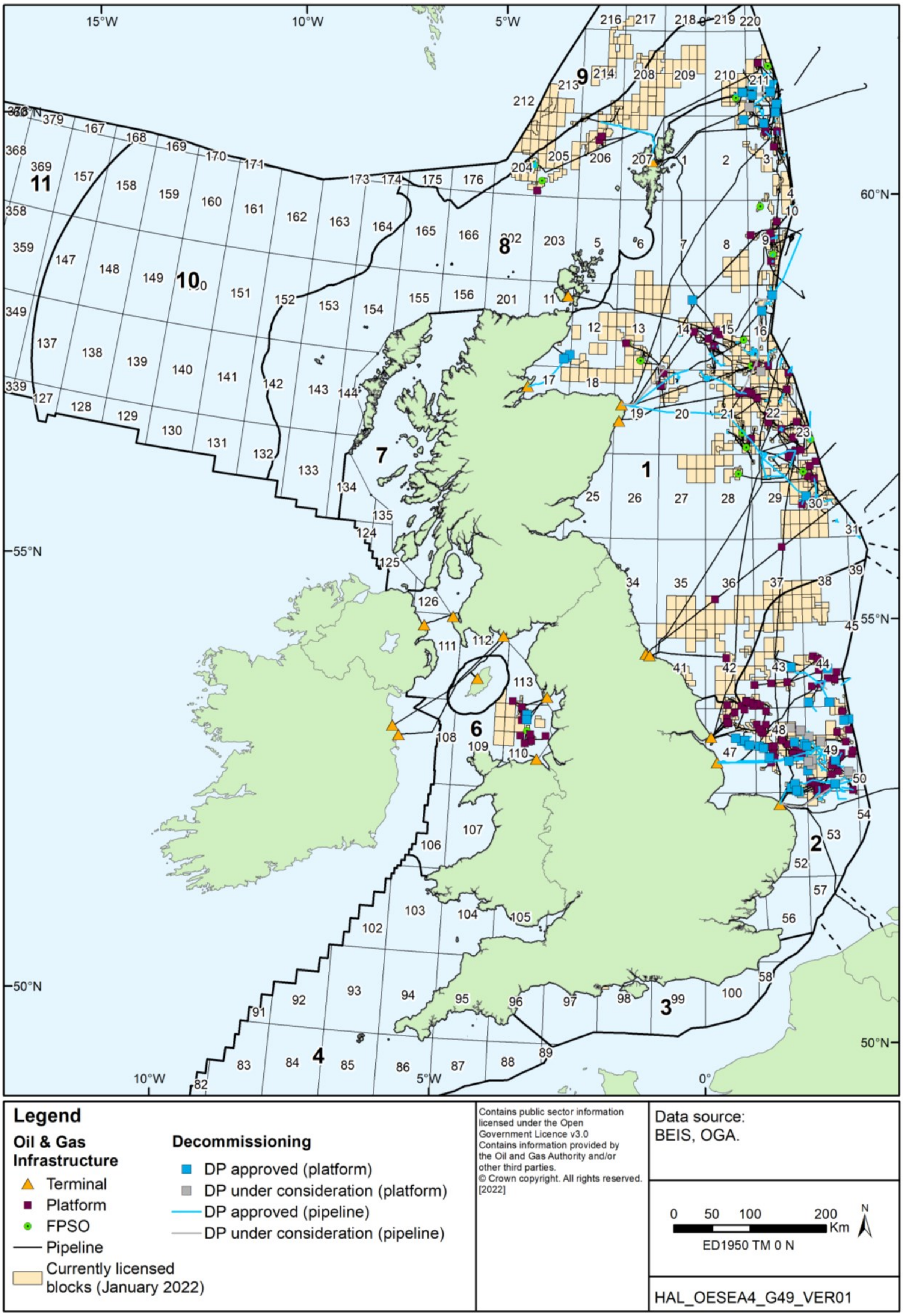
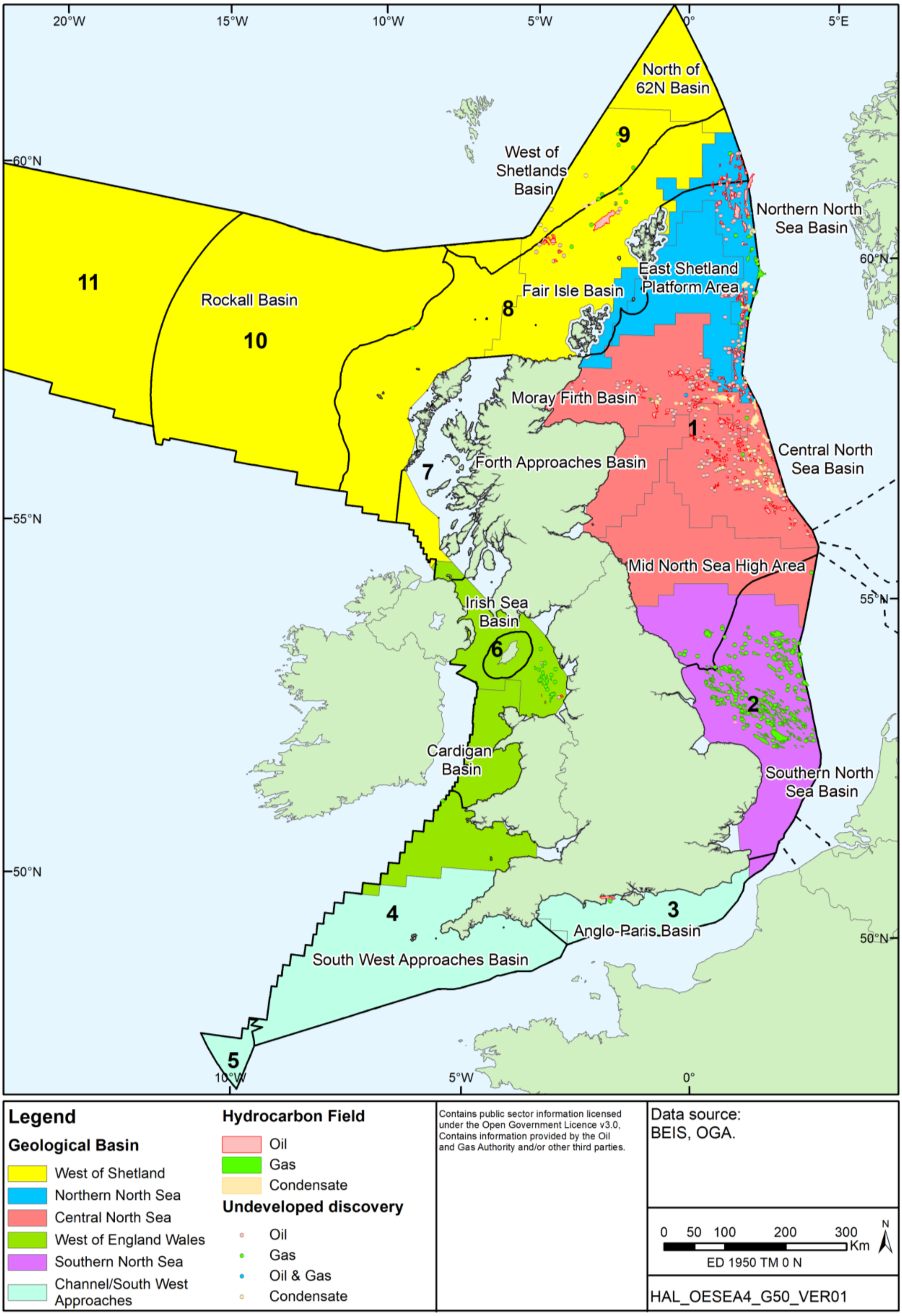
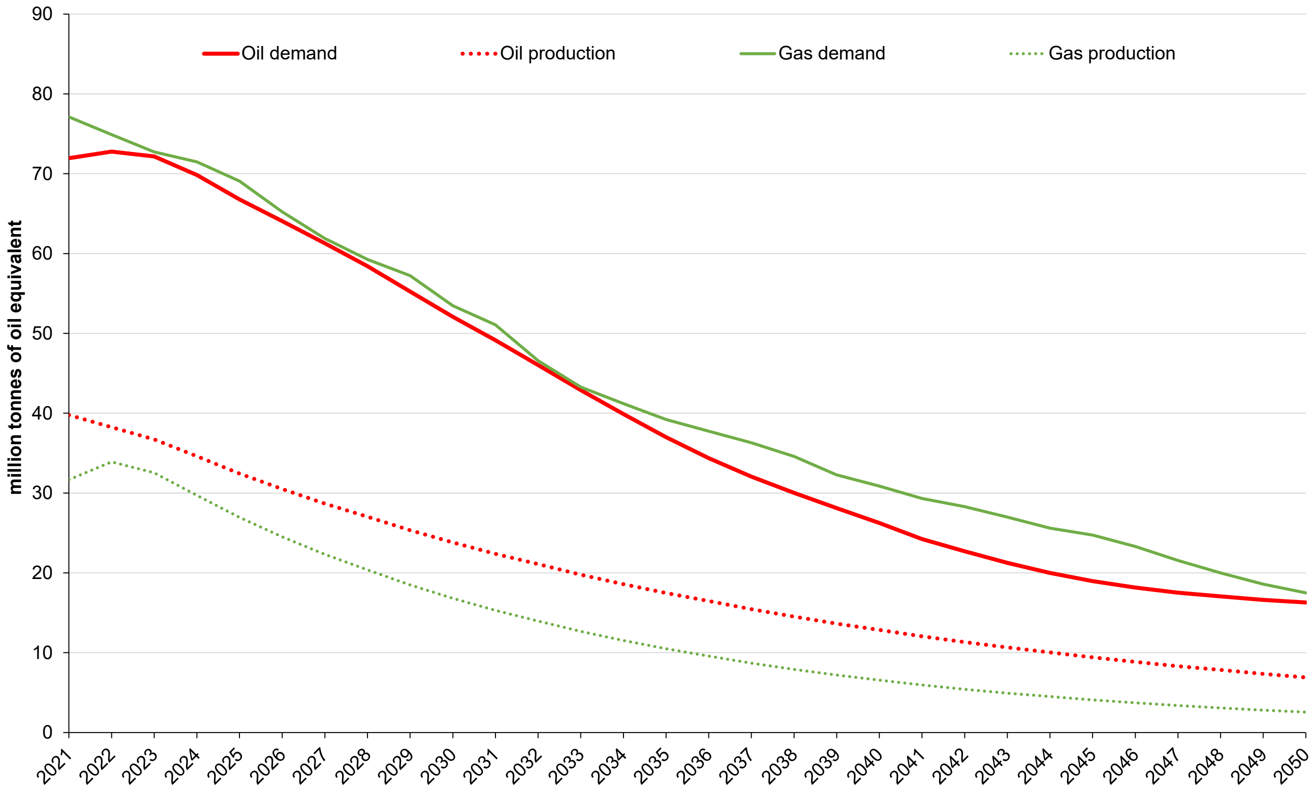


Figure 2.13: Major hydrocarbon basins of the UKCS, developed fields and significant* undeveloped discoveries



Note: * "significant" generally refers to the flow rates that were achieved (or would have been reached) in well tests (15 mmcfgd or 1,000 BOPD). It does not indicate the commercial potential of the discovery.

Figure 2.14: CCC Balanced Net Zero Pathway Demand and OGA Production Projections



Notes: Includes all UK production from onshore and offshore licences. Oil Demand includes Bunkers (estimated at 2.5 mtoe from 2020 onwards). After 2026, the daily oil and gross gas production rates are assumed to decline by 6% and 9% per year respectively. The demand projections are for the Balanced Pathway after CCC (2020b), with the addition of estimated non-energy use (based on the CCC's letter of 31st March 2021[62] setting out "Advice to the UK Government on compatibility of onshore petroleum with UK carbon budgets") and with a deduction for demand projected to be met by biogas.

The main stages of oil and gas activity are:

1. Exploration and appraisal: following successful licensing this involves initial exploratory drilling with well evaluation and testing typically using mobile drilling rigs, possibly preceded by seismic survey (note that purchase and reprocessing of existing seismic data is often used). Based on previous experience, typically less than half the wells drilled reveal hydrocarbons, and of that half less than half again will yield an amount significant enough to warrant development.

2. Development: includes production facility installation which may be fixed or floating, and generally the installation of pipeline(s), which for major developments could come ashore but are more often "tied back" to existing export infrastructure, and the drilling of producer and injector wells.

3. Production and export operations: involves the production of oil and gas, chemical use, flaring, power generation, produced water management/reinjection, reservoir monitoring and maintenance, routine supply vessel trips and return of wastes to shore.

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[62] https://www.theccc.org.uk/publication/letter-advice-to-the-uk-government-on-compatibility-of-onshore-petroleum-with-uk-carbon-budgets/

Future power sources may include electrification from shore, as part of a multi-purpose interconnector or from offshore renewables.

4. Decommissioning: including cleaning and removal of facilities, for reuse, recycling or disposal.

Further licensing of UKCS acreage for oil and gas exploration and production is anticipated to provide security of supply, and to reduce potential reliance on imports during the transition towards net zero, however, the future timing and nature of these rounds is uncertain, and may be contingent on meeting the requirements of periodic Climate Compatibility Checkpoints.

2.5.4 Hydrocarbon Gas Storage and Unloading

The inclusion in the current draft plan/programme of gas storage is part of the strategy to increase the UK's storage capacity and maintain resilience of gas supply in cold weather periods of high demand or interruptions to imported supplies. Hydrocarbon gas storage has the potential to take place in depleted and other hydrocarbon reservoirs and other geological structures (e.g. saline aquifers), and can be expected to take place in the same areas as existing oil and gas production, or in areas of extensive halite (rock salt) deposits. Salt caverns, unlike hydrocarbon reservoirs or aquifers, are created in thick halite formations through solution mining, where some of the salt is made soluble and discharged allowing space for the storage of hydrocarbon gas. There are extensive halite deposits in the southern North Sea and eastern Irish Sea, and the most prospective area for halites with gas storage potential (Smith *et al.* 2005) is the Triassic Preesall formation in the East Irish Sea Basin, for which there have been previous development proposals both onshore and offshore. At present, the only gas storage agreement for lease in UK waters is Larne Lough, which is related to the Islandmagee project (Figure 2.16).

The main stages of natural gas offloading and storage are:

1. Exploration/appraisal potentially including seismic survey exploration/appraisal drilling and reservoir/geological formation evaluation
2. Development (depleted hydrocarbon reservoir), including drilling of new or workover of existing wells, installation of storage facility or modification of existing infrastructure, with new or existing import/export pipelines, and potentially offloading facilities
3. Development (salt caverns), including the drilling of wells, construction of storage caverns by dissolution, installation of storage facilities, with new import/export pipelines, and potentially offloading facilities
4. Import, storage and export operations, involving the injection of combustible gas offshore, with routine supply vessel trips, return of wastes to shore, power generation, chemical use, flaring, produced water management and reservoir/structure monitoring
5. Maintenance
6. Decommissioning, including cleaning and removal of facilities

2.5.5 Carbon Dioxide Transport and Storage

The aspects of CCUS of relevance to this plan/programme are any offshore storage site and related surface/subsurface infrastructure including connecting offshore pipelines. The capture and onshore transportation of carbon dioxide are not covered by this SEA.

Prospective areas on the UKCS suitable for storage of carbon dioxide primarily include depleted offshore oil and gas reservoirs and saline aquifers, i.e. mainly sedimentary basins, and are therefore focussed on the southern, central and northern North Sea, and the Moray Firth Basins. Constructed salt caverns also have the potential to store gas. A theoretical P50[63] storage capacity of 78Gt has been estimated collectively for UKCS hydrocarbon fields and saline aquifers (Bentham *et al.* 2014), which is equivalent to over 200 years of UK carbon dioxide emissions at 2019 levels. To date, a number of carbon dioxide storage licences have been issued covering either depleted hydrocarbon reservoirs or saline aquifers (Figure 2.16).

Hydrocarbon reservoirs have geological characteristics suited to trapping carbon dioxide over long timescales (e.g. a suitable porosity/permeability and impervious cap rock), and the injection of CO_2 into hydrocarbon reservoirs can also be used for enhanced hydrocarbon recovery. In the longer term these reservoirs can be used exclusively for CCS. Due to the maturity of most of the UKCS hydrocarbon basins, the availability of sites for enhanced hydrocarbon recovery or dedicated CO_2 storage is likely to increase in the coming years and has the potential to exploit existing infrastructure. In fulfilment of an action under the CCUS Deployment Pathway (see above), the UK Government and the OGA undertook an initial review of offshore assets which have the potential to be reused, and also suggested legislative changes to allow for changes in the decommissioning liability arrangements for operators so that there is not a disincentive to transfer these assets for re-use[64]. The Government response to the consultation, published in August 2020, gave a range of future actions including ones related to further re-use assessment of offshore oil and gas assets, making data available, updated policy proposals and regulatory review. Further support for CCUS has been provided by UK Government, for example, through the CCUS Innovation Programme[65], the Industrial Decarbonisation Deployment and Roadmap administered by UKRI, and funding to support the transition from natural gas to hydrogen[66]. Based on the targets given in the 2020 Energy White Paper (two industrial CCUS clusters by the mid-2020s, presently identified to be the East Coast Cluster and HyNet North West with the Scottish cluster as a reserve, and a further two clusters by 2030, with an ambition to capture and store 20-30MtCO_2 per year by 2030) several facilities could become operational during the timescale of OESEA4, with a mixture of asset re-use and new facility installation. While the Energy White Paper refers to 10MtCO_2 by 2030, the Net Zero Strategy indicates the aim is to use CCUS to capture and store 20-30MtCO_2 per year by 2030. The CCC (2020b) have indicated the scale of CCS demand which could be required as part of their Balanced Pathway scenario, used elsewhere in this section, and is charted in Figure 2.15.

Information on over 500 potentially prospective storage structures is available through the CO_2Stored database, which makes available some of the information on the UK Storage

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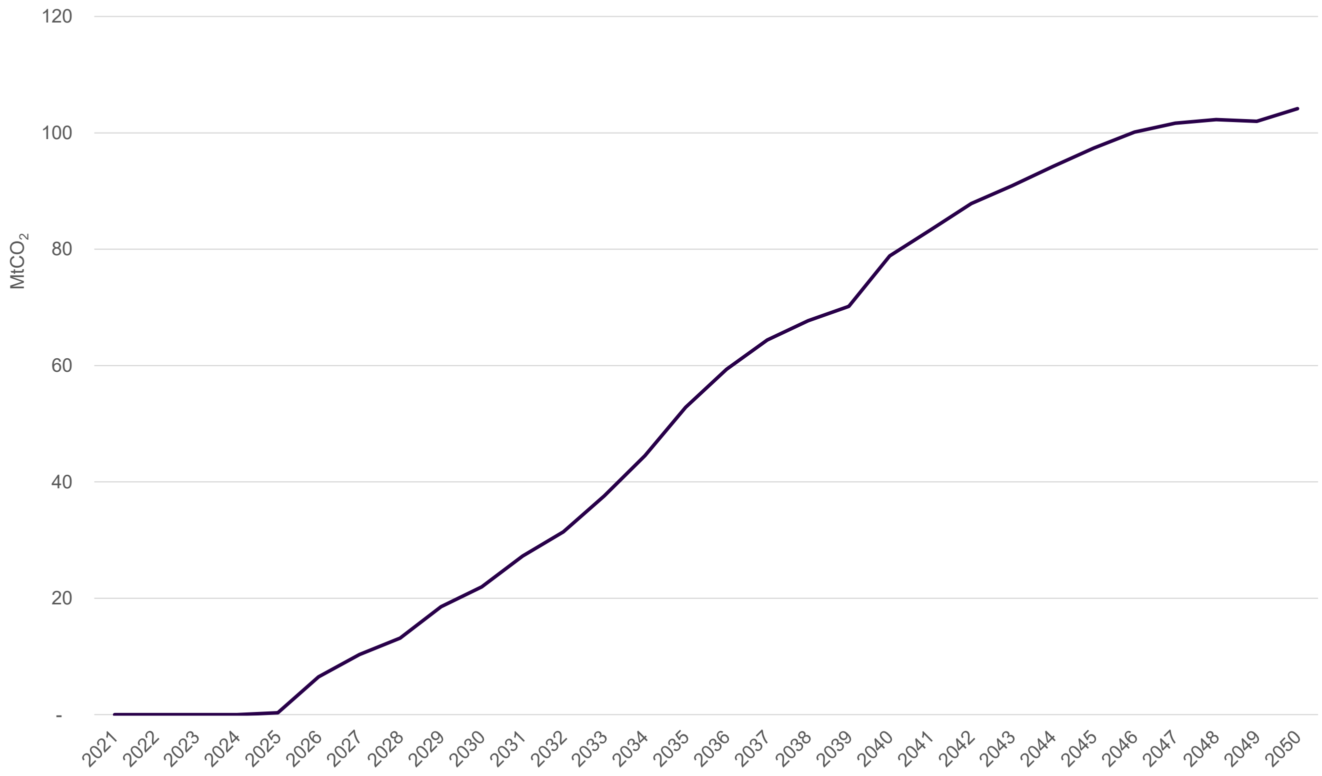
[63] P50 is a statistical confidence level for an estimate, where 50% of estimates (in this case of storage capacity) exceed the P50 estimate (and conversely 50% of estimates are less than the P50 value). It can be considered a good middle estimate
[64] https://www.gov.uk/government/consultations/carbon-capture-usage-and-storage-ccus-projects-re-use-of-oil-and-gas-assets
[65] https://www.gov.uk/government/publications/call-for-ccus-innovation
[66] https://www.gov.uk/government/news/pm-commits-350-million-to-fuel-green-recovery

Appraisal Project commissioned by the Energy Technologies Institute, and which is now being updated by The Crown Estate and the British Geological Survey (Bentham *et al.* 2014).

Saline aquifers provide the largest potential storage capacity on the UKCS, with the highest proportion of this capacity being in the central North Sea. Potential storage areas include the Triassic Bunter Sandstone and Ormskirk Sandstone of the southern North Sea and East Irish Sea Basins respectively, the Captain Sandstone of the Moray Firth, and numerous overlapping formations of the central and northern North Seas having a similar distributed to that area where hydrocarbon production has taken place to date. Saline aquifers can have similar characteristics to hydrocarbon reservoirs (i.e. suitably porous/permeable medium with geological constraints on migration) and may also be suited to CO_2 storage. The capacity of saline aquifers is not yet well established for the UKCS, but they have a theoretically large volume – for instance the most prospective southern North Sea formation, the Bunter Sandstone, is estimated to have a capacity of between 2.2Gt and 14.25Gt CO_2 (Holloway *et al.* 2006, Smith *et al*. 2010, Heinemann *et al.* 2012), and more generally, saline aquifers provide the majority of the potential storage capacity on the UKCS (60Gt excluding chalk aquifers, Bentham *et al.* 2014).

Figure 2.15: UK CCS demand for the Balanced Net Zero Pathway, 2021-2050



Source: CCC (2020b)

The main stages of carbon dioxide and storage activity in depleted oil and gas reservoirs and saline aquifers are:

7. Exploration/appraisal including seismic survey and exploration/appraisal drilling and testing

8. Development, including installation of injection facilities, generally with construction of import pipelines, and the drilling of injection wells and potentially aquifer water production wells

9. Import and injection operations involving the long term storage of carbon dioxide, with routine supply vessel trips, return of wastes to shore, power generation, chemical use, venting, potentially aquifer water production/management and storage reservoir monitoring

10. Maintenance

11. Decommissioning, including cleaning and removal of facilities

2.5.6 Hydrogen: power-to-gas and offshore hydrogen transport and storage

Hydrogen is an energy carrier which could contribute to carbon dioxide emissions reductions by being generated, for example, using renewables via electrolysis of water ("green hydrogen"), or natural gas, for example by Methane Reforming (MR) combined with CCS to remove and store the carbon dioxide generated as a by-product of the process ("blue hydrogen").

Power-to-gas involves the use of excess electricity produced by renewables, which would otherwise be curtailed, to generate hydrogen. Hydrogen may be produced onshore (as is done at a small scale on Orkney as part of two EMEC projects[67]), or possibly offshore, and could be used for storage (e.g. in fuel cells) to produce electricity at another time, or else be transported by pipeline (e.g. making use of offshore oil and gas pipeline infrastructure where feasible[68]), or possibly by vessel.

The small-scale Acorn CCS project based in North East Scotland is considering the feasibility of storing carbon dioxide from the St Fergus gas terminal, including (in a later phase) from hydrogen production, in a North Sea geological store. At a larger scale, The Zero Carbon Humber (ZCH) Partnership[69] plans to create a zero carbon industrial cluster using blue hydrogen combined with CCS linked to a southern North Sea geological storage site.

In addition to the storage of carbon dioxide in geological formations, there is the potential to store hydrogen[70] for later use, including in geological formations (see: Stone *et al.* 2009, Henkel *et al.* 2013, 2014, Bauer *et al.* 2017). Unlike natural gas and carbon dioxide, there is currently no consenting route for projects transporting hydrogen by offshore pipeline, or its storage in geological formations, either under the *Energy Act 2008* (as amended), or related Regulations such as the *Offshore Oil and Gas Exploration, Production, Unloading and Storage (Environmental Impact Assessment) Regulations 2020*. Similarly, the consenting route for hydrogen generation offshore requires definition.

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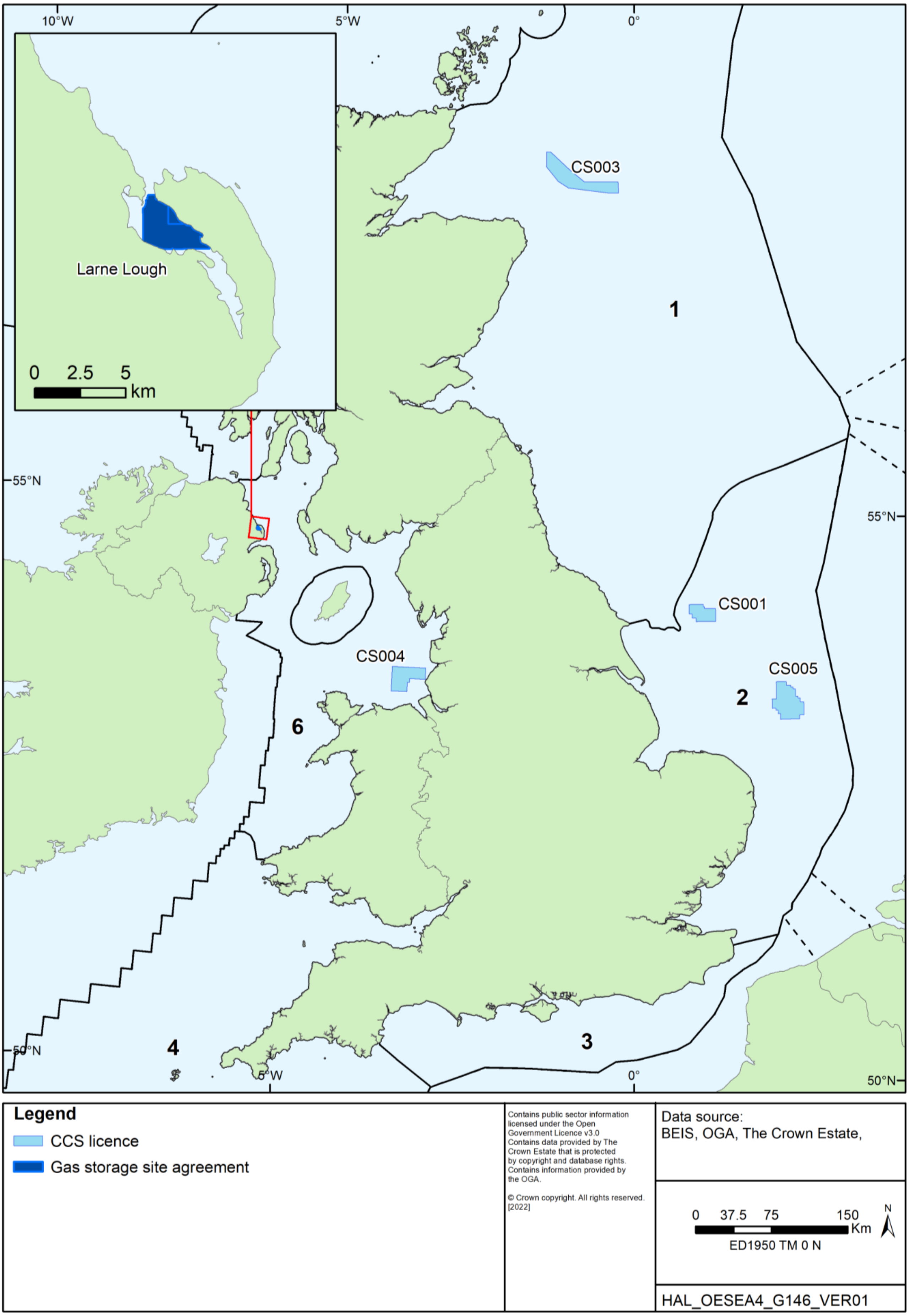
[67] Building Innovative Green Hydrogen systems in an Isolated Territory: a pilot for Europe (BIG HIT): https://www.fch.europa.eu/project/building-innovative-green-hydrogen-systems-isolated-territory-pilot-europe and Surf 'n' Turf: http://www.surfnturf.org.uk/
[68] As noted OGA (2020) UKCS Energy Integration, final report.
[69] https://www.nationalgrid.com/zero-carbon-humber-partnership-submits-ps75-million-bid-advance-uks-first-net-zero-industrial
[70] For example as investigated by the H_2STORE project

Figure 2.16: Carbon Dioxide Storage and Gas Storge Licences on the UKCS



The main stages of offshore hydrogen production and transport are:

1. Development, including installation of electrolysis facilities, generally with construction of export pipelines and cables supplying electricity

1. Production of green hydrogen offshore using electricity from an offshore renewable energy source, most likely offshore wind, and export operations

2. Maintenance

3. Decommissioning, including removal of facilities

2.6 Characterisation of the potential type and scale of activity

The following table outlines the potential type of activities which could take place in each Regional Sea (RS). The following summary information does not fully take account of the range potential constraints which are assessed in Section 5.15. Offshore hydrogen production has not been considered in this table as the potential for its deployment is a function of proximity to sources of energy for electrolysis (i.e. renewables) and potentially distance to sources of demand; it does not have its own resource areas like the other aspects of the plan (as outlined in Section 2.6 above).

Table 2.1: Potential activity by Regional Sea

RS	Oil and Gas	Wind	Wave	Tidal	Gas storage & CCS*
1**	Prospectivity is generally high in the northern North Sea, Moray Firth and central North Sea Basins, which is primarily for oil. These basins are mature and there will likely be a mix of exploration and decommissioning in the coming years. The east Shetland Platform and mid North Sea High areas are comparatively underexplored and have a low level of prospectivity.	No proposals for commercial scale wind farms have been made to date in the English sector of this Regional Sea. The area is prospective for fixed foundations in nearshore areas, or tethered devices at greater distances. It is possible that areas may be leased for commercial floating offshore wind in the coming years.	No proposals for wave devices have been made in the English sector of this Regional Sea. There is a small area to the north east which falls within the criteria for wave deployment (see above), however the area is distant from the coast and deployment here is considered unlikely.	Tidal ranges and speeds are generally regarded to be too low for commercial exploitation in the English sector of Regional Sea 1.	Existing offshore oil and gas infrastructure in mature fields provides the potential for re-use as storage facilities where structure design life and modifications allow. Proven sealing structures and an abundance of historical geological well and seismic data make Regional Seas 1 and 2 highly prospective for gas storage and CCS projects. In addition to former hydrocarbon reservoirs, there is a theoretically high storage capacity available in saline aquifers. Nearby clusters of high emissions, such as the Humber and Teesside, combined with the availability of storage sites make Regional Sea 2 particularly prospective.
2	Prospectivity is high in the southern North Sea Basin which is primarily for gas. This is a mature basin and there will likely be a mix of exploration and decommissioning in the coming years. A portion of the mid North	The southern North Sea contains the bulk of the current UK offshore wind capacity, both in operation and planning. The area remains highly prospective for offshore wind due to its shallow depths and the potential for suitable grid	Wave energy is generally regarded to be too low for commercial deployment.	Potentially suitable tidal stream locations are found off the Humber and Norfolk coast and are spatially very limited. It is possible that areas could be leased in these areas in the coming years, however devices for	

RS	Oil and Gas	Wind	Wave	Tidal	Gas storage & CCS*
	Sea High area is located in the north east of Regional Sea 2 (as above, underexplored, with low prospectivity).	connections. It is possible that further areas may be leased for commercial offshore wind beyond Round 4, however, the available resource is becoming limited.		these technologies during the currency of this SEA.	
3	Prospectivity in the Channel (Anglo-Paris Basin) has historically been for oil, produced by extended reach drilling from shore, however a single gas discover has also been made. The basin has relatively poor seismic coverage to define its structure, however prospectivity is considered to remain high.	Comparatively shallow water depths at proximity to shore with good wind resources have made the central and eastern Channel prospective for wind power. One project is currently operational off the coast of Brighton which is subject to plans for an extension. It is possible that further areas may be leased for commercial offshore wind in this Regional Sea, though fixed wind resource is limited by competing activities and interests.	Wave energy is generally regarded to be too low for commercial deployment.	Potentially suitable tidal stream locations are found across the central Channel, particularly off Portland, Purbeck and the Isle of Wight. Prospective areas for tidal range are present off the Sussex coastline. A lack of large embayments probably makes lagoon-type technologies more applicable here.	Suitable storage and sealing formations may be present, however potential connectivity to large emitters is more restricted than in other areas of the UK.
4	No economically exploitable hydrocarbon stores have been discovered to date in the South West Approaches Basin, and the majority of blocks in this area have never been licensed. The area remains underexplored, and prospectivity in the area is considered to be low.	Waters have generally proven to be too deep for fixed foundation technology, however the area is highly prospective for floating offshore wind, and there are a number of demonstration projects for such projects present, and commercial proposals are starting to emerge. It is likely that further areas may be leased for commercial offshore wind in this area	This area has some of the most prospective waters for offshore wave energy in the UK and contains the only wave demonstration sites in English and Welsh waters. Any further development of wave energy is expected to be in this Regional Sea.	Tidal stream energy is prospective off western Cornwall, within the Severn Estuary and off Pembrokeshire, with demonstration sites being located in the latter two areas. There has been historically very strong interest in the Severn as a potential source of tidal range energy. Several lagoon development proposals have previously	Comparatively smaller geological understanding make these areas unlikely candidates for gas storage or CCS compared with North Sea and East Irish Sea prospects.

RS	Oil and Gas	Wind	Wave	Tidal	Gas storage & CCS*
				been made. The potential for future commercial scale development is not certain, though it is the most prospective area for such development.	
5			Water depths and distances from shore generally make this area not prospective.	Water depths and distances from shore generally make this area not prospective.	
6*	Prospectivity is largely for gas and has to date been restricted to the East Irish Sea Basin. Oil has been commercially produced in only small quantities. This is a mature basin and there will likely be a mix of exploration and decommissioning in the coming years. The northern section of the Cardigan Basin has been subject to previous exploration, but without commercial success, and prospectivity is considered to be low.	The area is relatively shallow and there is the potential for further fixed foundation wind farms to be proposed, but the resource is becoming limited. Further deployment in this Regional Sea. Development is most likely in the East Irish Sea. It is possible that further areas may be leased for commercial offshore wind during the currency of this SEA.	Wave power in this area is generally regarded to be too low for commercial exploitation.	Tidal stream energy and related prospectivity is concentrated around the Lleyn Peninsula and Anglesey, with a number of projects having been proposed around the latter. A significant portion of the UK's potential tidal range energy is located along the North Wales and north east English coasts, incorporating coastal areas suited to lagoons and embayments where barriers could theoretically be used.	Existing offshore oil and gas infrastructure in mature fields provides the potential for re-use as storage facilities where structure design life and modifications allow. Proven sealing structures and an abundance of historical geological well and seismic data make the East Irish Sea area highly prospective for gas storage and carbon dioxide storage projects. Large industrial emitters in the Merseyside area also provide significant potential carbon dioxide sources.

RS	Oil and Gas	Wind	Wave	Tidal	Gas storage & CCS*
7*	The majority of Regional Sea 7 falls within the bay closing lines subject to landward Regulations. The remaining area has not been commercially exploited to date, however a number of blocks in Northern Irish waters have been previously licenced. Prospectivity is considered to be low.	n/a	n/a	n/a	n/a
8*	The western extent of Regional Sea 8 which is covered by the Rockall Basin is generally under explored. It is possible that further Blocks will be applied for during the currency of this SEA, however, prospectivity is generally considered to be low.	n/a	n/a	n/a	A paucity of major CO_2 emitters and comparatively smaller geological understanding make these areas unlikely candidates for gas storage or CCS compared with North Sea and East Irish Sea prospects.
9*	Exploration in this area has been comparatively small compared to the rest of the UK, however a number of significant oil and gas developments have taken place in the West of Shetland Basin. Geological barriers to seismic survey and drilling north of 62˚N has resulted in historically	n/a	n/a	n/a	

RS	Oil and Gas	Wind	Wave	Tidal	Gas storage & CCS*
	limited exploration, and a low prospectivity.				
10*	The Rockall Basin is generally under explored though has continued to attract some interest in recent licensing rounds and could be subject to further exploration activity. Prospectivity is considered to be low.	n/a	n/a	n/a	
11*	Areas outside of the EEZ are not considered.				

Notes: * Hydrogen production offshore does not readily fit within a regional sea consideration, as it is to some extent tied to where it could be produced i.e. proximity to renewables and thus does not have its own specific resource areas as other aspects of the plan do. **The Scottish Renewable Energy Zone and the territorial waters of Scotland and Northern Ireland are not included in this SEA.

3 SEA Approach

3.1 Scoping

A scoping step is used to identify issues of concern at an early stage so that they can be considered in appropriate detail in the SEA. Scoping also aids in the identification of information sources and data gaps that may require to be filled by studies or surveys to underpin the assessment.

The OESEA4 scoping specifically aimed to:

- Promote stakeholder awareness of the SEA initiative
- Ensure access to relevant environmental information
- Identify opportunities for potential collaboration and the avoidance of duplication of effort
- Identify information gaps so these could be evaluated and filled if necessary
- Identify stakeholder issues and concerns which should be considered in the SEA

An OESEA4 scoping document was prepared and a formal scoping exercise with the statutory Consultation Bodies/Authorities for Wales, Scotland, England and Northern Ireland and other stakeholders was conducted from 29th March to 7th May 2021. The scoping consultation was undertaken by emailing directly to the statutorily defined Consultation Bodies and Authorities and by also making the scoping document available on the BEIS Offshore Energy SEA pages of the gov.uk website[71].

The following consultation questions were asked:

1. Consultees are invited to highlight additional initiatives which they consider are relevant to the draft plan/programme.
2. Consultees are invited to draw attention to and provide (where relevant/possible) additional information and data sets which they consider of potential relevance to this SEA.
3. Do you agree with the choice of Regional Seas used to help describe the environmental baseline?
4. Are there any additional environmental problems you consider to be relevant to the SEA?
5. Are there any additional influences, and supporting data sources, on the likely evolution of the environmental baseline?

[71] https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process

6. Are there any additional alternatives that you feel the SEA should reflect?
7. Are there any objectives that you feel should be included or removed?
8. Are the indicators for each objective suitable? If not please suggest alternatives.
9. Do you have any comments on the sources of potentially significant effect for each of the activities covered by the draft plan/programme, including whether they should be scoped in or out of assessment in the Environmental Report?
10. Are there any additional information sources or existing monitoring arrangements which could be used to inform monitoring of the offshore energy draft plan/programme?
11. Do you have any comments on the proposed approach to consultation?

Responses were received from 28 organisations/members of the public, which were summarised in a Government Response published on 22nd November 2021, which included information on how the feedback would be taken account of in drafting the Environmental Report. In addition to responses to the specific consultation questions asked, a number of additional comments were received and these were also summarised in the Government Response.

3.2 The BEIS SEA process

The BEIS offshore energy SEA process has developed over time, drawing in concepts and approaches from a variety of individuals, organisations and other SEAs as well as addressing the requirements of legislation and guidance.

Since SEA 1 in 1999, the BEIS Offshore Energy SEA process has evolved and the following process improvements have been implemented:

- Establishment of a SEA Steering Group with wide representation from a range of stakeholders (established in early 2001)
- A formal scoping step with relevant consultation bodies and authorities
- Integrated management of survey, consultation and assessment processes
- Facilitation of public consultation through a dedicated website, now incorporated in the gov.uk site
- Widespread dissemination of data and information
- Development of modular documents applicable to more than one SEA
- Syntheses of data to facilitate access
- Commissioning of expert studies and research with results published (website and peer reviewed literature)

- Assessment workshop as part of Environmental Report preparation, involving the steering group and others
- Regional stakeholder workshops
- Sector meetings and workshops
- Environmental report available via website or as CD or hard copy
- Continuing development of the methods for the consideration of cumulative and synergistic effects

The process followed for this SEA is summarised below, but note that certain activities such as information gathering and stakeholder liaison continue throughout the process.

In previous SEAs, regional stakeholder workshops were undertaken to get input on the information base and other issues of relevance to the SEA. Due to the potential limitations associated with the COVID-19 pandemic, virtual events were held for OESEA4, with stakeholders contacted directly, via industry representative organisations and other forums.

The Environmental Report and draft plan/programme are being issued for an 8 week public consultation period. The Department and the Secretary of State will consider comments received from consultation in the decision making regarding the plan/programme. A Post Consultation Report will be prepared and placed on the SEA pages of the gov.uk website collating the comments and BEIS responses to them.

3.3 SEA process and stages completed to date

The BEIS offshore energy SEA process is underpinned by the requirements of the *Environmental Assessment of Plans and Programmes Regulations 2004* (as amended) – see Section 1.

A summary of the SEA process used for this SEA is given below and in Figure 3.1. The SEA process aims to help inform licensing and leasing decisions through consideration of the environmental implications of the proposed draft plan/programme.

The key stages in the conduct of this SEA are:

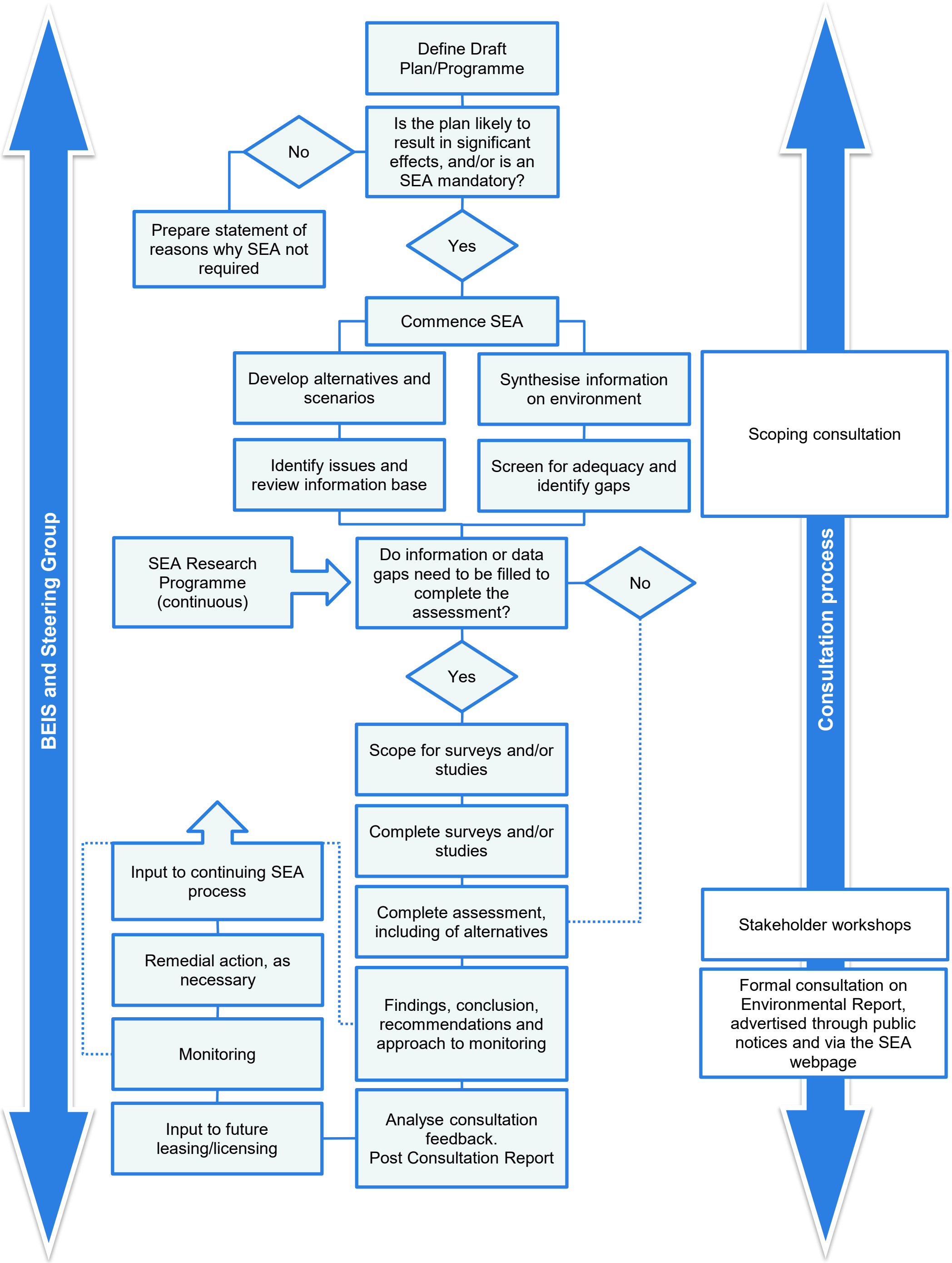
1. Instigation of draft plan/programme and identification of alternatives and draft objectives
2. Scoping for field work / longer term studies
3. Consultation with the Consultation Bodies and Authorities and other Stakeholders on the scope and level of detail of the Environmental Report
4. Information gathering and collation on:
5. Environmental baseline
6. Existing environmental problems

7. Potential effects of proposed plan
8. Other relevant initiatives, plans and programmes and their objectives
9. Assessment workshop
10. Assessment of effects including consideration of alternatives
11. Regional stakeholder workshops
12. Sector meetings and/or workshops
13. Production of Environmental Report
14. Public Consultation
15. Post consultation evaluation of feedback (post consultation report) input to decision on the plan (post adoption statement(s))
16. Monitoring plan implementation

The first 13 stages of the SEA are now complete and preparatory work has been undertaken for subsequent stages.

Responsibility for the publication of the Environmental Report rests with BEIS. Members of the Steering Group, as individuals and through their organisations, may comment on the proposed draft plan and the consultation materials (including this document) during the public consultation phase, and encourage others to comment.

Figure 3.1: Overview of the SEA process



3.4 Supporting studies

Since 1999, many studies have been commissioned as part of the BEIS SEA programme either to provide expert reviews or data syntheses in areas for which synoptic overviews were not published or readily available. These reports and new studies have been used to inform the current assessment documented in this report and are available from the BEIS SEA webpages of the gov.uk website, which includes an overview of current and ongoing projects, and are also archived by the BGS (https://webapps.bgs.ac.uk/data/sea/app/search).

3.5 SEA Objectives

The development of SEA objectives is a recognised way in which environmental considerations can be described, analysed and compared. The OESEA4 objectives and indicators are presented in Table 3.1 below. These were based on those first developed in OESEA, amended following successive rounds of scoping and discussion including at the Assessment Workshop. The guide phrases are included to assist in interpretation.

Table 3.1: SEA topics, objectives and indicators

SEA Objectives	Guide Phrases	SEA Indicators
Biodiversity, habitats, flora and fauna		
Contributes to conservation of the biodiversity and ecosystems of the United Kingdom and its seas. Avoids significant impact to conservation sites designated at an International and National level (e.g. Ramsar, SACs, SPAs, MCZs, MCMPAs, and SSSI). Avoids significant impact to, or disturbance of, protected species and loss of habitat.	Plan activities do not lead to the loss of biological diversity, the degradation in the quality and occurrence of habitats, and the distribution and abundance of species. Plan activities do not cause adverse effects on marine ecosystems/valued ecosystem components. Plan activities contribute to the ecological knowledge of the marine and coastal environment through survey and discovery. Plan activities do not lead to disruption in habitat and species connectivity. Plan activities do not lead to the introduction of noise at levels which adversely affect the marine environment, including by leading to significant effects on	No significant loss of diversity or decline in a population attributable to plan related marine activities and promotion of recovery wherever possible. Activities subsequent to licensing/leasing which overlap, or potentially affecting designated sites (e.g. SACs, SPAs, Marine Conservation Zones, Nature Conservation Marine Protected Areas), or with the potential to disturb a protected species, are compliant with the requirements of relevant UK and devolved Regulations[72], and consistent with national and regional policy. No adverse change in the environmental status of marine sub-regions, including in relation to the attainment of targets for MSFD descriptors; or in the ecological status of

[72] *The Conservation of Habitats and Species Regulations 2017*, *The Conservation of Offshore Marine Habitats and Species Regulations 2017*, the *Conservation (Natural Habitats, &c.) Regulations 1994* (as amended), the *Offshore Petroleum Activities (Conservation of Habitats) Regulations 2001* (as amended).

SEA Objectives	Guide Phrases	SEA Indicators
	conservation sites and sensitive species. Plan activities do not lead to the introduction of non-native species at levels which adversely alter marine ecosystems. The plan recognises the ecosystem importance of land-sea coupling, for instance its role in species migration. The plan promotes the achievement of good ecological/environmental status for water bodies and marine sub-regions as outlined at a European Level.	WFD transitional waters and the attainment of good status/potential. No adverse impact on the ability of the UK to achieve its objectives for good environmental status, and related MSFD indicators.
Geology and Soils		
Protects the quality of the seabed and its sediments, and avoids significant effects on seabed morphology and sediment transport processes. Protects the integrity of coastal and estuarine processes.	Activities arising from the plan do not adversely affect the quality and character of the geology and geomorphology of seabed or coastal sediments. Plan activities do not lead to changes in seafloor integrity	No adverse change in quality of seabed sediments, and seabed sediment transport, at a series of regional monitoring stations[73]. No significant physical damage to designated marine and coastal geological

[73] Including Oil & Gas UK environmental monitoring committee surveys.

SEA Objectives	Guide Phrases	SEA Indicators
Avoids significant damage to geological conservation sites and protects important geological/geomorphological features.	which could adversely affect the structure and function of ecosystems. Plan activities avoid adverse effects on designated geological and geomorphological sites of international and national importance.	conservation sites (e.g. GCRs, SSSIs, MCZs/MPAs).
Landscape/Seascape		
To accord with, and contribute to the delivery of the aims and articles of the European Landscape Convention and minimise significant adverse impact on seascape/landscape including designated and non-designated areas.	Activities do not adversely affect the character of the landscape/seascape, or do not exceed the capacity of the character of an area to accommodate change. The plan helps to conserve the physical and cultural visual resource associated with the land and sea.	No significant impact on nationally-designated areas (including the setting of heritage assets). Number of areas of landscape sensitivity (e.g. national or local landscape designations) affected by proposed developments (e.g. offshore wind). Extent of the visual resource potentially affected by plan activities. Trajectory of change in coastal Character Areas defined at UK constituent country level show no adverse effects arising from plan activities.
Water Environment		
Protects estuarine and marine surface waters, and potable and other aquifer resources.	Plan activities do not result in concentrations of contaminants at levels giving rise to pollution effects.	No adverse change in quality of WFD water body status, including in relation to attainment of good ecological

SEA Objectives	Guide Phrases	SEA Indicators
Avoid significant impact on flood and coastal risk management activities.	Plan activities do not result in permanent alteration of hydrographical conditions which adversely affect coastal and marine ecosystems. Plan activities do not result in adverse effects on saline and potable aquifer resources.	status or potential, or good chemical status. No adverse impact on the ability of the UK to achieve its objectives for good environmental status, and related MSFD indicators. UKCS Exploration and Production (E&P) meets OSPAR discharge reduction targets. Number of oil and chemical spills and quantity of material spilled. No adverse impact on flood risk as a result of plan activities.
Air Quality		
Avoids degradation of regional air quality from plan related activities.	The plan contributes to the achievement of air quality targets outlined in the Clean Air Strategy 2019, Cleaner Air for Scotland 2, and other strategies of devolved administrations. Emissions from plan activities do not contribute to, or result in, air quality issues which adversely affect human health or the wider environment.	Monitoring of local air quality shows no adverse impact. Targets relating to airborne emissions at a local, regional and UK level are not exceeded.

SEA Objectives	Guide Phrases	SEA Indicators
Climatic Factors		
Minimises greenhouse gas emissions.	The plan contributes to decarbonisation in the energy sector, and the achievement of targets relating to greenhouse gases at a national and international level, which include the UK's Net Zero target, related carbon budgets, and the Nationally Determined Contribution under the Paris Agreement.	Reductions in upstream greenhouse gas emissions from oil and gas exploration and production, consistent with requirements under the Oil and Gas Strategy. UK progress towards meeting legally mandated greenhouse reduction targets, and the relative reduction in emissions delivered by aspects of the plan/programme. Progress towards 2030 targets for offshore wind installed capacity, and offshore carbon dioxide transport and storage associated with CCUS (e.g. that deployed in industrial clusters).
Resilience to climate change	Plan activities recognise the potential impact of climate change during their lifetime, in relation to their potential impact on coastal change, flood risk, or other climate change adaptation. Plan activities recognise the potential for climate change related impacts to affect them, and take this into account in their design.	See also; water environment indicators in relation to flood and coastal risk management.

SEA Objectives	Guide Phrases	SEA Indicators
Population and Human Health		
Has no adverse impact on human health and wellbeing.	Plan activities do not result in, or contribute to the contamination of fish and other seafood for human consumption at levels which exceed those established in legislation or other relevant standards. Plan activities avoid adverse effects on physical and mental health.	Progress in achieving measures set out by OSPAR, for the continued reduction in the harmfulness of offshore discharges. No adverse impact on the ability of the UK to achieve its objectives for good environmental status, and related MSFD indicators. Relevant Office for National Statistics wellbeing metrics. Percentage of population in good health.
Avoids disruption, disturbance and nuisance to communities.	Plan activities avoid adverse nuisance to communities, for instance through noise or vibration. Adverse effects on the quality or access to areas used for recreation (e.g. amenity, sailing, surfing), are minimised or avoided.	Monitoring in relation to Noise Action Plans shows no adverse effects. See also; seascape indicators and those for other users of the sea, material assets.
Other users of the sea, material assets (infrastructure, and natural resources)		
Balances other United Kingdom resources and activities of economic, safety, security and amenity value including defence, shipping, fishing, aviation, aggregate extraction, dredging, tourism and recreation against the need to develop offshore energy resources.	Plan activities integrate with the range of other existing uses of the marine environment. Plan activities do not result in adverse effects on marine assets and resources.	Spatial planning capable of addressing changes in technology, policy and prioritisation of site selection. Economic and social impact (both positive and negative).

SEA Objectives	Guide Phrases	SEA Indicators
Safety of Navigation.	Plan activities avoid adverse effects on, and contribute to the maintenance of, safe navigation, including recognised shipping routes, traffic separation and existing and proposed port operations.	Increased collision risks and restrictions on pollution prevention methods or Search & Rescue options in the event of an emergency.
Reduces waste.	Properties and quantities of waste and litter resulting from plan activities do not cause harm to the coastal and marine environment.	Progress in reducing volumes of waste to landfill from plan activities.
	Cultural Heritage	
Protects the historic environment and cultural heritage of the United Kingdom, including its setting.	Activities avoid adverse effects on the character, quality and integrity of the historic and/or cultural landscape, including those sites which are designated or registered, and areas of potential importance.	Any impact upon the condition of designated sites and features (including impact on their setting) and all other recorded sites and features.
Contributes to archaeological knowledge.	Plan activities contribute to the archaeological and cultural knowledge of the marine and coastal environment through survey and discovery.	Enhanced knowledge of the potential marine archaeological resource, and number of archaeological finds reported through best practice as a result of plan activities, and their deposit with national curatorial bodies of archaeological studies produced by offshore energy projects.

3.6 SEA Scope

The area of study for this Offshore Energy SEA is shown in Figures 1.3 & 1.4, and the main activities relevant to each aspect of the draft plan/programme, including the potential scale of deployment are outlined in Section 2.6. Those activities can interact with the natural and broader environment in a number of ways.

The main potential sources of environmental effects from activities which could follow adoption of the draft plan/programme are:

- Noise (impulsive, semi-continuous or continuous)
- Physical damage or change to the seabed and subsurface
- Other indirect physical effects on seabed and water column
- Ecological effects of presence of structures
- Interactions with other users of the sea
- Visual intrusion
- Chemical and other inputs
- Atmospheric emissions
- Electromagnetic fields
- Waste disposal onshore
- Decommissioning and legacy issues
- Accidental events

All the major stages of offshore renewable energy, oil and gas, gas storage and carbon dioxide storage development, operation and decommissioning are covered by environmental regulations including the requirement for Environmental Impact Assessment at the development stage (see Appendix 3).

The SEA assessment considered the likely significant effects of the implementation of the plan including short, medium and long-term effects, permanent and temporary effects, positive and negative effects, and secondary, cumulative and synergistic effects on:

- Biodiversity, habitats, flora and fauna
- Geology, substrates and coastal geomorphology
- Landscape/seascape
- Water environment
- Air quality
- Climate and meteorology
- Population and human health

- Other users, material assets (infrastructure, other natural resources)
- Cultural heritage
- Conservation of sites and species

and the interrelationship between the above.

With respect to climate and meteorology, and as stated in the response to the scoping consultation dated November 2021, the SEA will not include an assessment of the environmental effects of the downstream emissions arising from the end use of extracted oil and gas. The draft plan/programme covers the exploration for and production of oil and gas from the UKCS. The Department has considered carefully whether the degree of connection between developments that might come forward pursuant to the draft plan/programme and end use emissions is sufficient to make those emissions a likely significant effect that needs to be included in the SEA. Hydrocarbons are sold to the domestic or worldwide market, and the end uses of these hydrocarbons are various and may be for fossil fuel and non-fossil fuel purposes including following a process of refinement. It is acknowledged that the processes and products associated with these end uses will result in greenhouse gas emissions, but these are likely to be far removed in both time and space from development that might take place pursuant to the draft plan/programme, and the nature, location and extent of such effects are therefore not sufficiently closely causally connected to implementation of the draft plan/programme to be taken into account in the SEA. These do not constitute a likely significant effect of implementing the draft plan/programme itself.

3.7 Assessment methodology

The assessment is presented as evidence based discussion (Section 5) citing peer reviewed and other literature as appropriate together with spatial GIS analysis shown as maps and graphics. The assessment considers the implications of the draft plan/programme for relevant existing environmental problems including those relating to any areas of particular environmental importance, such as areas designated under the *Conservation of Habitats and Species Regulations 2017* and the *Conservation of Offshore Marine Habitats and Species Regulations 2017*. The assessment draws on stakeholder perspectives on key issues relating to the plan/programme obtained through consultation with regulators, local authorities, operators/developers and others. The results of the assessment are summarised for each alternative in a receptor based matrix format (Section 5.17).

3.7.1 Habitats Regulations Assessment

As noted in Section 2.6, activity leasing and licensing are split between a number of authorities, and for the purposes of Habitats Regulations Assessment (HRA), The Crown Estate is the competent authority for further renewables leasing, and the Secretary of State is the competent authority for further seaward oil and gas licensing and carbon dioxide storage at the strategic level.

The Crown Estate undertook HRA for Round 3 leasing in 2009, for a number of extensions to existing wind farms in 2017[74], and are presently preparing a HRA for the Round 4 preferred projects. BEIS have undertaken HRA for successive rounds of oil and gas licensing, with OESEA3 covering those of the 29th to 32nd Rounds. No licensing rounds have taken place for offshore carbon dioxide storage to date. Instead, individual HRAs have been undertaken based on work programmes submitted as part of carbon dioxide storage licence applications. This Environmental Report considers the potential for effects on conservation sites, but at a high level since it has a wide geographical coverage (the UKCS for some activities) and the potential timing, nature and intensity of activities that could be associated with the adoption of the draft plan/programme are not fully defined. Further rounds of seaward oil and gas licensing (which may be subject to periodic climate compatibility checkpoints) would also be subject to strategic HRA, undertaken during the round and in advance of decisions on individual licence. Similarly, should a licensing round for carbon dioxide storage take place in the future, strategic level HRA would be undertaken during the round and in advance of decisions on individual licences. The timetable and nature of any future HRA relating to the renewable leasing component of this plan rests with The Crown Estate.

3.8 Alternatives to the draft plan/programme

SEA Guidance, including on the selection of alternatives (e.g. ODPM 2005, Partidário 2012, EPA 2015), has been considered as part of the assessment process of the draft plan/programme. The SEA Regulations[75] require that the Environmental Report should:

"...identify, describe and evaluate the likely significant effects on the environment of—

(a) implementing the plan or programme; and

(b) reasonable alternatives taking into account the objectives and the geographical scope of the plan or programme"

And:

"...An outline of the reasons for selecting the alternatives dealt with..."

The development of reasonable alternatives is, therefore, made in the wider context of the plan/programme geographical scope, legislative and policy context, including the legal competence of the plan-making authority, which includes the policy context outlined in Section 2.2 (namely enhancing security of energy supply and contributing to meeting the UK's carbon budgets).

The alternatives were initially considered using a modified version of the hierarchy in ODPM (2005):

[74] https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2019-28-gw-of-offshore-wind-extension-projects-to-progress-following-completion-of-plan-level-habitats-regulations-assessment/
[75] Regulation 12(2) and paragraph 8 of Schedule 2 of the *Environmental Assessment of Plans and Programmes Regulations 2004* (as amended)

Need or demand: is it necessary?
Can the need or demand be met without implementing the plan or programme at all?

⬇

Mode or process: how should it be done?
Are there technologies or methods that can meet the need with less environmental damage than 'obvious' or traditional methods?

⬇

Location: where should it go?

⬇

Timing and detailed implementation:
When, in what form and in what sequence should the plan be carried out?
What are the important issues? Do existing controls and measures address them? What other controls and measures are required?

The results of this consideration are summarised below:

Is there a need or demand?

Security of supply is a key objective of energy policy in the UK. This security of supply may come from both domestic renewable energy and oil and gas production, augmented by secure international energy supply agreements. Production of domestic oil and gas has been in decline since 1999, with imports exceeding exports for gas and oil since 2004 and 2005 respectively. Whilst the major offshore hydrocarbon basins of the UK are at a mature stage of production, central estimates for reserves in fields in production or development are 396 million tonnes of oil and 151 billion m^3 of gas. Central estimates for recoverable reserves and marginal discoveries are 765 million tonnes of oil and 483 billion m^3 of gas[76]. Section 9A of the *Petroleum Act 1998* places an obligation on the Oil and Gas Authority to produce a Strategy for achieving the "principal objective" of maximising the economic recovery of UK hydrocarbons. The current OGA Strategy[77] is a statutory document which sets out obligations on "relevant persons", which include the Secretary of State, the OGA, petroleum licence holders, operators appointed under those licences, the owners of upstream petroleum infrastructure, those planning and carrying out the commissioning of upstream petroleum infrastructure and owners of relevant offshore installation. The central obligation of the OGA strategy are that, relevant persons must, in the exercise of their relevant activities, take the steps necessary to:

a. secure that the maximum value of economically recoverable petroleum is recovered from the strata beneath, relevant UK waters; and, in doing so

b. take appropriate steps to assist the Secretary of State in meeting the net zero target, including by reducing as far as reasonable in the circumstances greenhouse gas

[76] Figures are for 2019: https://www.ogauthority.co.uk/news-publications/publications/2020/uk-oil-and-gas-reserves-and-resources-as-at-end-2019/
[77] https://www.ogauthority.co.uk/regulatory-framework/the-oga-strategy/

emissions from sources such as flaring and venting and power generation, and supporting carbon capture and storage projects.

The Strategy, therefore, fulfils its requirements under the Petroleum Act, and recognises the need for activities to contribute to the UK Government's net zero targets.

UK gas storage capacity[78] is presently 1.5 billion m^3, with demand for gas in 2020 being 74 billion m^3. The overarching National Policy Statement for Energy (NPS EN-1) recognises that gas storage infrastructure will be required to contribute to meeting peak gas demand, allowing for sustained delivery of required gas volumes and to provide access to competitive supplies, during the transition to net zero.

The further deployment of offshore wind has the potential to make a substantial contribution to decarbonising the UK's electricity supply, with the Government having set a target of 40GW of installed offshore wind capacity by 2030, with substantially more required thereafter as part of the transition towards net zero. The UK (includes England, Wales and Scotland) presently has ~10.5GW of installed offshore wind capacity, with some 14GW consented but not yet operational, with a further 16GW in planning or pre-planning. Recognising the relative maturity of other marine renewables, the Government has not set capacity targets for these.

The UK Government is taking a "twin track" approach to hydrogen production which includes both "green" hydrogen produced using electrolysis using renewable electricity, and "blue" hydrogen which uses natural gas with CCS, and has set targets of 5GW of low carbon hydrogen production by 2030, and an ambition to capture 20-30MtCO_2 per year by 2030, to which offshore renewables, seaward gas production and offshore CO_2 transport and storage will contribute.

The current decline in domestic hydrocarbon production, the need to enhance security of supply whilst decarbonising the energy mix in keeping with related targets associated with renewables capacity and greenhouse gas emissions reductions, and the statutory obligations placed on the UK authorities and others through *inter alia* the *Petroleum Act* and *Climate Change Act*, clearly indicate a need for further leasing and licensing as outlined in the draft plan/programme (Section 2.6).

Mode or process

Within the context of marine energy production, fixed offshore wind and offshore oil and gas exploration and production and are considered to be the most mature technologies at present which will contribute to the delivery of the objectives of the draft plan/programme. Floating offshore wind has only been deployed at demonstration scale to date but there is an expectation that it will contribute substantially to future capacity, particularly post 2030. Similarly, while full chain CCUS is yet to be demonstrated in the UK, offshore carbon dioxide transport and storage substantially builds on established oil and gas technologies

[78] https://www.ofgem.gov.uk/publications/gb-gas-storage-facilities-2021

and methods, and projects scheduled within the 2020s will contribute to the objectives of the plan/programme. Wave and tidal technologies remain at demonstration scale and are unlikely to see large scale commercial deployment in the waters relevant to this plan/programme for some time.

Location

The presence of exploitable wind, wave and tidal resources and commercial hydrocarbon resources, and hydrocarbon gas and carbon dioxide storage capacity is variously a function of location, geological history and existing sensitivities and uses which dictate the areas of potential interest/feasibility.

A number of marine planning processes have separately taken place in UK waters. Marine planning in the UK has to date not been spatially prescriptive but has defined the range of offshore uses and potential constraints on certain types of development by location, emphasising priorities and promoting activity co-location where appropriate. The policies from the various UK marine plans and the overarching Marine Policy Statement have informed this assessment in this Environmental Report.

The draft plan/programme for future leasing/licensing assessed in this SEA is not a spatial plan, but has been drafted in the context of the potential UK resource and current industry interest, UK policy and legislative context, and a range of potential constraints as outlined in the marine plans, other sources and the analysis undertaken in Section 5.15.

Timing and detailed implementation (see Section 2.5 for an overview of the leasing/ licensing process)

The plan/programme is needed so that:

Further areas of English and Welsh waters can be leased for offshore wind and other marine renewable technologies.

Further areas on the UKCS can be licensed for hydrocarbon exploration and production in currently unlicensed blocks.

Further relevant areas of the EEZ can be leased/licensed for offshore gas storage (including for carbon dioxide).

Hydrogen production in the relevant areas of English and Welsh waters can be enabled.

Early implementation of the plan would allow potential synergies in terms of use of existing infrastructure (e.g. pipelines) to be taken advantage of (e.g. including for reuse for alternative activities such as natural gas or CO_2 transport and storage). The extent of such synergies will decline if the plan is delayed as infrastructure is decommissioned and removed.

The above consideration indicates that the proposed plan/programme has the potential to help deliver a number of UK Government policies and legislative commitments, but that the future location and scale of leasing/licensing is dependent on a number of factors including key resource locations and constraints, and the commercial interest in developing the resources. Three broad alternatives to the draft plan/programme are considered for this SEA and have been subject to scoping. These are:

17. Not to proceed with further licensing and/or leasing

18. To proceed with a leasing and licensing programme

19. To restrict the areas offered for leasing and licensing temporally or spatially

Based on scoping feedback, the first alternative, not to proceed with further licensing and leasing, has been further defined through a set of sub-alternatives listed below:

a. Not to undertake any further seaward oil and gas licensing rounds

b. Not to licence and lease areas of the UKCS for carbon dioxide storage

c. Not to licence and lease areas of the UKCS for hydrocarbon gas storage

d. Not to proceed with further renewables leasing, including rounds for offshore wind or individual leasing for wet renewables

e. Not to proceed with any leasing or licensing requirements needed for offshore hydrogen production, transport and storage offshore[79]

These alternatives are considered reasonable as they reflect the high level nature of the draft plan/programme and its objectives in relation to the national policy context. The draft plan/programme is not spatially specific in defining areas where to develop any particular technology, nor do all aspects have well-defined targets beyond those in UK Government policy. In addition, there are uncertainties about the scale and location of the leasing/licensing that could take place on the adoption of the draft plan/programme. Some of this uncertainty relates to how well-defined key resource areas are, for example geological features suitable for carbon dioxide storage or commercial hydrocarbon accumulations.

The reasonable alternatives to the draft plan/programme are shown in Table 3.2 along with a brief overview of the potential outcome of each. The potential effects of the adoption of these options are considered in Section 5.17.

Table 3.2: Overview of reasonable alternatives

Alternative	Description	High level policy outcome
Not to proceed with further licensing and/or leasing for one or more aspects of the draft plan/programme	Licensing and/or leasing for one or more aspects of the draft plan/programme would not proceed. For example, this could include no further licensing for seaward oil and gas exploration and production, no further leasing	This alternative would not meet all of the objectives of the plan/programme. Its selection would be in conflict with a number of Government policy objectives and obligations, for example, to pursue recovery of domestic hydrocarbons and to decarbonise the UK energy mix.

[79] Note that legislative changes may be required to facilitate hydrogen transport and storage in geological formations

Alternative	Description	High level policy outcome
	for renewables, or no further leasing and licensing for gas storage (including carbon dioxide). The restriction of each element of the draft plan/programme will be considered separately as a series of sub-alternatives.	If aspects of the draft plan/programme were not pursued, this would lead to one or more of the following: greater reliance on hydrocarbon imports, a reduction in security of supply and a reduction in the ability of UK Government to meet its greenhouse gas emissions reduction obligations.
Proceed with further licensing or leasing	Licensing and leasing may continue in relevant UK waters for all aspects of the draft plan/programme. The SEA does not identify definitive spatial or temporal restrictions on leasing or licensing.	This alternative would allow the draft plan/programme to contribute to the achievement of a range of UK Government policy goals and legal requirements on security of supply and energy decarbonisation. The scale of any leasing or licensing round is contingent on the level of commercial interest and so the potential level of activity which could follow the adoption of the plan/programme under this alternative is not certain, (despite this uncertainty, estimates of the potential scale of activity is outlined Section 2.6).
Proceed with further licensing or leasing, but restrict these spatially or temporally	Licensing and leasing may continue in relevant UK waters for all aspects of the draft plan/programme, though it is concluded that some areas may not be suitable to development, for example, where it can be clearly demonstrated at a strategic level that activity could not take place there, or where levels of uncertainty are such that further evidence or research is required to inform assessment.	This alternative is likely to provide a similar outcome as continuing with the leasing/licensing round, though less of the resource area for certain technologies may be available for deployment. There is the possibility that this restriction could result in fewer leases/licences being issued. The scale of effect of such restriction on the objectives of the plan and Government policy on energy decarbonisation and security of supply, is a function of the scale of spatial or temporal restriction, and to what extent it interacts with areas of key resource and interest for commercial development.

4 Overview of Environmental Baseline

4.1 Introduction

The following section and associated appendices provide environmental information as required under Schedule 2 of *The Environmental Assessment of Plans and Programmes Regulations 2004* (Regulation 12(3)).

The environmental baseline for the Offshore Energy SEA 4 is provided in full as Appendix 1. The baseline is described under a series of headings which relate to issues identified by the SEA Regulations on which to judge the "…*likely significant effects on the environment, including short, medium and long-term effects, permanent and temporary effects, positive and negative effects, and secondary, cumulative and synergistic effects*…" These include:

- Biodiversity, habitats, flora and fauna
- Geology, substrates and coastal morphology
- Landscape/seascape
- Water environment
- Air quality
- Climate and meteorology
- Population and human health
- Other users, material assets (infrastructure, other natural resources)
- Cultural heritage
- Conservation of sites and species

and the interrelationships of the above.

The environmental baseline considers all the above headings in a UK context, before providing more detailed information on key features specific to UK Regional Seas, as defined in Section 4.2. Within Section 4.3, summary details are provided for each Regional Sea, with further information and figures available in a series of sub-appendices to Appendix 1 (1a-1j).

Section 4.4, Likely evolution of the baseline highlights, "…*relevant aspects of the current state of the environment and the likely evolution thereof without implementation of the plan or programme*."

Finally, Section 4.5, Relevant existing environmental problems, identifies for each Regional Sea, "*Any existing problems which are relevant to the plan or programme including, in particular those relating to any areas of particular environmental importance, such as areas designated pursuant to Council Directive 2009/147/EC on the conservation of wild birds and the Habitats Directive*."

Throughout Sections 4.2, 4.3 and 4.4, signposts are provided to the locations of further information in the appendices.

4.2 Overview of the environmental baseline

4.2.1 UK Context

Biodiversity, habitats, flora and fauna

The UK has a rich marine biodiversity reflecting both the range of habitats from estuaries, through coastal waters to depths of >2400m, and its position where several biogeographical provinces overlap (see for example Longhurst (1998) and Spalding *et al.* (2007)). Some species and habitats are naturally rare, whilst others are endangered by human activities, and actions to protect and promote biodiversity are being taken at many levels. This section is subdivided into ecological components, with separate descriptions for plankton, benthos, cephalopods, fish & shellfish, turtles, marine birds and marine mammals.

4.2.1.1 Plankton

In broad biogeographical terms, the planktonic flora and fauna of UK waters is part of the North-East Atlantic Shelves Province which extends from Brittany to mid-Norway. In addition, the deeper Faroe-Shetland Channel and areas to the north are within the Atlantic sub-Arctic Province. Each province can be subdivided according to hydrography and plankton composition. The phytoplankton community is largely dominated by diatoms and dinoflagellates, with others, such as the calcifying coccolithiphore *Emiliana huxley*, becoming significant components during their seasonal peak in abundance. Phytoplankton blooms typically take place in spring, with a smaller bloom in late summer. Some phytoplankton blooms may be toxic to marine life. The timing, composition and size of these blooms are dependent on a range of environmental factors with important spatial differences across the UKCS. The zooplankton community is dominated by copepods, particularly *Calanus* species which show a strong geographical divide, with *C. finmarchicus* and *C. helgolandicus* dominating northern and southern waters respectively. Jellyfish, krill and salps are also abundant, as are the larvae of fish, and many benthic animals (meroplankton).

4.2.1.2 Benthos

The composition of the seabed fauna of the UK reflects the intersection of four biogeographical zones:

- Boreal Province including the North and Irish Seas
- Lusitanian-Boreal Province comprising the Celtic Sea and west coasts of Ireland and Scotland
- Arctic Deep-Sea Province, a deep water zone centred on the Norwegian Sea but extending into the Faroe-Shetland and Faroe Bank Channels
- Atlantic Deep-Sea Province, a deep water zone to the west of northeast Europe

Within each Province it is possible to distinguish a series of faunal communities inhabiting specific sediment types and depth ranges. Often these communities extend over wide areas (e.g. the fine sands of the central North Sea and the sandy muds of the Fladen Ground in the northern North Sea) and include both infauna and epifauna. In addition, there are a number of highly localised habitats and communities, including reefs of long lived horse mussels and cold water corals, where high biodiversity is accompanied by high sensitivity to human pressures. Habitat characterisation across the UKCS continues to improve, including through the efforts made in identifying, designating and monitoring MPAs.

4.2.1.3 Cephalopods

Most cephalopods in UK waters are long-finned squids, short-finned squids, bobtail squids, octopuses or cuttlefish. The long-finned squids (including *Loligo forbesii*) tend to have a more coastal and northerly distribution. Short-finned squids are oceanic species and are recorded particularly to the west of the UK. Bobtail squids are abundant in shallow, coastal regions, while octopuses and cuttlefish are more common in southern areas. A number of deep-sea cephalopods are present in the deep waters of the Faroe-Shetland Channel and Rockall Trough.

4.2.1.4 Fish and shellfish

A wide range of biogeographic distribution patterns are shown by the fish in UK waters. The majority of continental shelf species have a north-east Atlantic/northern Atlantic distribution, although a proportion are found globally in the tropics/subtropics and others have a circum-polar pattern of occurrence. Widely distributed species often include local stocks with distinct breeding times and locations (e.g. herring). Widespread pelagic species include herring and mackerel, particularly around the western and northern parts of the UK. Demersal species include gadoids (e.g. cod, whiting) and flatfish (e.g. plaice, dab). Demersal communities tend to be more diverse in southern areas of the UK. Diadromous fish in UK waters include sea trout, Atlantic salmon and European eel, with significant recent declines reported for both salmon and eel. A number of sharks and rays are present in UK waters, including the basking shark for which western coasts appear particularly important. Deep water fish show different distribution patterns with major differences occurring north and south of the Wyville Thomson Ridge (ca. 60°N), and a distinct species group found in the cold waters of the Faroe-Shetland Channel and Norwegian Sea. Widespread commercial shellfish species include crustaceans (e.g. *Nephrops*, brown crab), bivalve molluscs (e.g. scallops, cockles) and gastropod molluscs (e.g. whelks). Many of these species, such as *Nephrops* and scallops, are closely tied to particular seabed sediments and so occupy distinct grounds. Virtually all commercially fished species are heavily exploited although there is some evidence of recovery for some stocks.

4.2.1.5 Turtles

Of the five species recorded in UK waters, the vast majority of records are of the leatherback turtle (*Dermochelys coriacea*) which is the only species considered a regular member of the UK marine fauna. While turtles have been observed along the majority of UK and Irish coasts, records are concentrated on the west and south coasts of Ireland, southwest England, south and northwest Wales, the west coast of Scotland, Orkney and Shetland.

4.2.1.6 Birds

The bird fauna of the UK is western Palaearctic, that is the great majority of species are found widely over western Europe and extend to western Asia and northern Africa. There are 3 regular patterns of species occurrence: resident, summer visitors (to breed) and winter visitors. Some of the summer visitors undertake long migrations to overwinter in southern Africa or South America. The seabird community in the UK comprises a number of gull, auk, tern and skua species, while numerous waders, ducks, and geese make up seasonal and year-round assemblages in coastal wetlands. A few species are found only or predominantly in the UK. For example, the three Pembrokeshire islands of Skomer, Skokholm and Middleholm are estimated to hold some 50%, and the Isle of Rum off western Scotland between a quarter and a third of the world's breeding population of Manx shearwaters.

4.2.1.7 Marine mammals

Many of the species of cetaceans found in UK waters have a worldwide distribution, although a number have restricted ranges, typically temperate to sub-Arctic or Arctic waters of the North Atlantic. British whales and dolphins include resident species as well as migrants (regularly moving through the area to and from feeding and breeding grounds) and vagrants (accidental visitors from the tropics or polar seas). The most abundant cetacean in UK waters is the harbour porpoise. The SCANS-III survey completed in the summer of 2016 (Hammond *et al.* 2017), provided abundance estimates for a wide range of species, including: harbour porpoise, bottlenose dolphin, Risso's dolphin, white-beaked dolphin, white-sided dolphin, common dolphin, striped dolphin, pilot whale, all beaked whale species combined, sperm whale, minke whale and fin whale. Two species of seal breed in the UK; the grey seal has a North Atlantic distribution with the UK holding over 40% of the world population; and the harbour seal, found along temperate, sub-Arctic and Arctic coasts of the northern hemisphere, with the UK population representing over 5% of the global total. Otters inhabit a variety of aquatic habitats, with some populations feeding in shallow, inshore marine areas. The most important otter populations utilising coastal habitats occur in western Scotland, Shetland, west Wales and the Wash and north Norfolk coast. Small numbers of the Nathusius' pipistrelle bat occur seasonally over UK waters on migrations between the UK and mainland Europe.

Geology substrates and coastal processes

The distribution of geological strata in the UKCS is determined by past geological and geomorphological processes. The distribution of sediments and certain topographic features is a function of the underlying geology, and millennia of aeolian, fluvial and glacial activity both in the marine and terrestrial environment. The distribution of sediments and deep geological structure of the UKCS, and the North Sea in particular, is quite well known, particularly in areas of mature oil and gas production which have been extensively explored since the 1960s. Oil and gas reserves are dependent on viable source rocks and a suitable impermeable cap-rock, and these reservoirs are responsible for the distribution of much offshore activity. Certain topographic features are notable, primarily for the quality of habitat they provide, and these are bound by geology (e.g. Haig Fras) or sediment type (e.g. north Norfolk sandbanks). There are over 100 estuaries in England and Wales of relevance to the draft plan, which can be divided into a number of broad geomorphological types. Potential areas which may be suitable for gas storage and CCS include hydrocarbon reservoirs, halite deposits and saline aquifers.

Existing levels of contamination in the UK marine environment vary considerably on both regional and local scales, and in general have declined appreciably in recent decades. The majority of marine pollution comes from land-based activities; most pollutants enter the UK marine environment through direct discharges of effluents, land run-off (mainly via rivers) or indirectly via the atmosphere. The highest concentrations of contaminants, and hence the greatest effects, are therefore often in inshore areas. Water samples with the highest levels of chemical contamination are found at inshore estuary and coastal sites subject to high industrial usage. In offshore waters, contaminant levels (chiefly hydrocarbons) in water and sediments are generally expected to be at or near background concentrations. Levels are expected to be higher at close proximity to oil and gas infrastructure, with concentrations decreasing with increasing distance from the source.

Landscape/seascape

Seascape is defined by the European Landscape Convention (ELC) as "an area perceived by people, whose character is the result of the action and interaction of natural and/or human factors", and can be separated into areas of sea, land and intervening coastline, and more recently in the MPS as, "landscapes with views of the coast or seas, and coasts and the adjacent marine environment with cultural, historical and archaeological links with each other." The study of seascape is not only concerned with the physical character of a given view but the interaction of that view with individuals and how changes can affect overall visual amenity. Seascapes and coastal environments (including the sea itself) are extensively used for recreation which generates significant tourist income from which many coastal communities are dependent, and this can strongly conflict with commercial and industrial activity (Hill *et al.* 2001). The 'value' of many of the UK's seascapes is reflected in the range of designations which relate in whole or in part to the scenic character of a particular area (e.g. AONB, Heritage Coast, National Scenic Area), however the ELC and MPS (and most recently seascape assessments covering the English Marine Plan regions) define landscape and how they are to be considered in more general terms, acknowledging the value of all landscapes whether or not they are subject to designation.

Water environment

The UK marine water environment is highly varied, ranging from entirely oceanic conditions to the north and west of the UK to complex estuarine systems widely distributed around the coast. It is also a dynamic environment, with a complex system of currents and varied oceanographic conditions including areas of considerable frontal activity and high-energy wave and tidal environments. The OESEA4 baseline will describe key information sources and monitoring programmes, as well as the characteristics of the UK water environment with respect to water masses and circulation, stratification and frontal zones, coastal tidal flows, temperature, salinity and wave climate.

Air quality

Whilst air quality is not monitored routinely offshore, regular air quality monitoring is carried out by local authorities in coastal areas adjacent to each Regional Sea and by the OSPAR Comprehensive Atmospheric Monitoring Programme (CAMP) network. The air quality of all local authorities is generally within national standards set by the UK government's air quality strategy though a number of Air Quality Management Areas (AQMAs) have been declared to deal with problem areas, primarily related to road transport. Industrialisation of the coast and certain inshore areas has led to increased levels of pollutants in these locations which decrease further offshore, though oil and gas platforms provide numerous fixed point sources of atmospheric emissions. Shipping emissions represent a significant source of pollutants with emission control areas in operation (sulphur oxide) or approved (nitrogen oxide) in the North Sea.

Climate and meteorology

The UK lies within temperate latitudes and the climate is generally mild. Numerous easterly moving depressions meet the UK in the west leading to a gradient of relatively high wind speeds and precipitation in the exposed west and relatively low wind speeds and precipitation in the sheltered south and east. The upland nature of much of the west coast also contributes to this west-east gradient, with topography-induced enhanced precipitation, particularly in the north-west. The UK has a strong maritime influence, which has the effect of reducing the diurnal and annual temperature ranges; such effects are most notable at the coast and on islands (e.g. Orkney, Shetland). The North Atlantic Oscillation (NAO) has also been linked with variations in UK sea surface temperatures, wind strength, direction and rainfall. Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. There is a high degree of confidence that global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate (IPCC 2018). Related changes include increase in sea-level, possibly more changeable and extreme weather, and alteration to metocean conditions (also covered in relevant topic areas elsewhere).

Population and human health

The total mid-2019 UK population is estimated to have been 66.8 million people[80]. Population density was highest in England at 432 persons per km2, comparably lower in Wales and Northern Ireland at 152 and 137 persons per km2 respectively, and the lowest by a considerable margin in Scotland at 70 persons per km2. In coastal areas, there are lower densities around much of the southwest of England, west and north Wales, the far north of England, and much of Scotland excluding the central belt. The highest coastal densities are around much of southeast England, part of northeast England, the Firths of Forth and Clyde, part of northwest England, south Wales and around the Severn Estuary. These areas are typically where conurbations are largest and most numerous, although more isolated areas of higher densities are dotted around much of the coast. Higher densities are also observed in several coastal areas of Northern Ireland.

Life expectancy at birth in the UK in 2017 to 2019 was 79.4 years for males and 83.1 years for females. England had the highest life expectancy at birth of 79.7 for males and 83.3 for females, Wales and Northern Ireland were similar at 78.5 and 78.7 for males and 82.3 and 82.6 for females, with Scotland having the lowest life expectancy at birth of 77.1 for males and 81.1 for females[81].

Other users, material assets (infrastructure, other natural resources)

UK waters are subject to a multitude of uses – particularly in coastal areas. The range and importance of existing and potential uses of the sea will be fully described in an appendix to the Environmental Report. This will use accurate and recent information on other current and likely uses of the sea in the foreseeable future, using input from marine spatial plans where these have been completed.

The UK is heavily reliant on shipping for the import and export of goods and will remain so for the foreseeable future. Over 95% of the goods entering or leaving the UK are transported by ship, with substantial numbers of vessels also transiting UK waters *en route* to European and more distant ports. In recognition of the vessel traffic densities and topographic constraints on various routes, the IMO has established a number of traffic separation schemes and other vessel routeing measures to reduce risks of ship collision and groundings. In addition, IMO regulations required that from 2005, an Automatic Identification System (AIS) transponder be fitted aboard all ships of >300 gross tonnage engaged on international voyages, all cargo ships of >500 gross tonnage and all passenger ships irrespective of size. AIS data allow precise tracking of individual vessels and provide accurate information on important areas for larger vessel navigation. From 2012, fishing vessels over a certain size (initially >24m, but >15m since 2014) have also been required to have an AIS installed.

Fishing in the UK has a long history and is of major economic and cultural importance. In 2018, there were 11,961 working fishermen in the UK (of which 80% were full time), operating 6,036 vessels (MMO 2020a). These vessels, while fishing in UK and non-UK waters, landed 698,000 tonnes of sea fish and shellfish in 2018 (426,000 tonnes into UK ports), with a total

[80] https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates

[81] https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/lifeexpectancies/bulletins/nationallifetablesunitedkingdom/2017to2019#life-expectancy-at-birth-in-uk-countries

value of £989 million (£727 million into UK ports) (MMO 2020). The livelihoods of individual fishermen depend on their ability to exploit traditional fishing grounds and to adapt to changing circumstances to maximise profit. Consequently, they are vulnerable to competition within the UK industry and with foreign vessels, and to being displaced from primary grounds. Various sources of information on fishing effort show that while the majority of UK waters are fished to some extent, certain areas receive considerably more effort than others. In general, the greatest density of fishing effort takes place in coastal waters, for both static (such as pots, traps or gillnets) and mobile (such as trawls and dredges) gears. Further offshore, the density of effort was greatest to the northeast of Scotland (particularly the Fladen Ground), around the Northern Isles and to the southwest of the UK.

Military use of the coasts and seas of the UK is extensive, with all three Services having defined Practice and Exercise Areas, some of which are danger areas where live firing and testing may occur. Additionally, several military radars – Air Surveillance and Control Systems (ASACS) – are present around the coasts of the UK. Tourism and recreational use of UK coasts and coastal waters is of major importance in many areas. Major recreational uses of the sea beyond beaches and coastal paths include yachting (for which the Royal Yachting Association has published charts of cruising and racing routes), surfing and sea angling. Taking indirect effects into account, the total estimated economic impact of sea angling in the UK in 2017 was estimated to be £1.94 billion and supporting c. 16,300 jobs (Hyder *et al*. 2020). Many visitors to the coast cite unspoilt and beautiful natural scenery as the important factors influencing their selection of location to visit. The importance of such attributes are widely recognised and protected through designations such as National Parks, AONBs and National Scenic Areas.

Various areas of sea are used or licensed/leased for marine aggregate extraction, telecommunications and other cables, disposal of capital and other dredging wastes, offshore wind farms and other marine renewables, surface and subsea oil and gas production, hydrocarbon gas storage and export infrastructure, and carbon dioxide storage. Potential future uses/enhanced use of the sea and seabed includes carbon dioxide storage in geological formations, wave, tidal and hydrogen projects, and subsea cables forming connections as part of an offshore grid. Projects in these areas are either in the demonstration phase or in early planning, but are expected to be commercially proven or be in planning in the coming years.

Cultural heritage

The collective inventory and knowledge of maritime sites in particular is quite poor and may be subject to recording biases. Archaeology associated with human and/or proto-human activities either on the current seafloor of the southern North Sea, in the coastal zone of the British Isles and further inland, has the potential to date back at least as far as 500,000 years BP. Relatively recent finds of flint artefacts from the Cromer Forest-bed Formation, Suffolk date to as early as 700,000 years.

The current understanding of marine prehistoric archaeology is based on knowledge of the palaeolandscapes of the continental shelf between the UK and Europe during glacial phases and limited finds of archaeological materials, augmented with knowledge of analogous cultural and archaeological contexts from modern day terrestrial locations. The record for wreck sites is biased towards those from the post-Medieval and later periods, presumably a function of greater traffic and increased reporting associated with the introduction of marine insurance and the Lloyds of London list of shipping casualties in 1741. The strategic military importance of the sea, the importance of the North Sea as a fishing area, the importance of maritime trade routes and the treacherous nature of many near-shore waters, has led to a large number of ship and aircraft wrecks in UK waters.

A number of coastal sites have been designated as cultural World Heritage Sites for example St Kilda, the Cornwall and West Devon Mining Landscape and the Heart of Neolithic Orkney.

Conservation of sites and species

Designated conservation sites are widespread and abundant around the UK coast; a variety of levels of designations exist from statutory international to voluntary local, affording various levels of protection to habitats, species, and geological, cultural and landscape features. Some of the most widespread designations include Special Areas of Conservation and Special Protection Areas which cover a range of terrestrial and marine habitats and species, and Sites/Areas of Special Scientific Interest (SSSIs/ASSIs), which are largely terrestrial but which may contain coastal or intertidal components. The *Marine and Coastal Access Act 2009* required the identification and designation of Marine Conservation Zones (Marine Protected Areas in Scotland) and the current network of sites is the result of several designation phases. Detailed listing and descriptions of conservation sites, species and nature conservation measures will be provided as an appendix OESEA4.

4.3 Summary of UK Regional Seas

The previous Offshore Energy SEAs (OESEA and OESEA2) used the draft Regional Sea boundaries defined by JNCC (2004) as a means of considering the broad scale biogeographical regions within UK waters. Following a review of these and other boundaries during scoping for OESEA3, a modified version of the Charting Progress 2 boundaries were used (Figure 4.1) to distinguish several important areas including: the Atlantic South West Approaches (Regional Sea 5), and the Faroe-Shetland Channel (Regional Sea 9), Rockall Trough and Bank (Regional Sea 10), and Atlantic North West Approaches (Regional Sea 11). It is considered that the basis for these Regional Seas has not altered in the period since the publication of OESEA3.

The text below describes the broad physical features of each Regional Sea, including the features upon which their boundaries are based. Detailed information on key features of each of the Regional Seas will be provided by the various sub-appendices of the Environmental Report.

4.3.1 Regional Sea 1

The northern North Sea is bounded by the Flamborough front to the south, marking the transition from the shallow mixed waters of the southern North Sea to the deeper waters (50-200m) in the north which stratify thermally in summer along with a transition from sands to muddier sediments. Waters are generally of coastal origin but with a strong influx of Atlantic water in the north; turbidity is moderate. The northern boundary marks the transition from water dominated by the continental shelf current to the North Sea waters of mixed origin.

Regional Sea 1 supports an increasing diversity of cetacean species from south-north, high densities of seals (particularly around the Northern Isles), and an important population of bottlenose dolphins along the Scottish east coast. The adjacent coastline represents an important migratory pathway for many Arctic-breeding species, while the widespread and often remote cliff habitats support vast numbers of breeding seabirds; seabird densities at sea are relatively high over much of the area. The deeper waters over the mud and muddy sand of the

Fladen Ground support an abundance of fish and *Nephrops*, yielding one of the most valuable fishing grounds in UK waters; additionally, inshore waters are heavily fished throughout the area. Regional Sea 1 supports a high number of coastal and offshore designations encompassing SAC, SPA,MPA and MCZ sites.

Oil and gas development is extensive, particularly in the east, and renewables activity is centred on the territorial and offshore waters of the Moray Firth and the Firth of Forth. The Meygen tidal power development in the Pentland Firth represents the first commercial scale tidal stream array in the world and there are a number of tidal and wave lease areas granted in the territorial waters around Orkney and Shetland.

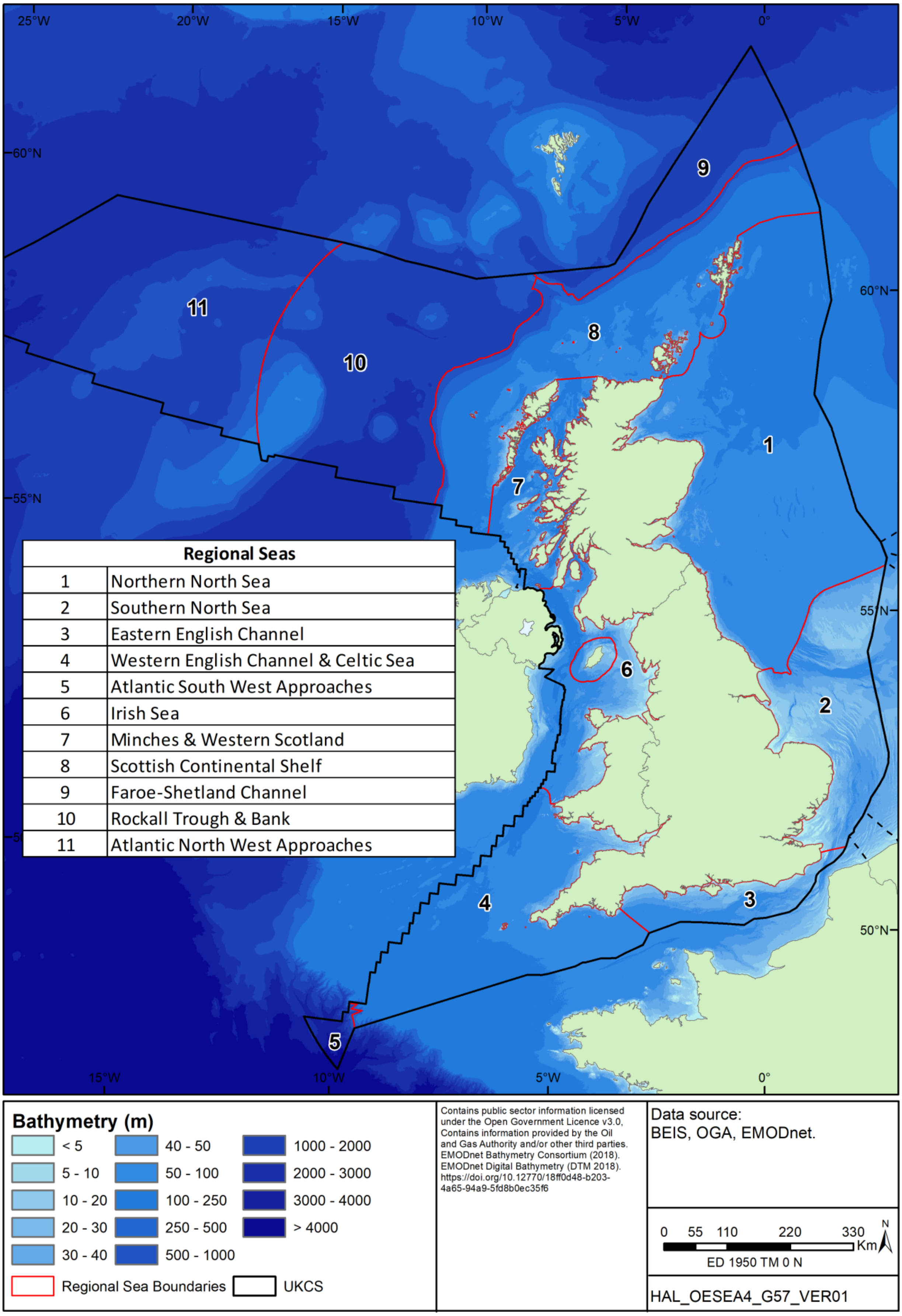
4.3.2 Regional Sea 2

The southern North Sea extends from the Flamborough front in the north to north of the Dover Straits in the south, with a transition from North Sea water to Atlantic water. This region is shallow (generally 0-50m), with a predominantly sandy seabed, and mixed water experiencing large seasonal temperature variations. The influences of coastal water are particularly marked in this region, the water is turbid, and it exhibits a characteristic plankton composition.

Much of Regional Sea 2 is less than 50m water depth, with many extensive sandbank features present at less than 25m depth; these include areas which have been designated under the Habitats Directive such as Dogger Bank SAC, the North Norfolk Sandbanks and Saturn Reef SAC, the Inner Dowsing, Race Bank and North Ridge SAC and the Haisborough, Hammond and Winterton SAC. Further seabed features have been designated as Marine Conservation Zones. The western flank of the Dogger Bank also supports high densities of seabirds, with notable colonies on the east coast located at Flamborough Head including for kittiwake, gannet, guillemot, razorbill and fulmar. Harbour porpoise are widely distributed throughout much of the area with the Southern North Sea SAC including key winter and summer habitat for the species. Large (but declining) numbers of harbour seals breed on the coast adjacent to the Wash; these animals forage widely in adjacent waters. Similarly, grey seals are present in increasing numbers throughout the area with a notable haulout and breeding site located at Donna Nook on the entrance to the Humber Estuary SAC.

The region experiences high densities of shipping activity, particularly in the south, and major shipping lanes run approximately parallel to the entire length of the coast. Fishing effort is moderate overall, with vessels generally avoiding the shallowest of sandbank areas, although inshore effort is fairly high in the south with international effort high in the southeast. Many dredging licence and application areas are present in the region. Gas development is extensive south of the Dogger Bank to approximately 53°N, and both decommissioning and recent new development is progressing in the area. A number of existing, under construction and planned offshore wind farms are present in the greater Wash and Thames, the Dogger Bank and off Holderness (Hornsea area) and East Anglia. Regional Sea 2 is the most prospective area for carbon dioxide storage due to its underlying geology, and an Agreement for Lease and the first Carbon Dioxide Appraisal and Storage Licence located to the east of the Yorkshire coast, with another off Lincolnshire over the former Viking and Victor gas fields.

Figure 4.1: Regional Sea subdivisions to be used in OESEA4



4.3.3 Regional Sea 3

The eastern English Channel is bounded by the Dover Straits to the east and extends to the west to a line drawn between Start Point and Cherbourg on the north coast of France. Depths are generally shallow and rarely exceed 60m. There are isolated deeps of 80-100m (e.g. the Northern Palaeovalley) and shallower deeps (60-70m) such as St Catherine's Deep to the south of the Isle of Wight. Waters are mixed, with strong tidal current velocities in the central channel which decrease to the west and east. The seabed is variable; a general transition can be observed from coarser sediments in the west to sand in the east, although localised rock outcrops occur throughout the English Channel basin. Water temperatures vary considerably with season. The western boundary denotes a transition in benthic fauna from the eastern English Channel (Boreal fauna) to a different community in the western English Channel (Lusitanean fauna).

Regional Sea 3 contains a range of coastal SPA sites (e.g. Chesil Beach & The Fleet, Chichester & Langstone Harbours, Pagham Harbour, Solent & Dorset Coast). Additionally SACs include those with marine components (South Wight Maritime) or entirely offshore sites (Wight-Barfleur Reef SAC), augmented by a large number of MCZs.

The majority of Regional Sea 3 receives high to very high densities of shipping traffic, and has a water depth of less than 60m. The coastline is one of the most densely populated in the UK, and adjacent waters are used by a great number of recreational vessels. Additionally, very high levels of fishing activity occur, particularly in inshore waters, with high levels of effort by non-UK vessels also observed in this area. Many dredging licence and application areas are present in the region and the Rampion offshore wind farm development was completed in 2018 with a potential extension planned.

4.3.4 Regional Sea 4 and 5

The western English Channel and Celtic Sea is a large region west of a line drawn between Start Point and Cherbourg and extending to approximately the 500m depth contour on the continental slope in the west. It is bounded to the northeast by the Celtic Sea front, marking the transition from oceanic water to the coastally influenced waters of the Irish Sea. Depth in the region varies from 50-200m with a general trend of increasing depth towards the west. The seabed is largely composed of sand and gravels with isolated rocky outcrops. The waters are generally subject to seasonal stratification, although mixing and seasonal temperature variation is greater in the east. The southern boundary is marked by a transition to warmer water and a community containing a greater number of Lusitanean species. The region is heavily influenced by Atlantic water, with reduced coastal influences; turbidity is moderate.

The Atlantic south west Approaches (formerly considered as a separate Regional Sea in OESEA and OESEA2), is a region bounded to the east by the shelf break and extends westwards into the northeast Atlantic. As only a very small proportion of this region lies within UK waters, it is therefore grouped with the adjacent Regional Sea 4. The seabed is generally composed of fine material. The water is oceanic in origin, with negligible coastal influences, low turbidity and is stratified. While comparable to the other deep water Regional Seas, influences from the Mediterranean current are stronger in this region leading to Lusitanean species being present in the water column. The area is intersected by submarine canyons, characterised by the upwelling of nutrient-rich deep waters and with cold-water corals present.

A large area with a water depth less than 60m extends west from the Bristol Channel to approximately 5°W, and also to some distance off the coast of north Cornwall. Surveys have observed seasonally high densities of seabirds in coastal waters around southwest England, while densities are also seasonally high in the north of the area around southwest Wales. The Celtic Sea is an important area for cetaceans, particularly common dolphins which may be seasonally present in large numbers. A large proportion of UK's leatherback turtle sightings occur in this region. In offshore waters west of Land's End lies Haig Fras – an area of rocky reef designated as a SAC. Additional SAC sites containing reef features are located in inshore waters including Start Point to Plymouth Sound and Eddystone SAC, Lizard Point SAC and Lands End and Cape Bank SAC. More recently, Marine Conservation Zones have been designated for features including high to moderate energy circalittoral, infralittoral or intertidal rock, and coarse sediments (Skerries Bank and Surrounds MCZ, Padstow Bay MCZ, East of Haig Fras MCZ). Two designated sites are located in the south west Approaches, including The Canyons MCZ (deep sea bed, cold water coral reefs, coral gardens, sea-pen and burrowing megafauna communities) and the South-West Deeps (West, subtidal coarse sediment, subtidal sand, subtidal mixed sediments, Celtic Sea relict sandbanks, subtidal mud and fan mussel), with the South-West Deeps (East, Celtic Sea relict sandbanks, deep-sea bed, subtidal coarse sediment and subtidal sand features) site yet to be submitted.

The inshore waters off the southwest coast of England receive some of the highest levels of fishing effort in UK waters. Fishing effort is also high across the majority of Regional Sea 4, while this area is also of considerable importance to recreational craft and commercial shipping. Several dredging licence and application areas are present in the inner Bristol Channel and off the south Wales coast. To date offshore energy activity has been limited, with no commercial hydrocarbon discoveries and proposals for marine renewables being at demonstrator scale. There have been a number of proposals for tidal lagoon developments in the Severn (Swansea Bay, Cardiff and Newport) but the planning permission for the Swansea Bay tidal lagoon has recently expired.

The South West Approaches has a low prospectivity for early Mesolithic or Palaeolithic finds relative to other areas of Regional Sea 4 such as the Severn (e.g. Fitch & Gaffney 2011), however it does contain numerous losses associated with World War I and II are automatically considered as underwater cultural heritage, in line with the principles of the 2001 Convention on the Protection of the Underwater Cultural Heritage.

4.3.5 Regional Sea 6

The Irish Sea is bounded to the south approximately by the Celtic Sea front, and extends north to a line from the Mull of Kintyre, Scotland, to Fair Head, Northern Ireland, and includes the North Channel. Movements of species suggest the North Channel to represent an area of gradual transition rather than sharp change. The seabed is variable in nature, although dominated by glacigenic deposits re-worked by tidal currents. Waters are strongly influenced by coastal processes and turbid with influxes of water from the Celtic Sea and north from the continental shelf current. Stratification occurs in deeper waters but not in the coastal margin or in the north east of the area.

UK waters within the Irish Sea are generally shallow, with the majority of the area less than 60m depth from the coast west to approximately 5°W. Seabird densities are seasonally high in the west, particularly in the far north and south Irish Sea. Concentrations of Manx shearwaters occur in the Irish Sea (e.g. Irish Sea SPA), with colonies on islands off Pembrokeshire (e.g. Skomer Skokholm and the Seas off Pembrokeshire SPA) and in the Inner Hebrides representing the majority of the world breeding population of this species. Other SPAs include Anglesey, Liverpool Bay, the Dee Estuary and Morecambe Bay and Duddon Estuary, which are important for breeding terns and overwintering species including red-throated diver, common scoter, little gull and wider internationally important wintering waterbird assemblages. Bottlenose dolphins occur off the west and north Welsh coast, with sightings focussed in

Cardigan Bay where the species is the primary reason for designation of the Cardigan Bay SAC and one of the qualifying features of the Lleyn Peninsula and the Sarnau SAC. Shell Flat and Lune Deep SAC is located in inshore waters near Morecambe Bay, and the territorial waters of Northern Ireland contain The Maidens SAC (reefs, sandbanks and grey seal) and Red Bay SCI (sandbanks). There are a number of designated MCZs located in Liverpool Bay including Fylde MCZ (subtidal sand and mud) and West of Walney MCZ (subtidal sand and mud, sea-pen and burrowing mega-fauna communities), as well as a number of MCZ just outside the territorial waters of the Isle of Man (West of Copeland; subtidal sediments, Queenie Corner; subtidal mud, sea-pen & burrowing megafauna communities and South Rigg; moderate energy circalittoral rock, subtidal mixed and coarse sediments, mud and sand, sea-pen & burrowing megafauna communities). In offshore waters, the Croker Carbonate Slabs SAC and Pisces Reef Complex SAC are designated for Annex I submarine structures made by leaking gases and reefs respectively.

High densities of shipping are experienced in the central St. George's Channel, off north Wales leading to the Mersey, and in the North Channel. High levels of fishing effort occur in the north, particularly to the west of the Isle of Man and off the Cumbria coast. Considerable gas infrastructure is present in the eastern Irish Sea associated with producing gas fields (and hence potential future CO_2 storage) and there are a limited number of producing oilfields. There are also a number of existing and planned offshore wind farms.

4.3.6 Regional Sea 7

The Minches and west Scotland is bounded to the south by a line from the Mull of Kintyre to Fair Head, to the west by the Malin front, and to the north by a line from the Butt of Lewis to Cape Wrath. The region encompasses waters which are largely sheltered from Atlantic swells by Northern Ireland and the Outer Hebrides. The seabed is characterised by muddy sand and mud, although more gravel is present in the south of the region. The waters in the region largely comprise North Atlantic water as part of the continental shelf current but are modified by coastal influences. The majority of the waters in the region stratify in the summer months, and turbidity is moderate-low.

Regional Sea 7 is characterised by relatively deep waters considering its coastal nature. The complex, undulating coastline with many islands is predominantly rural with very low population density and remote from large conurbations. The region is of high environmental sensitivity for a range of features. A high diversity and abundance of marine mammals and seabirds are present, along with many coastal otter populations. This area supports some of the highest densities of harbour seals in UK waters. Fishing effort is very high throughout much of the area, and is dominated by small, inshore vessels. Cold water corals occur in the area, and other reef features are present in many of the sheltered sea lochs. These lochs also support extensive mariculture activities.

A very large number of designated conservation sites are present along the adjacent coast, including numerous habitat, species and landscape designations, as well as the East Mingulay SAC. Additionally, numerous MPAs have been designated, which include the Small Isles and Wester Ross – both have been selected on the basis of supporting a range of habitat and species features, with the former containing the only known aggregation of fan mussels in UK waters, and also marine geodiversity features. Three other significant MPA proposals are located in Regional Sea 7; these are, the Sea of the Hebrides, North-East Lewis and Shiant East Bank. Proposed site features range from seabed habitats and fauna (including fan mussel aggregations, basking shark, sandeel and marine mammals including minke whale and Risso's dolphin). Each site is also proposed for marine geodiversity features.

4.3.7 Regional Sea 8

The Scottish continental shelf runs along the continental shelf to the north and northwest of the UK. It is bounded to the west, south of the Wyville Thomson Ridge, by the 1,000m depth contour - reflecting the changes in community composition which has been observed in various studies on shelf slope fauna. To the north of the Wyville Thomson Ridge (also a designated SAC), the boundary lies along the 600m contour where the influence of cold Norwegian Sea/Arctic Intermediate water commences. The entire continental shelf is dominated by the warm (>8ºC) North Atlantic waters of the continental shelf current until the Orkney and Shetland Isles. The boundary to the east reflects the division between Lusitanean and Boreal fauna in the channel between the Orkney and Shetland Islands, with Lusitanean fauna occurring in the Orkney Islands but not in the Shetland Islands. The seabed is characterised by sand and coarse sediment of glacigenic origin re-worked by tidal processes, and in deeper areas close to the shelf break sediments have been formed into iceberg ploughmarks – a complex matrix habitat of stony ridges and sandy troughs. Water in this region is subject to seasonal stratification, has low turbidity and there is a low level of material of terrestrial origin entering the sea.

Regional Sea 8 covers a large area and range of water depths, although waters shallower than 60m are generally restricted to those immediately west of the Outer Hebrides. The region supports a rich diversity and abundance of marine mammals, with all typical UK shelf species present in addition to many oceanic, deeper water species along the shelf edge to the north and west. Large numbers of grey seals breed on the several small remote islands present, including those around Orkney and Shetland. Seabird densities are high throughout coastal waters and to a considerable distance offshore. Of particular environmental sensitivity is the St. Kilda archipelago. Lying 66km west of the Outer Hebrides, these islands support very large populations of breeding seabirds and receive numerous conservation designations, including dual World Heritage status for both its natural and cultural significance, and SPA designation for the islands and surrounding waters. Large numbers of breeding seabirds also occur on the adjacent coast of the Outer Hebrides, north mainland and Northern Isles. The region includes two sites designated for reef features (Stanton Banks SAC and Solan Bank Reef SAC), and more recently MPA sites including the West Shetland Shelf, North-west Orkney and part of the Faroe-Shetland Sponge Belt.

Shipping density is particularly high along the north mainland and through the Pentland Firth, while fishing effort is moderately high throughout the majority of the region. A limited amount of oil and gas activity occurs to the west of Shetland. Population density along the adjacent coast is the lowest in the UK.

4.3.8 Regional Sea 9

The Faroe-Shetland Channel is characterised by the influx of dense cold water from the Arctic and Norwegian Sea into the channel at depths below 600m. The western boundary of the region is the Wyville Thomson Ridge which prevents the majority of the flow of cold water from entering the Rockall Trough, which instead exits to the northwest via the Faroe Bank Channel. The seabed of the channel is mainly composed of silt and clay at the base with more sand and some areas of gravel and cobbles/boulders on the flanks of the continental slope, particularly in areas sculpted in the past by icebergs; glacial dropstones occur throughout the area. Water temperatures vary considerably through the water column, from approximately 0°C at the seabed but above 600m depth, where North Atlantic water flows, between 6.5-8°C. Both main water masses in the region are oceanic in origin and turbidity is typically low but there are periods with elevated turbidly in near slope areas. The cold waters at depth result in a different characteristic benthic community to that found at shallower depths in adjacent areas or in the Rockall Trough.

Regional Sea 9 supports a diverse and abundant cetacean community, including many poorly understood oceanic and deep-diving species such as sperm whales, beaked whales and large baleen whales. Evidence suggests that this area represents a migratory route for a number of cetacean species. Along the southwest boundary of the area lies the Wyville Thomson Ridge SAC, a large area of full salinity stony and bedrock reef. The area also includes part of the Faroe-Shetland Sponge Belt MPA, and the North-East Faroe-Shetland Channel MPA. Amongst other features, both are designated for deep sea sponge aggregations and offshore subtidal sands, and contain representative marine geomorphological features.

A number of UKCS Blocks are presently licensed in Regional Sea 9, which has been subject to historical licensing covering most of the area. No fields have been developed to date in Regional Sea 9, however, a number of discovery fields are present.

4.3.9 Regional Sea 10 & 11

Regional Seas 10 and 11 cover the Rockall Trough and Bank and Atlantic North West Approaches. These are deep-sea regions west of the Scottish continental shelf, bound to the east by the 1,000m depth contour and to the west by the western extent of the UKCS. The seabed supports a different faunal community to that observed at depths less than 1,000m, and is mainly composed of muddy sand and mud, with clay mud present in the deep waters to the west. In shallower water, on Rockall Bank and the seamounts, the fauna is likely to be similar to those found at the western edge of the Scottish continental shelf. The waters of these regions are totally oceanic in origin with negligible inputs of material of a terrestrial origin and little seasonal change in primary productivity. Turbidity is very low. Waters are cooler in the Atlantic North West Approaches due to an influx of south flowing Arctic water.

Compared to UK shelf waters, information on the natural environmental of Regional Seas 10 and 11, particularly the Atlantic North West Approaches, is sparse. Known key features include a diversity and abundance of cetaceans, including several large baleen whales species and deep diving species. Evidence suggests that this area represents a migratory route for a number of cetacean species. Several seamounts are present which are known to contain extensive reef habitat, including cold-water corals. In the far northeast of the region lies the Wyville Thomson Ridge SAC, and the Darwin Mounds SAC. In the far west of Regional Sea 10 lies the North West Rockall Bank SAC. Moderate levels of fishing effort by UK vessels occur over topographical rises in the area, such as the Anton Dohrn seamount and Rockall Bank; these features are also fished extensively by non-UK vessels.

Relatively little oil and gas licensing has taken place in Regional Sea 10; the most recent licensing in the area was in the 28th Round (2014), however, these licences have now been relinquished.

4.4 Relevant Existing Environmental Problems

The SEA Regulations requires consideration of any existing environmental problems which are relevant to the plan or programme including, in particular, those relating to any areas of environmental importance, such as areas designated under the Habitats Regulations. More recently, the principal problems in UK waters have been reviewed and considered in relation to MSFD descriptors of GES, and set against relevant targets and monitoring programmes with a view to meeting the requirements of the MSFD[82]. These inputs have been reviewed and are considered here in relation to their implications for this SEA. In addition to these, a number of other potential problems of relevance to the SEA not specifically related to conservation of environmental protection are considered, for instance in relation to material assets and cultural heritage. No judgement of importance should be inferred from the position of problems/issues in the section.

4.4.1 Eutrophication

The majority of UK waters do not experience significant eutrophication – the eutrophication problems are restricted to a small number of areas in coastal waters, primarily estuaries and embayments with restricted water circulation. In a limited number of areas on the north east and southern coasts of the UK and on the south-west coasts of England and Wales and in Northern Ireland, inputs of nutrients of anthropogenic origin (notably nitrate and phosphate from agriculture and urban waste water sources) have resulted in nutrient enrichment in some small estuaries and bays. In general, changes in nitrogen and phosphorus inputs, concentrations of contaminants, chlorophyll concentrations and oxygen levels show improvements. Where measures have been taken to reduce nutrient inputs, it may take a long time to result in the desired outcome due to time lags between taking measures and change in the large reservoirs of nitrogen that have built up in soils and ground-waters in previous decades. However the existing programmes for assessing the eutrophication status for coastal and marine waters developed under the WFD and the OSPAR Convention have to a large extent already been applied successfully with the UK largely achieving GES in the most recent (2018) assessment[83].

4.4.1.1 Implications for SEA

The SEA must consider the potential implications of the draft plan/programme on attaining good environmental status of both marine and coastal/estuarine waters. One of the descriptors for determining GES under the MSFD (Descriptor 5) is that human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters. Whilst plan level activities may not directly contribute to or generate eutrophication, any effects which could lead to cumulative effects should be considered.

4.4.2 Hazardous Substances

The UK has largely achieved its aim of GES for contaminants. The updated assessment of achieving GES with respect to descriptor 8 (Defra 2019b) indicates that concentrations of hazardous substances in the Celtic Seas and the Greater North Sea and their biological effects are generally meeting agreed target thresholds which means they are at levels that should not cause harm to sea life (89% for contaminant concentrations and 96% for biological effects). Highly persistent legacy chemicals are the cause of the few failures, mainly in coastal waters close to polluted sources.

Heavy metals (mercury, cadmium, and lead), polycyclic aromatic hydrocarbons (PAHs), organotins and synthetic substances such as polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) are routinely measured for OSPAR. Measurements focus on marine sediments and on organisms in which these contaminants tend to accumulate or through which they biomagnify up the food chain. Contaminant concentrations have

[82] See Charting Progress 2, Marine Strategy Part 1 and Part 2.
[83] https://moat.cefas.co.uk/pressures-from-human-activities/eutrophication/

continued to decrease in the majority of areas assessed within the OSPAR area. Although concentrations are generally below levels likely to harm marine species, they mostly have not yet reduced to background levels. Concerns remain in some localised areas with respect to high levels of mercury, lead, and certain PCB compounds and locally increasing concentrations of PAHs and cadmium in open waters[84].

The volume of oil accidentally spilled varies widely from year to year and is generally small and of relatively minor significance unless there is a major spill.

4.4.2.1 Implications for SEA

The SEA must consider international and national scale measures to reduce operational and accidental discharges at sea and from the terrestrial environment in relation to the possible impacts of the draft plan/programme (e.g. operational and accidental discharges from oil and gas exploration and production, and transportation and storage of carbon dioxide), in the context of targets set for the attainment of good environmental status under the MSFD particularly for descriptor 8, including that, "Concentrations of substances identified within relevant legislation and international obligations are below the concentrations at which adverse effects are likely to occur" and that "Occurrence and extent of significant acute pollution effects (e.g. slicks resulting from spills of oil and oil products or spills of chemical) and their impact on biota affected by this pollution should be minimised through appropriate risk based approaches."

4.4.3 Marine Litter

The issue of marine plastics (which represent ~70% of all marine litter) has attracted increasing scientific, media and societal attention in recent years. The potential negative consequences to marine fauna of entanglement and ingestion of macro-plastic (i.e. >5mm in size) continue to be reported, while there is a growing body of evidence on the global prevalence of microplastic pollution (<5mm in size, including fibres and particles). Due to their persistence and increasing global annual production, levels of plastic in the marine environment are presumed to be rising and likely to do so for years to come, albeit with trends varying geographically and by type of plastic. In particular, the quantity of microplastic is likely to increase, as existing marine litter is eroded into increasingly small fragments and accumulations in river systems are flushed into the sea. The biological consequences of microplastic ingestion and their entry into the human food chain are largely unknown, and are the subject of increasing research.

4.4.3.1 Implications for SEA

The importance of tackling marine litter has been highlighted in the MSFD, and the high-level objective for descriptor 10 is the reduction of the amount of litter and its degradation products on coastlines and in the marine environment to levels that do not pose a significant risk to the environment. Defra is working with OSPAR to establish the feasibility of setting appropriate reduction targets and/or threshold values for litter on beaches, on the sea floor, sea surface, and microplastics, as well as whether the amount of litter ingested by marine animals will have adverse effects. The SEA must consider how marine litter is controlled for the potential activities arising from the plan (e.g. in relation to MARPOL Annex V), and any other potential waste sources and how they are handled (including waste to shore).

[84] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/key-messages-and-highlights/contaminant-concentrations-are-decreasing-concerns-remain/

4.4.4 Impact of Climate Change

The pace of warming of the sea over the past 30 years has been highest to the north of Scotland and over much of the North Sea, rising at up to 0.24°C per decade. Plankton and fish communities are already changing in response to warming. Fish like sea bass and red mullet are becoming more common further north, while stocks of cold-adapted species in the North Sea such as cod, haddock and whiting have declined. Additionally, there is a northwards movement of non-native species.

Sea level is rising, increasing the risk to coastal erosion, and from flooding and loss of intertidal habitat due to 'coastal squeeze'. This is a particular concern in the southern North Sea, eastern Channel and Bristol Channel regions due to continued adjustment of the land following the end of the last glaciation, which is resulting in gradual sinking, and the coasts of south-eastern England are low lying. The coasts of the south and east are also generally formed of soft sediments compared to those in the north and west, which are susceptible to erosion and retreat. The southern North Sea and Channel coasts have the highest proportion of coastal defence and flood protection schemes in the UK and further development in response to rising sea level will add to the existing pressure on intertidal sediment habitats. In some areas, shoreline management plan and other coastal policies are directing management towards managed realignment or retreat where further defences may not be economically feasible or else would themselves be environmentally detrimental. A connected issue relates to the challenges involved in identifying and creating areas of potential compensatory habitat (e.g. in relation to flood defence measures and effects on SAC or SPA sites) as mitigation against loss of intertidal areas.

In addition to the direct effects of temperature changes, other effects include those from ocean acidification. Approximately 25% of all anthropogenically emitted carbon dioxide has been absorbed by the oceans, with acidification expected to continue to take place, with projections for 2100 in the range 0.06-0.32 pH (a change of approximately 0.1 pH units is regarded to have been connected to anthropogenic carbon dioxide uptake to date). Ecological consequences of reduced pH include changes to the carbonate system which could affect a range of calcifying organisms such as echinoderms, molluscs and corals.

4.4.4.1 Implications for SEA

Although oil and gas production will result in greenhouse gas emissions, upstream emissions directly related to the draft plan/programme are being addressed, for example, via the OGA strategy. With respect to downstream emissions, as explained at section 3.6 of this report, these emissions are excluded from the scope of OESEA4 since BEIS has concluded that they fall outside the likely significant effects of the plan or programme which is being assessed. Those effects are nonetheless recognised even though they are not the subject of separate assessment under this environmental report.

Overall, the activities associated with the draft plan/programme are expected to make a net contribution to the reduction of UK carbon dioxide emissions, as set out in the relevant UK carbon budgets. This would be through carbon dioxide storage, and an increase in the proportion of UK energy demand supplied by renewable technologies. As such, adoption of the plan/programme subject to any spatial considerations and recommendations arising from OESEA4 will also contribute to the achievement of the UK's legally binding carbon budgets, including the target of net zero emissions by 2050, and in maintaining energy security.

The SEA should also consider relevant UK policy (e.g. MPS and National Planning Policy) and that of devolved administrations with regards to the design and siting of developments, particularly at or near the coast, in terms of resilience to climate change effects including sea-level rise.

4.4.5 Pressures on Fish Stocks

The latest updated assessment towards achieving good environmental status (Defra 2019b) reported that demersal fish communities were recovering from over-exploitation in the past, but GES had not yet been achieved in either the Greater North Sea or the Celtic Seas, nor would be achieved for all fish communities by 2020. A partial assessment of pelagic shelf fish did not provide a clear result. ICES advise that several North Sea stocks are harvested unsustainably (e.g. cod, whiting, haddock, mackerel, and blue whiting). However in both regions, recent trends in the number of sensitive species increasing in abundance suggest an improving situation and further decline in the population abundance of sensitive fish species has been halted[85] (see also OSPAR Intermediate Assessment[86]). While some recovery in sensitive fish species abundance is noted for the Celtic Sea, when considering the Greater North Sea, evidence for population recovery is unclear (OSPAR 2017[87]).

4.4.5.1 Implications for SEA

Activities resulting from implementation of the draft plan/programme may have the potential to improve local fish stocks through the designation of safety zones around structures, and fish attraction to structures, though the corollary to this is fisheries displacement. The SEA should also consider any potential source of effect on fish and shellfish from activities, in the context of the current understanding of fish stocks and pressures on these from other activities, and those targets and indicators set under the MSFD descriptor on populations of commercially exploited fish.

4.4.6 Declines in Bird Numbers

Along the eastern coast of the UK, some seabirds have continued to decline in numbers, and experience poor or failed breeding, possibly due to the combined effects of climate change and fishing on key species (e.g. sandeels). Fish discards from trawling may have contributed to elevated population sizes in some species (also noting that bycatch also results in impacts on species). However, the implementation of the discard ban, phased in from 2015-2019 across the majority of EU fisheries, is expected to impact those seabird species that exploit this resource, e.g. herring gull, lesser black-backed gull, great black-backed gull, great skua, northern gannet, northern fulmar and black-legged kittiwake (JNCC 2021a). While the wider seabird population trends for 1986-2019 still show an increase for some species, e.g. northern gannet, black-headed gull and razorbill, there is still a general decline in several recorded species, most notably Arctic skua, black-legged kittiwake, northern fulmar, little tern and European shag. In some cases, this decline may be slowing and populations may be stabilising, albeit at numbers lower than that seen from the last census; the publication of final results from the Seabirds Count census (2015-2021) will provide a clearer understanding of seabird populations around the UK and Ireland.

Declines in seabird breeding numbers have also been observed to the west of Scotland associated with predation by introduced mammals and food supply shortages, the latter of

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[85] https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/fish/abundance/
[86] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/fish-and-food-webs/recovery-sensitive-fish/
[87] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/key-messages-and-highlights/fish-communities-recovering/

which may be due in part to climate change, although eradication programmes of introduced predators on some islands is providing respite for seabirds vulnerable to predation.

While insufficient data makes it difficult to produce population trends for some species from Northern Ireland, a pattern of decline for some species e.g. northern fulmar, is evident, with (severe) weather, predation and food shortages cited as reasons for poor breeding or breeding failures. However, relative to overall UK trends, populations of some species, notably black-legged kittiwake, are stable; although numbers of this species have remained relatively stable or declined at a lower rate in Northern Ireland compared to that of the rest of the UK, due to the increased global conservation status of the species, it has moved to the Red List in the Birds of Conservation Concern Ireland (BoCCI) (BTO 2022).

Populations of some waterbird species continue to decline, with numbers reduced at principal sites (those supporting more than 75,000 birds) on both the east and west coasts of the UK. Climate change is thought to be one of the biggest drivers of broad scale changes in wintering numbers and distributions; milder weather around the Baltic is likely shortening time many species spend in the UK, low numbers and poorer breeding success could be the result of adverse weather at breeding locations in Russia, while climate change is also thought to be leading to short-stopping in migration journeys of some species (e.g. European white fronted goose and goldeneye) and influencing colonisation by egrets. At a site-specific level, pressures such as coastal human disturbance and development at estuaries can affect numbers (Frost *et al.* 2021).

4.4.6.1 Implications for SEA

Given that many seabird and waterbird species may be in decline, the SEA should review potential areas which could be licensed/leased for oil and gas, offshore wind, marine renewable or carbon transport and storage activities, and ensure awareness so that potential activities do not exacerbate the risk of surface pollution or significant disturbance to bird populations, and also understand collision risk related mortality from projects. Potential activities which may impact on coastal and marine SPAs will be subject to Appropriate Assessment by the relevant Competent Authority. The SEA should consider any potential effect of plan activities in the context of targets relating to bird abundance and productivity under MSFD descriptors 1 and 4.

4.4.7 Damage to Seabed Habitats

Significant damage has occurred to shallow sediment habitats and reefs as a result of bottom fishing practices especially beam trawling (OSPAR 2010). Around the UK, coastal and offshore seabed sediment habitats such as sands and muds are impacted by a range of activities, however the spatial extent of damage generated by bottom trawling activity, which may damage ecosystem functioning, is considered to the main source of pressure on benthic environments with an appropriate indicator developed for the updated assessment of GES (Defra 2019b).

The extent of physical damage indicator for the UK Marine Strategy combines the distribution and sensitivity of habitats (resilience and resistance), with information on the distribution and intensity of human activities and pressures that cause physical damage, such as mobile bottom gear fisheries (other human activities to be included in later rounds of assessments). Whilst there are considerable data gaps, results from 2010 to 2015 showed pressure and disturbance caused by fishing activities to be widespread, occurring to some degree in 57% of the cells within UK waters. Only the UK portion of OSPAR Region V (Wider Atlantic) was within the agreed disturbance targets (<15%). The assessed areas with the highest levels of disturbance were the southern Celtic Seas and English Channel, with around 75% of cells showing higher levels of disturbance. The habitat identified as being subject to the highest disturbance was sublittoral mud, with more than 75% of the total habitat area identified as subject to high disturbance in the southern Celtic Seas, northern Celtic Seas and northern North Sea[88]. More recent data estimated that mobile bottom-contacting gears had been deployed over approximately 490,185km^2 (*ca*. 73%) of the Greater North Sea and 409,425km^2 (*ca*. 45%) of the Celtic Seas ecoregions in 2018 (ICES 2021a,b). While at significantly smaller scales, and with more transitory impacts, the installation and decommissioning of offshore energy infrastructure (e.g. wind farms, oil and gas surface and subsea facilities) also has caused some physical disturbance, particularly in the major hydrocarbon basins of the North Sea.

4.4.7.1 Implications for SEA

The SEA should review potential areas which could be licensed/leased for oil and gas, offshore wind, marine renewable or carbon transport and storage activities and ensure awareness of existing problems related to the benthos so that potential activities do not exacerbate problem. Safety zones around surface infrastructure (500m for oil and gas, and up to 50m for operational renewables devices) will likely locally reduce trawling activities in these areas thereby reducing trawling pressure on benthos. The potential for marine renewable devices to affect sediments and seabed morphology (e.g. through energy removal, changes to tidal regimes) should also be considered. The SEA should consider effects from activities likely to arise from adoption of the plan on benthos in the context of those targets set to achieve good environmental status under MSFD descriptors 1 and 6.

4.4.8 Poor Knowledge of the Status of Marine Mammals

At present, there are insufficient data on the populations of marine mammals in the OSPAR region III Celtic Seas (OSPAR 2010). Within this region, dolphins, porpoises and grey seals are impacted through fisheries by-catch. Harbour seals are counted every five or six years, the minimum to assess their status, and other marine mammals have little systematic recording. Three surveys of cetaceans in European Atlantic waters (SCANS-I to III) have taken place, which have provided an indication of the nature and distribution on marine mammals on the UKCS. Marine mammals may become entangled in ropes and nets in coastal waters to the west of Scotland and in the Minches there is concern about entanglement of minke whales, which are important to the local economy, through marine wildlife watching.

4.4.8.1 Implications for SEA

There is the potential for disturbance of marine mammals from the activities that may result from implementation of the draft plan/programme. Activities will be spatially variable, though noise will certainly be concentrated for example in areas of renewable energy development involving pile driving, and oil and gas exploration activities using seismic survey methods, principally the North Sea, Irish Sea and west of Shetland. The SEA should consider such activities in the context of current controls on their occurrence, available mitigation, and implications in relation to monitoring under the MSFD. There is also a collision risk associated with offshore structures and shipping activity.

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[88] https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/benthic-habitats/physical-damage/ and also see: https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/key-messages-and-highlights/fish-communities-recovering/

4.4.9 Problems associated with the conservation of species and habitats

Pressures such as the removal of species (e.g. by fishing), loss of and damage to habitats (including from offshore energy activities that affect the seabed), the introduction of non-indigenous species, obstacles to species migration and poor water quality are still present. Some pressures are still increasing in parts of the OSPAR area and all can act in synergy or be exacerbated by climate change. These pressures result in loss of biodiversity, including declines in the abundance and variety of species and habitats. Interruption of ecological processes, such as spawning, migration, and biological communication, may also occur.

The most sensitive features are those that are easily damaged and slow to recover. Reefs of the cold-water coral *Lophelia pertusa* and individuals of the fan mussel *Atrina fragilis* are slow-growing and delicate and can be severely damaged by bottom trawl fisheries.

Coastal waters contain feeding grounds, spawning and nursery areas, and feature on migration routes for seabirds and some fish species. These areas also host intense and varied human activities, which exert a wide range of pressures and can lead to the damage or loss of key habitats in estuaries and intertidal areas. Salt marshes and seagrass beds, which are highly productive and act as natural carbon sinks, are under pressure from relative sea-level rise and coastal development. Key areas of the shelf seas, including offshore banks and reefs, and frontal zones between different water masses, play important roles in pelagic productivity. Fishing is recognised as a key pressure on species and habitats in the shelf seas and there continues to be a need for information about ecologically important areas to guide improvements in management.

With reference to habitats and species protected under the Habitats Directive, JNCC have assessed their conservation status. This assessment of conservation status does not only relate to that component of the habitat area or species population to be found in Special Areas of Conservation, but to the totality of the habitats and species throughout the United Kingdom. The 2019 Article 17 report[89] prepared under the Habitats Directive is the fourth, six year report.

When assessing the conservation status of habitats, four parameters were considered: range, area, structure and functions (referred to as habitat condition), and future prospects. For species, the parameters were: range, population, habitat (extent and condition) and future prospects. Each of these parameters was assessed as being in one of the following conditions: Favourable, Unfavourable-inadequate, Unfavourable-Bad, or Unknown. An overall assessment was determined by reference to the conclusions for the individual parameters, and, in general, reflects the least favourable of the individual parameter conclusions.

The overall UK assessments for eight Annex I marine habitats assessed included: 3 which were determined to be in ‘unfavourable-bad’ condition (estuaries; mudflats and sandflats not covered by seawater at low tide; sandbanks which are slightly covered by seawater all the time); 4 in ‘unfavourable-inadequate’ condition (coastal lagoons; large shallow inlets and bays; reefs; submerged or partially submerged sea caves), and 1 in ‘unknown’ condition (submarine structures made by leaking gases). Compared to the 2013 assessment, there was a large decline in the overall status of sandbanks which are slightly covered by seawater all the time, in part due to a change in the method, with the OSPAR indicator Extent of physical damage to

[89] https://jncc.gov.uk/our-work/article-17-habitats-directive-report-2019/

predominant and special habitats[90] being used to assess the condition of offshore sandbanks, and which was also regarded to provide a more accurate assessment.

Of the 22 Annex II marine species assessed: 5 were considered in ‘unfavourable-inadequate’ condition (common seal, maerl, allis shad, twaite shad, Atlantic salmon), 3 in ‘favourable’ condition (grey seal, river lamprey, otter), and 14 in ‘unknown’ condition (leatherback turtle, bottlenose dolphin, common dolphin, harbour porpoise, killer whale, long-finned pilot whale, Risso’s dolphin, Atlantic white-sided dolphin, white-beaked dolphin, minke whale, fin whale, sperm whale, sea lamprey, brook lamprey). With respect to the cetacean species there has been a change in overall conservation status from favourable to unknown since 2013. This is due to the implementation of a more robust assessment methodology, supported by updated EU Commission guidance, which requires consideration of population trends in setting the Favourable Reference Population (FRP) value. However, this requires a higher number of UK population estimates over time than are currently available, resulting in the unknown conclusion.

Burns *et al.* (2020) provide information on trends in abundance and breeding success of seabird and waterbird species, many of which are protected by SPA designations.

4.4.9.1 Implications for SEA

The SEA should consider the implications of the draft plan/programme and its alternatives on the wider marine environment, in relation to the features of conservation sites of International and national importance, and those areas for which designations are proposed. The SEA will need to draw attention to the current location of these sites and the species or habitats for which they are designated, and any sites which are currently being considered for designation, in addition to characterising the present baseline condition and issues relating more generally to the marine environment. At this more general level, the SEA must consider the potential implications of the draft plan/programme on attaining good environmental status of both marine and coastal/estuarine waters as determined by the WFD and MSFD.

4.4.10 Changes to landscape and seascape

Prior to the development of offshore renewables, offshore developments in UK waters have primarily been in relation to North Sea oil and gas installations where the only representation of such developments at the coast or on land was generally in the form of cable and pipe landfall and associated infrastructure, and also helicopter, port activity and vessel traffic. Drilling activity and production platforms have in the most part been too far from shore to be visible, notable exceptions being Beatrice in the Moray Firth, exploration well sites off Dorset and Cardigan Bay, structures in the east Irish sea and those associated with the Cromarty Firth rig support industry. The more recent development of offshore renewables, namely offshore wind farms, has led to a greater consideration of landscape/seascape issues as most have been restricted on technical and economic grounds to water depths of up to 60m (i.e. primarily in nearshore waters). Cost reduction and technical advances (including future tethered turbines) has led to deployment progressively moving offshore in most European countries. Pressures from changes to landscape and seascape also involve those onshore, including continued urban expansion and the development of the onshore renewables industry.

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[90] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/biodiversity-status/habitats/extent-physical-damage-predominant-and-special-habitats/

4.4.10.1 Implications for SEA

The SEA should consider the potential scale and location of activities which could arise from the adoption of the plan in relation to seascape (including historic seascape) character, in the context of existing and proposed developments, and relevant landscape planning policy as contained in National Policy Statements, the MPS and national and regional marine plans of the UK and devolved administrations. Attention should be brought to designated landscapes, including Areas of Outstanding Natural Beauty and National Parks and their features.

4.4.11 Impact of air quality on human health and the environment

Though the UK's terrestrial air quality is generally improving there are still areas which do not meet current exceedance levels for pollutants, primarily NO_2, SO_2 and particulate matter. SO_2 and NO_2 are known to be involved in acid deposition and the human health effects of particulates are still poorly understood but appear to have a considerable impact. Estimates of the fraction of mortality attributable to long-term exposure to current levels of anthropogenic particulate air pollution ranged from around 2.5% in some local authorities in rural areas of Scotland and Northern Ireland, to over 6% in some local authorities in the east and south east of England.

4.4.11.1 Implications for SEA

Consider potential scale of plan activities in relation to current air quality problems and in the context of the range of emissions controls there are for plan activities.

4.4.12 Possible disturbance of submerged cultural heritage

There is an increasing awareness of submerged archaeological material located for example in the southern North Sea, though their distribution is speculative and even the specific location of known sites are sometimes not precise. These include former occupied landscapes (palaeolandscapes) and any potential associated material, in addition to more recent maritime archaeology. These areas and sites are vulnerable to offshore operations which disturb the seabed (e.g. drilling, piling, cabling, and trawling), though development-led studies, for instance associated with the aggregates industry, have added considerably to knowledge in this area.

4.4.12.1 Implications for SEA

The SEA should consider the potential effects of plan activities in relation to current understanding of submerged cultural heritage in the context of international and national protection measures and planning policy. The SEA should raise awareness of available industry guidance (e.g. Gribble & Leather 2011) on marine cultural heritage.

4.4.13 Coastal erosion and flooding

A large proportion of the UK coastline is suffering from erosion (ca. 17% in the UK) with England (ca. 30%) and Wales (ca. 23%) having the greatest proportion of eroding coast, particularly the Yorkshire and Humber region. The coastline of England is also the most protected with ca. 46% of its length lined with coastal defence works (seawalls, groins) or fronted by artificial beaches. Estimates of the number of properties at risk from flooding and/or coastal erosion in England indicate that almost 3,000 dwellings are at risk for the period (2010-2025). Implementation of the respective Shoreline Management Plans (SMPs) was predicted to reduce this number to about 170.

4.4.13.1 Implications for SEA

The SEA should consider the potential scale and location of activities in particular tidal range schemes which could arise from the adoption of the plan, with respect to their potential impact on coastal erosion and flooding, and relevant SMP policies.

4.4.14 Underwater noise

Many human activities introduce sound into the marine environment, e.g. shipping, geophysical survey, underwater construction, and the use of sonars and explosives (and also the disposal of unexploded ordnance). Some of these sounds are of very high amplitude at source and often of low frequency, and therefore may be detectable by marine mammals at substantial ranges from the source. Recent technological developments have introduced many new sources of noise in offshore waters. Those typically of greatest concern to marine mammals, and marine fauna in general, are those producing the most intense sound pressure levels: seismic exploration, underwater explosions, sonar (particularly naval), pile-driving and some acoustic harassment devices (AHDs). However, less intense noise sources such as shipping are also of concern due to their persistent nature and long-range of audibility. Shipping is the dominant noise source at low frequencies in most locations, and its contribution to increased ambient noise levels has been considerable in recent decades.

4.4.14.1 Implications for SEA

The SEA should consider the potential scale and location of activities which could arise from the adoption of the plan, with respect to their potential to cause injury and/or disturbance to marine mammals and other sensitive marine fauna.

4.4.15 Cetacean bycatch

The OSPAR Intermediate Assessment (OSPAR 2017) recognised that bycatch was a major cause of human-induced mortality of harbour porpoise with nearly 4,000 harbour porpoises of a total population in excess of 490 000 drowned in fishing nets annually in the OSPAR area. However, it noted there was low confidence in the bycatch estimates due to incomplete monitoring data.

More recently, the 2020 ICES fisheries overview for the Greater North Sea also noted the patchy observer information with an unknown amount of bias, but advised that bycatch of common dolphins in the western English Channel (the far southwestern part of the Greater North Sea) may be unsustainable in population terms, while the bycatch of harbour porpoise in the Greater North Sea in nets was the ASCOBANS 1% precautionary environmental limit (ICES 2020a). For the Celtic Sea ecoregion, fisheries with high risk of cetacean bycatch were bottom setnets (bycatch of harbour porpoises) and pelagic trawls, particularly those for bass (bycatch of common dolphin) (ICES 2020b).

The ICES working group on bycatch of protected species (WGBYC) completed Bycatch Risk Assessments (BRA) for harbour porpoise in the Celtic Seas (CS) and Greater North Sea (NS) ecoregions. Data were pooled from 2015-2017 and minimum and maximum bycatch rates extrapolated using 2017 fishing effort data for nets, bottom trawls and pelagic trawls. The percentage mortality of the Greater North Sea harbour porpoise population was estimated at between 0.33-0.59% in nets, and in the Celtic Seas between 0.29-0.8% in nets and bottom trawls combined. Both estimates were below the ASCOBANS 1.7% threshold defining unacceptable levels of interaction and below the 1% precautionary environmental limit. However, it was noted that ICES ecoregions were arbitrary and unlikely to reflect the true population structure of harbour porpoise; the working group therefore conducted a further BRA using the latest definition of a Celtic Sea subpopulation and this suggested that levels of mortality in 2017 due to bycatch may be between 2.1-5.6% of that subpopulation (ICES 2019a).

4.4.15.1 Implications for SEA

The SEA should consider the potential scale and location of activities which could arise from the adoption of the plan, with respect to their potential to impact cetacean populations which may be experiencing levels of bycatch deemed unacceptable.

4.5 Likely Evolution of the Baseline

Schedule 2 of the *Environmental Assessment of Plans and Programmes Regulations 2004* (as amended) requires that the Environmental Report provides information on the likely evolution of the relevant aspects of the current state of the environment without implementation of the plan/programme.

4.5.1 Biodiversity, habitats, flora and fauna

4.5.1.1 Plankton

The MSFD requires that the biodiversity, distribution and abundance of species and habitats be in line with prevailing physiographic, geographic and climatic conditions. The current status of pelagic habitats in the Greater North Sea and Celtic Seas is uncertain as plankton communities are experiencing changes in biomass, abundance, and community structure that may have consequences on the functioning, dynamics and structure of the whole marine ecosystem. Prevailing oceanographic and climatic conditions are likely to be driving these changes, but the extent of pressure from direct human activities is unclear. GES also requires that ecosystems are not adversely affected by eutrophication, contamination, and non-indigenous species introduced through anthropogenic activities. The planktonic ecosystem of the British Isles meets these criteria as, though eutrophication and contamination may occur in some highly localised areas, the majority of plankton are unaffected by nutrient loading or chemical contamination. Additionally, changes to marine foodwebs caused by alterations in plankton phenology (trophic mismatch) or community composition appear to be related to prevailing oceanographic and climatic conditions and are not likely to be the direct result of anthropogenic pressures although the cumulative effects of these pressures on the food web are unclear.

Long-term trends in the plankton indices indicate a general increase in phytoplankton biomass for most regions in the North Atlantic and in the regional seas around the British Isles, with differing timings for the main step-wise increase occurring being later in oceanic regions compared to the North Sea. In the North Sea, the population of the previously dominant and important zooplankton species (the cold-water copepod *Calanus finmarchicus*) has declined in biomass by 70% since the 1960s. Species with warmer-water affinities (e.g. *Calanus helgolandicus*) are moving northwards to replace the species but are not as numerically abundant (Edwards *et al.* 2020). Currently the distributions of plankton organisms are moving northwards at an average rate of ~23km per year, although the rates of individual species vary substantially (Beaugrand *et al.* 2009). There is also evidence from the Continuous Plankton Recorder survey that warming temperatures decrease the size of the plankton community for both phytoplankton and zooplankton; this may also eventually lead to a decrease in size of fish species (Beaugrand *et al.* 2010).

The most recent MCCIP report card (Edwards *et al.* 2020) indicates a medium level of confidence in predictions of future changes to plankton from climate change. Future warming and increased ocean acidification are likely to alter the geographical distribution of primary and secondary plankton production (0-5 yrs), affecting ecosystem services such as oxygen production, carbon sequestration and biogeochemical cycling (20-50 yrs). Such changes have the potential to place additional stress on fish stocks and therefore on mammals and seabird populations which rely on fish as prey species.

4.5.1.2 Benthos

Over recent geological timescales (ca. 11,000 years) seabed habitats around the UK have been subject to continuous processes of change associated with post-glacial trends in sea level, climate and sedimentation. In the shorter term, seasonal, inter-annual and decadal natural changes in benthic habitats, community structure and individual species population dynamics may result from physical environmental influences (e.g. episodic storm events; hydroclimatic variability and sustained trends) and/or ecological influences such as reproductive cycles, larval settlement, predation, parasitism and disease.

Clark & Frid (2001) reviewed long-term changes in the North Sea ecosystem, at all trophic levels, and concluded that in the northern, western and central areas of the North Sea, long-term changes are predominantly influenced by climatic fluctuations. Here, primary productivity during a particular year is related to the effect of weather on the timing of stratification and the resulting spring bloom. In the southern and eastern areas of the North Sea, the lack of stratification and the large inputs of nutrients mean that primary productivity is more strongly influenced by variations in anthropogenic nutrient inputs, and is only weakly related to climatic variation. However, the weight of evidence shows that long-term changes in the ecosystem may ultimately be related to long-term changes in either climate or nutrients, although the long-term dynamics of certain taxa and communities do show evidence of being influenced by both anthropogenic factors and/or internal factors such as competition and predation.

The most recent MCCIP Report Card 2020 scientific review of shallow and shelf subtidal habitats (Moore & Smale 2020) concluded that:

- North Sea infaunal (burrowing) species have shifted their distributions in response to changing sea temperature, however, most species have not been able to keep pace with shifting temperature, meaning that species are subjected to warmer conditions. Leading (expanding) edges are responding more quickly than trailing (retreating) edges, which has been observed elsewhere in the world.
- A number of studies have used modelling approaches to predict changes in the distribution and/or abundance of kelp and cold-water corals at the UK scale, and benthic infauna and epifauna within the North Sea. All suggest significant shifts in species ranges into the future leading to altered community structures with implications for food-web dynamics, fisheries, carbon cycling and ultimately human society.

The MSFD requires that benthic biodiversity (descriptor 1) and sea-floor integrity (descriptor 6) are not adversely affected. The UK updated assessment for MSFD (Defra 2019b) indicated that it was not likely that GES will be achieved for benthic habitats by 2020. The main problem is caused by physical disruption of the seabed from fishing gear. The nature of the future management of fisheries in UK waters is likely to reflect the proposals set out in the White

Paper, Sustainable Fisheries for Future Generations[91]. Potential future issues could arise from enhanced coastal squeeze from climate change related sea-level rise, impacts from ocean acidification, and from tidal range devices on intertidal habitats.

4.5.1.3 Cephalopods

The biology and ecology of many cephalopod species remains little known and as a result, the potential effects of a changing climate on cephalopod populations are not easy to predict. However, it is known that for many species, temperature has an important influence on a number of life history processes, including recruitment (through maturation rate and the rate of embryonic development), the timing of migration and the distribution range. As well as this, food availability and predator abundance and distribution are likely to be affected by changes in the marine environment.

4.5.1.4 Fish and Shellfish

The general colonisation of the warming southern North Sea and Celtic Sea regions by Lusitanean demersal species (e.g. sea bass), and a retreat of Boreal species (e.g. cod, whiting) into the deeper parts of UK waters in the northern North Sea is likely to continue. However, variations in habitat preferences and sensitivities to prey and environmental conditions of individual species, the possible role of food web effects, and particularly the extent of future fisheries may complicate this simple picture. Some pelagic fish species have and are likely to continue to show pronounced latitudinal responses to seasonal sea temperatures (e.g. anchovy, horse mackerel), although predicting their likely distribution is complicated by the important influence of poleward flowing shelf edge currents which carry warm water into high latitudes. Species which are unable to adapt their distributions due to strict habitat association (e.g. lesser sandeels which closely associate with coarse sandy sediments) are likely to be less able to respond to predicted climate changes (Heath *et al.* 2012).

The latest updated assessment towards achieving good environmental status as part of the UK Marine Strategy (Defra 2019b) reported that in 2018 demersal fish communities were recovering from over-exploitation in the past, but GES had not yet been achieved in either the Greater North Sea or the Celtic Seas, nor would be achieved for all fish communities by 2020. However in both regions, recent trends in the number of sensitive species increasing in abundance suggest an improving situation.

4.5.1.5 Turtles

Records of marine turtle sightings and strandings in UK waters indicate that they are predominantly of leatherback turtles (e.g. Penrose & Gander 2014), with UK waters likely to represent the northerly limit of routine seasonal leatherback foraging migrations (e.g. McMahon & Hays 2006). Leatherback turtles visit only during the warmer months of the year and it has been suggested that through climate change increased seawater temperature might allow them to utilise UK waters for longer (McMahon & Hays 2006). However, the low numbers of recorded turtles and the quality of recording effort make determining likely future trends very difficult.

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[91] https://www.gov.uk/government/consultations/fisheries-white-paper-sustainable-fisheries-for-future-generations

4.5.1.6 Birds

Seabird breeding populations in the UK increased in size over much of the last century, but since 1999 populations of some species have seen significant declines; in 2015, the UK seabird indicator stood at 22% below the 1986 baseline, with most of the decline occurring since the mid-2000s. Some of the greatest reductions have occurred in the northern North Sea and Scottish Continental Shelf and the decline has largely been driven by the declines for Arctic skua and black-legged kittiwake (BTO website, Burns *et al.* 2020). Breeding success has also declined over the same period for several species; between 2003-2018, data from the six most frequently monitored Arctic skua sites, recorded complete failure 43 times, with productivity below 0.2 chicks fledged on a further 16 occasions.

Of the top three threats to the world's seabirds (in terms of numbers affected and average impact), climate change is considered to be one of the primary causes of the decline in seabird populations in the UK; climate change affecting populations either directly (mortality from extreme weather) or indirectly (via changes in in food supply) (Mitchell *et al.* 2020). Lack of food availability is a possible cause of poor breeding success in Arctic skua; this species steals prey (e.g. sandeels) from other seabird species, and reduced sandeel numbers around Shetland, thought to be as result of hydro-climatic, sea temperature and oceanographic changes, has reduced prey abundance and availability for these host species, and thus reduced feeding opportunities for Artic skuas (JNCC 2021a).

Warmer winter sea temperatures have resulted in changes in abundance, distribution and species composition of plankton in the North Sea that have contributed to the reduction in abundance and quality of seabird prey species such as sandeels, at times of peak energy demands in the breeding season, with knock-on effects for seabirds (Mitchell *et al.* 2020). There is growing evidence that breeding phenology is changing, with seabirds becoming increasingly de-synchronised from their prey, and species which have been unable to keep pace with the temporal changes of sandeel and their prey life history events, have had to rely on prey of lower calorific value during the chick rearing period (JNCC 2020a). However, regional variations in the impacts of climate change are apparent, with weaker effects on seabird demography in the Irish Sea and Celtic Sea (Mitchell *et al.* 2020).

There is increasing evidence that the overwintering distributions of many waterbirds (e.g. wildfowl and wader species) have changed, along with evidence that populations of many wader species and some wildfowl specie are in long-term decline (Burton *et al.* 2020). In recent decades, in response to warming, distributions for some species have shifted north and eastwards out of the UK. A correlation between temperature and distribution shift is more evident on those "deep water habitats" species (as defined by Pavón-Jordán *et al.* 2018) such as tufted duck, goldeneye, smew, and goosander, all of which are diving ducks, requiring ice-free water, less so with dabbling ducks (species defined as associated with "shallow-water habitats), e.g. wigeon. This has resulted in declines in usage of the UK's sites, e.g. by waders, in favour of The Netherlands, Sweden and Finland, but also suggests a wider, overall decline in abundance; there is growing evidence that predation and nest loss is a driver in the decline of wader populations, while changing land-use is also a threat that may translate into observed changes (Burton *et al.* 2020). A change in migration (and breeding) timing is also evident, with a general advancement in first arrival dates (e.g. wildfowl and waders) to breeding sites (resulting in those species which breed in the UK arriving earlier, and those species which over-winter in the UK, departing earlier to their breeding grounds).

4.5.1.7 Marine Mammals

Whilst the ability to detect long-term trends in cetaceans around the UK is limited by the paucity of effort-based sightings data, range shifts appear to have been observed in a number of cetacean species (Evans & Bjørge 2013). For example, short-beaked common dolphin and striped dolphin appear to have extended their shelf sea range further north off western Britain and around into the northern North Sea, and these have been linked to increasing sea temperatures, and there has been a southerly shift in distribution of harbour porpoise in the North Sea. However, the mechanisms causing those changes remain uncertain, and for some species, it is difficult to differentiate between short-term responses to regional resource variability and longer-term ones driven by climate change. With respect to seals, whilst it is possible that recent demographic changes (increases in most grey seal populations and declines in some harbour seal populations) are linked in some way to climate-mediated changes in food supply, other factors (depletion of food resources from fishing, recovery from epizootics, interspecific competition, density dependent effects) may be more important (SCOS 2008, cited in Evans & Bjørge 2013).

4.5.2 Geology, Substrates and Coastal Geomorphology

The environmental baseline is likely to evolve slowly in the absence of anthropogenic influences. At present there are no anthropogenic activities which are likely to cause significant regional scale changes to geology and sediments, though trawling and dredging activities can generate localised scour and sediment plumes, and energy removal has the potential to result in local or regional changes to sedimentary processes.

Relative sea levels under the RCP 2.6 scenario are predicted to rise by 29-70cm by 2100 (relative to 1981-2000 average) (for London) – note there are regional UK variations in the predicted rate of sea-level rise, including due to glacial isostasy. For example, under the same scenario, Edinburgh is predicted to experience sea level change of 8-49cm by 2100. Under the RCP8.5 scenario sea level is expected to rise to between 53-115cm for London and 30-90cm for Edinburgh (Palmer *et al.* 2018). Coastal erosion is estimated to affect 17% of UK coasts and there are large regional variations connected with coastal rock types – England and Wales have the highest overall erosion rates with 28% of coasts retreating at more than 10cm per year. These rates are expected to rise in the future, corresponding primarily to higher sea levels.

4.5.3 Landscape/Seascape

There are presently 8 (2 in Scotland) offshore wind farms in planning and a further 6 (4 in Scotland) which have been consented, adding to the 40 (6 in Scotland) which are operational or the 6 (3 in Scotland) under construction. A number of these are, or are likely to be, visible from the coast and future leasing rounds for wind and other renewable technologies which could be developed in proximity to the coast, or be coast connected, are possible. There is a likelihood of landscape effects from coastal and terrestrial wind generation projects, other marine energy developments and continued industrial, port and urban expansion.

4.5.4 Water Environment

Climate change has and will continue to have a pervasive effect on all aspects of the coastal and marine environment including flooding, coastal erosion, water quality and resources. Over the 21st century, the ocean is projected to transition to unprecedented conditions with increased temperatures (virtually certain), greater upper ocean stratification (very likely), further acidification (virtually certain), oxygen decline (medium confidence), and altered net primary production (low confidence). The rates and magnitudes of these changes will be smaller under scenarios with low greenhouse gas emissions (very likely) (IPCC 2019).

Warming of UK shelf seas is projected to continue over the coming century with most models suggesting an increase of between 0.25°C and 0.4°C per decade. There may be some regional differences with warming expected to be greatest in the English Channel and North Sea, with smaller increases in the outer UK shelf regions (MCCIP 2020, Tinker & Howes 2020).

There is a history of strong variability in UK wave climate. Inter-annual variability in the modern wave climate is strongest in the winter and can be related to atmospheric modes of variability, most notably the NAO. Rather dramatic increases in wave height occurred between 1960 and 1990, but these are now seen as just one feature within a longer history of variability and there is no clear pattern in results since 1990. There is as yet no consensus on the future storm and wave climate (Woolf & Wolf 2013, Wolf *et al.* 2020).

Temperature stratification over the NW European shelf seas is showing evidence of beginning slightly earlier in the year, on average although it is very difficult to decipher trends against natural variability (Sharples *et al.* 2013, 2020).

4.5.5 Air Quality

Air quality statics for the UK (urban and rural areas) indicate a general long-term improvement in air quality metrics, and fewer days of moderate or higher pollution although prolonged hot and sunny conditions in 2018 and 2019 and associated higher ozone levels were responsible for an increase in the number of days of moderate or higher pollution at urban sites. Road transport is the main source in 97% of the air quality management areas declared for NO_2 and in 79% of the AQMAs declared for PM10.

Atmospheric emissions associated with offshore oil and gas have in general remained relatively stable over the last decade although data for the latest year (2017) indicated increases in SO_2, CO_2, NO_x and NMVOC compared to 2016 figures. SO_2 emissions vary greatly year on year, as they are largely dependent on consumption of diesel for power generation which is determined by periods of shut down and as fields deplete there is a greater reliance on diesel to replace fuel gas. Carbon dioxide accounts for the greatest proportion of emissions to air from UKCS offshore installations, primarily generated from fuel consumed by combustion equipment to provide electrical power and drive compressors for oil and gas export (Oil & Gas UK 2018). Factors which may influence atmospheric emissions in the future, include ageing fields requiring a higher consumption of energy (e.g. additional compression), and the consequent depletion of available gas for fuel, which may require additional usage of diesel for power generation leading to increased atmospheric emissions (OSPAR 2014); however, recent energy integration concepts such as platform electrification from shore or offshore renewable sources may significantly ameliorate this.

4.5.6 Climate and Meteorology

Reflecting the long-term warming trend since pre-industrial times, observed global mean surface temperature (GMST) for the decade 2006–2015 was 0.87°C (likely between 0.75°C and 0.99°C) higher than the average over the 1850–1900 period (very high confidence). Estimated anthropogenic global warming is currently increasing at 0.2°C (likely between 0.1°C and 0.3°C) per decade due to past and ongoing emissions (high confidence) and is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate (high confidence). Potential regional changes to climate associated with global warming up to 1.5°C, include warming of extreme temperatures in many regions (high confidence), increases in frequency, intensity, and/or amount of heavy precipitation in several regions (high confidence), and an increase in intensity or frequency of droughts in some regions (medium confidence) (IPCC 2018).

4.5.7 Population and Human Health

In the UK as a whole, population is expected to increase to 69.2 million by mid-2030 compared with the estimated UK population for mid-2019 (66.8 million). Growth is projected to be most significant in England (3.9% growth) and least in Scotland (*ca*. 0.3%) over the same period[92]. Within England, regions in the north are projected to grow at a slower rate than regions in the Midlands (East Midlands – 7.2%) and south. The North East is the region with the slowest projected population growth (2.3%)[93]. Continued growth will increase population density which is already greater in the south (402 persons/km^2 for coastal authorities in Regional Sea 3) than the north (13 persons/km^2, Regional Sea 7). Human health in the UK is unlikely to change considerably in the near future, with life expectancy at birth projected to increase to 82.6 years for males and 85.5 years for females by 2043, an increase of around three years since 2019. The UK population is an ageing population with the proportion aged >85 years projected to almost double over the next 25 years.

4.5.8 Other Users

Existing marine activities include shipping and port activities, military exercises, fishing, recreational sailing, oil and gas exploration, production and decommissioning, aviation and offshore wind farm construction and operation. Port activities have been continuously expanding and associated with this expansion, shipping tonnage has also increased. The fishing industry is dynamic with frequent and sometimes unpredictable changes in fish abundance and distribution, climatic conditions, management regulations and fuel costs all affecting activity. Consequently the baseline is rapidly evolving. In general, the fishing industry has been in decline in recent years in terms of numbers employed, vessels at sea and catch, and in coming years technical developments, economics, changes in management strategy and changes in target species, abundance, composition and distribution are all likely to be important. Additionally, offshore development including of offshore energy, and fisheries management measures including in Marine Protected Areas, may result in some fisheries displacement. A number of demonstrator and small array scale wave and tidal power electricity generation devices have been deployed which may lead to commercial scale developments in the future. Whilst the planning permission for the Swansea Bay tidal lagoon has recently expired, there are a number of other tidal lagoon projects at the pre-planning stage which may be developed during the currency of OESEA4.

4.5.9 Cultural Heritage

There is an increasing awareness of submerged archaeological material located for example in the southern North Sea, though their distribution is speculative. These areas are vulnerable to offshore operations which disturb the seabed (drilling, piling, cabling). The development of increasingly sophisticated detection methods, mapping, and underwater excavation and

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92 https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/bulletins/nationalpopulationprojections/2020basedinterim

93 https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/datasets/regionsinenglandtable1

updated guidance to industry means that the recovery of archaeological material or information is increasingly likely.

4.5.10 Conservation of Sites and Species

MCZs and MPAs established under the *Marine and Coastal Access Act 2009* (and equivalent Acts of the devolved administrations) have the aim of completing an ecologically coherent and well-managed network of MPAs, together with existing and future SACs, SPAs, OSPAR and other conservation sites. Defra, the Welsh Government, the Scottish Government and the Department of Agriculture, Environment and Rural Affairs Northern Ireland have recently reported on progress on the MPA network. As of March 2021, there were 372 designated MPAs protecting 38% of UK waters compared to 217 sites covering 8% of UK waters in 2012. The recent assessment of progress towards an ecologically-coherent and well-managed network of Marine Protected Areas in the UK concluded that MPAs across the UK marine area will contribute towards achieving and maintaining GES over the coming years, and to an ecologically coherent and well-managed network of MPAs under the OSPAR Convention[94].

4.5.11 Onshore

Coastal habitats in the UK (e.g. saltmarsh, machair, sand dunes, shingle and maritime cliff and slope), provide many ecosystem services, such as flood defence, climate regulation, and tourism opportunities, which are all beneficial to society and the economy. They represent a zone of transition between the terrestrial and marine domain and are in a constant state of flux. Coastal processes are dependent on tides, waves, winds, flora, fauna, and sediment processes; they are susceptible to and altered by climatic changes, whilst also vulnerable to, and often negatively affected by, human activities (Burden *et al.* 2020).

The total rise in sea-level around the UK coast may exceed one metre by 2100 (Palmer *et al.* 2018). The frequency of intense storm events is expected to increase and lead to more coastal flooding. Temperatures are expected to rise, particularly in the south and east of the UK. Winter precipitation is likely to increase markedly on the northern and western UK coastline. Coastal erosion is also expected to increase, partly due to sea-level rise. Low-lying and soft-sediment coasts in the east of England will be most vulnerable as they are most easily eroded. The most-exposed locations and estuaries may be particularly vulnerable (Burden *et al.* 2020).

Jones *et al.* (2013) and Burden *et al.* (2020) summarise the likely impact that climate change will have on coastal habitats. In addition to sea-level rise, changes in temperature, rainfall, wind speed and direction will affect dune landform development, but the likely results of such changes are uncertain. The range of some plant communities may extend northwards, such as the *Leymus arenarius* and the *Ammophila arenaria-Festuca rubra-Hypnum cupressiforme* subcommunity. Warmer and wetter conditions may be favourable in terms of dune stabilisation and development, these are likely to be offset by drought periods and storms. Hydrological changes in dune slacks may also lead to changes in dune slack communities. Low-lying machair habitats are similarly affected by sea-level rise and storm events should they increase as a result of climate change. Similarly, saltmarsh environments may be affected by sea-level rise and any increase in storminess, which may further decrease their extent. Their inability in some cases to adjust through inland migration enhances their vulnerability. Regional changes in precipitation could also result in effects such as changes in sediment supply from freshwater runoff, and species distribution could be affected by elevated carbon dioxide levels. Shingle

[94] https://moat.cefas.co.uk/biodiversity-food-webs-and-marine-protected-areas/marine-protected-areas/

beaches and structures may be affected by changes in wave and tidal energy potentially resulting in the movement of some features out of designated site boundaries. Where movement is not considered acceptable (e.g. in proximity to Dungeness power station), replenishment will be required. There is likely to be landward migration of narrow beaches (coastal squeeze), and coastal defences may be more at risk of being undermined as beach levels lower. Sea-level related impacts to key shingle areas may be disproportionate as they coincide with areas where projected sea-level rise is greatest (i.e. in the south and east). Changes in vegetation of shingle beaches are also likely (for instance the loss of the northern oysterplant in several southern areas is attributed to warmer temperatures, along with assisting the spread invasive garden species which could displace native species. Additionally, more frequent storms could also affect the rate of recolonisation of sparse native vegetation.

Maritime cliffs may erode more rapidly as sea-level and storminess increase, exacerbated by an increase in rainfall which may help promote a greater number of landslips. Such increased disturbance would favour early successional species and may reduce vegetation mosaics important for scarce invertebrates, and warmer temperatures may also favour invasive species.

5 Assessment

5.1 Assessment approach and methodology

OESEA4 covers a very large marine area comprising all UK waters with water depths ranging from the intertidal to more than 2,400m. The assessment has to address complex issues and multiple interrelationships, where a score based matrix assessment on its own would be inadequate. The assessment is therefore supported by an evidence based consideration presented in the sections which follow. In addition, significant use has been made of Geographical Information System (GIS) tools to collate, process, analyse and present spatial information both in the following assessment and baseline presented in Appendix 1.

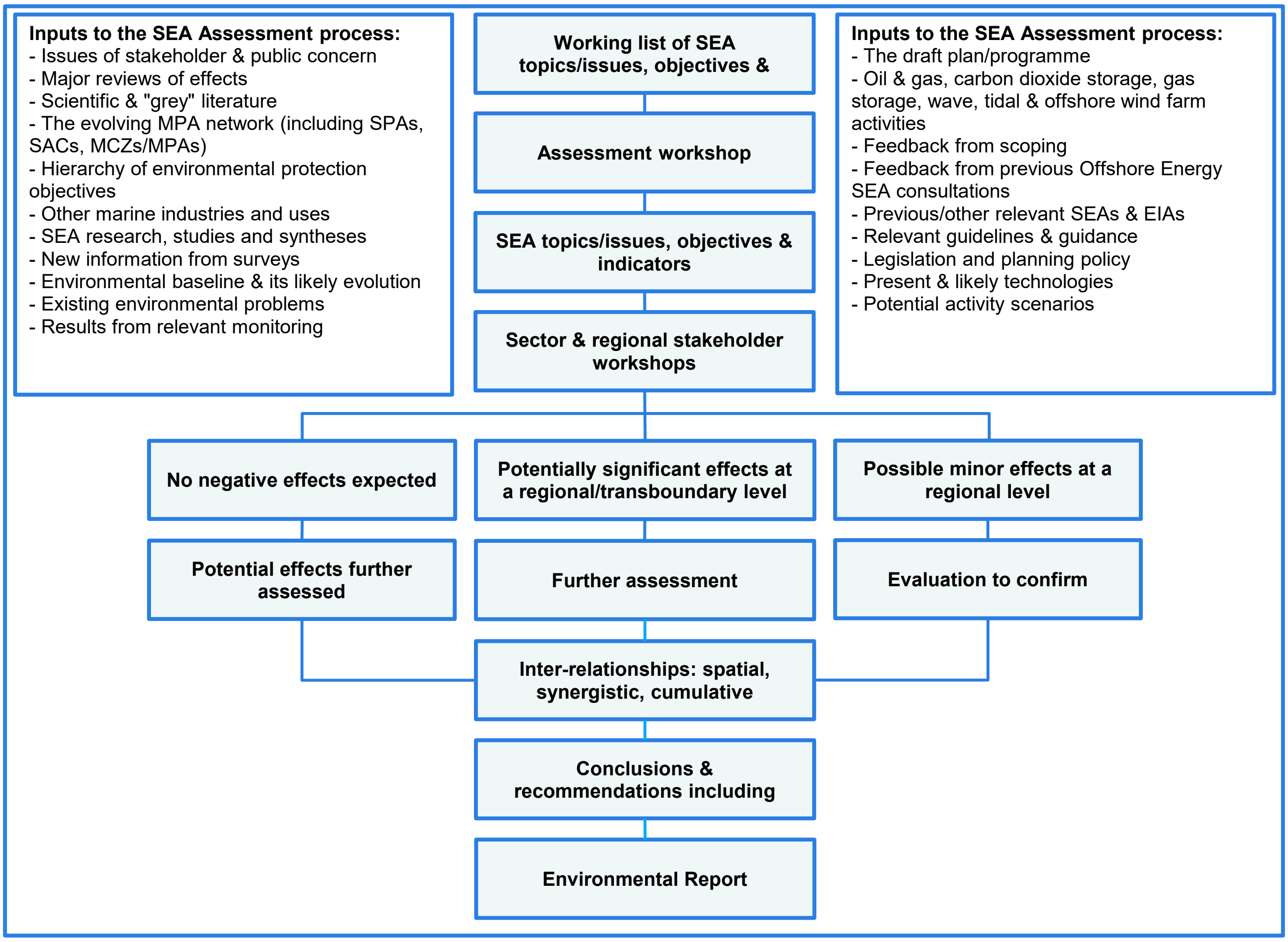
The assessment for this SEA is a staged process (Figure 5.1) incorporating inputs from a variety of sources:

- Baseline understanding of the relevant receptors (including other users) grouped according to the SEA Directive (see Appendix 1 *Environmental baseline* and Section 4 and the range of studies undertaken through the SEA process) together with existing environmental problems and the likely evolution of the baseline conditions.
- The likely activities, and potential sources of effect (see Box 5.1) and the existing mitigations, regulatory and other controls (see Appendix 3), and wider policy context and other relevant initiatives (see Appendix 2).
- The evolving regulatory framework.
- The evolution of technology.
- The SEA objectives (see Section 3.5).
- The evidence base regarding the relative risks and potential for significant effects from all aspects of the draft plan/programme.
- Steering Group, statutory consultee and stakeholder perspectives on important issues, information sources and gaps, and potential areas to exclude from licensing derived from scoping, stakeholder workshops (Appendix 4), and other meetings and communications.

At a strategic level, a distinction has been drawn for various effect mechanisms between impacts which may be significant in terms of conservation status of a species or population (and hence are significant in strategic terms), and impacts which may be significant to individual animals, but which will not influence sufficient numbers to have a significant effect on population viability or conservation status.

This approach does not imply that mortality or sub-lethal effects on individual animals are unimportant (clearly there are welfare considerations, particularly for avian and mammalian species); but it is appropriate that strategic considerations are made at a biogeographic population or species level – as is done for example, in the selection of qualifying features for SPAs and SACs.

Figure 5.1: Assessment process



5.2 Potential sources of significant effect

Previous SEAs have been informed by activity/effect matrices (e.g. Marlin), which have sought to link human activities with effects on the marine environment. In recent years, significant work has been undertaken in the area of sensitivity assessments and activity/pressure (i.e. mechanisms of effect) matrices (e.g. Tillin *et al.* 2010, Tillin & Tyler-Walters 2014, Defra 2015, Robson *et al.* 2018, the Scottish Government Feature Activity Sensitivity Tool, FeAST, the MarESA tool, Tyler-Walters *et al.* 2018). These matrices are intended to describe the types of pressures that act on marine species and habitats from a defined set of activities and are related to benchmarks where the magnitude, extent or duration is qualified or quantified in some way and against which sensitivity may be measured – note that benchmarks have not been set for all pressures. The sensitivity of features to any pressure is based on tolerance and resilience, and can be challenging to determine (e.g. see Tillin & Tyler-Walters 2014, Pérez-Domínguez *et al.* 2016, Maher *et al.* 2016), for example due to data limitations for effect responses of species making up functional groups and/or lack of consensus on expert judgements. Outputs from such sensitivity exercises can therefore be taken as indicative.

In addition to the potentially significant effects identified (see Box 5.1 below) for the draft plan/programme which is the subject of this SEA (and subject to scoping and variously discussed with the SEA Steering Group and stakeholders – see Appendix 4), the JNCC activity/pressure matrices referred to above were reviewed to ensure that all sources of effect have been identified for plan related activities.

Potential sources of effects from the activities which could follow adoption of the draft plan/programme in terms of the likely significant effects on the environment, identified by SEA topic, are listed in Box 5.1 below. A question mark indicates uncertainty of potential for effect. The sources of potentially significant effect identified in Box 5.1 have been categorised by Assessment Topic (left hand column, see key below) which forms the basis of the subsequent assessment sections. The potentially significant effects identified in Box 5.1 represent potential issues for further consideration in the assessment (relevant assessment section is signposted in the right hand column).

Key to Assessment Topics

	Noise		**Marine discharges**
	Physical damage to features and habitats (includes energy removal)		**Air quality**
	Physical presence		**Climatic factors**
	Landscape/seascape		**Accidental events**
	Waste		

Assessment Topic	Box 5.1:Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H production/ transport	Assessment Section
Biodiversity, habitats, flora and fauna										
	Physical damage to/loss of biotopes from infrastructure construction including seabed preparation, operation and maintenance, and decommissioning (direct effects on the physical environment)	X	X	X	X	X	X	X	X	5.4
	Changes/loss of habitats related to the placement of structures on the seabed and related protection materials	X	X	X	X	X	X	X	X	5.4
	Behavioural and physiological effects on marine mammals, birds and fish from deep geological seismic surveys	X	X	X						5.3
	Behavioural and physiological effects on marine mammals, birds and fish from other geophysical surveys	X	X	X	X	X	X	X	X	5.3
	Behavioural and physiological effects on marine mammals, birds and fish associated with construction phase noise[95]	X	X	X	X	X	X	X	X	5.3
	Behavioural and physiological effects on marine mammals, birds and fish associated with operational noise	X	X	X	X	X	X	X	X	5.3
	Behavioural and physiological effects on marine mammals, birds and fish associated with decommissioning noise	X	X	X	X	X	X	X	X	5.3
	The introduction and spread of non-native species	X	X	X	X	X	X	X	X	5.6, 5.9
	Behavioural disturbance to fish, birds and marine mammals etc from physical presence of infrastructure and support activities	X	X	X	X	X	X	X	X	5.6

[95] May include piling noise, and the detonation of unexploded ordnance (UXO).

Assessment Topic	Box 5.1:Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H production/ transport	Assessment Section
	Collision risks to birds				X	X	X	X		5.6
	Collision risks to bats				X					5.6
	Collision risks to water column megafauna (e.g. fish, marine mammals), includes entanglement in moorings and from vessels	X	X	X	X	X	X	X		5.6
	Barriers to movement of birds				X	X	X			5.6
	Barriers to movement of fish and marine mammals				X	X	X	X		5.6
	Changes/loss of habitats from major alteration of hydrography or sedimentation (indirect effects on the physical environment)				X	X	X	X		5.5
	Effects on prey species	X	X	X	X	X	X	X		5.6
	Potential for effects on flora and fauna of produced or treated water and drilling discharges	X	X	X	X	X	?	X	X	5.9
	EMF effects on electrosensitive species	X	X	X	X	X	X	X	X	5.6
	The nature and use of antifouling materials				?	X	?	X		5.9
	Accidental events – major oil or chemical spill	X								5.13
	Accidental events – major release of carbon dioxide			X						5.13
	Accidental events – major release of hydrogen								X	5.13

Assessment Topic	Box 5.1:Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H production/ transport	Assessment Section
Geology and Soils										
	Physical effects of anchoring and infrastructure construction (including pipelines and cables), operation and maintenance, and decommissioning on seabed sediments and geomorphological features (including scour)	X	X	X	X	X	X	X	X	5.4
	Sediment modification and contamination by particulate discharges from drilling etc or resuspension of contaminated sediment	X	X	X	X	X	X	X	X	5.9
	Effects of reinjection of produced water and/or cuttings and carbon dioxide	X	X	X						5.9
	Onshore disposal of returned wastes – requirement for landfill	X	X	X	X	X	X	X		5.10
	Post-decommissioning (legacy) effects – cuttings piles, footings, foundations, *in situ* cabling etc	X	X	X	X	X	X	X	X	5.4
	Changes to sedimentation regime and associated physical effects				X	X	X	X		5.5
	Accidental events – risk of sediment contamination from oil spills	X								5.13
	Accidental events – blow out impacts on seabed	X								5.13
	Offshore disposal of seabed dredged material	X	X	X	X	X	X	X	X	5.4
Landscape/Seascape										
	Potential effects of development on seascape including change to character (interactions between people (and their activities) and places (and the natural and cultural processes that shape them))	X	X	X	X	X	X	X	X	5.8

Assessment Topic	Box 5.1:Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H production/ transport	Assessment Section
Water Environment										
	Contamination by soluble and dispersed discharges including produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction	X	X	X	X	X	?	X	X	5.9
	Changes in seawater or estuarine salinity, turbidity and temperature from discharges (such as aquifer water and halite dissolution) and impoundment		X	X			X			5.9
	Energy removal from wet renewable devices, and offshore wind farms				X	X	X	X		5.5
	Changes to thermal stratification, current strength and wave climate				X	X	X	X		5.5
	Accidental events - contamination of the water column by dissolved and dispersed materials from oil and chemical spills or gas releases	X	X	X						5.13
Air Quality										
	Local air quality effects resulting from vessel and power generation exhaust emissions, flaring and venting	X	X	X	X	X	X	X	X	5.11
	Air quality effects of a major gas release or volatile oil spill	X	X	X					X	5.11
Climatic Factors										
	Contributions to net greenhouse gas emissions	X	X							5.12
	Reduction in net greenhouse gas emissions			X	X	X	X	X	X	5.12
	Effects on blue carbon	X	X	X	X	X	X	X	X	5.12

Assessment Topic	Box 5.1:Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H production/ transport	Assessment Section
	Population and Human Health									
	Potential for effects on human health associated with reduced local air quality resulting from atmospheric emissions associated with plan activities	**X**	**X**	**X**						**5.11**
	Potential for effects on human health associated with discharges of naturally occurring radioactive material in produced water	**X**	**X**	**?**						**5.9**
	Accidental events – potential food chain or other effects of major oil or chemical spills or gas release	**X**	**X**	**X**						**5.13**
	Other users of the sea, material assets (infrastructure, and natural resources)									
	Positive socio-economic effects of contributing to greenhouse gas reduction			**X**	**X**	**X**	**X**	**X**	**X**	**5.12**
	Interactions with fishing activities (exclusion, displacement, seismic, gear interactions, “sanctuary effects”)	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**5.7**
	Other interactions with shipping, military, potential other marine renewables and other human uses of the offshore environment	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**5.7, 5.15**
	Accidental events – socio-economic consequences of oil or chemical spills and gas releases	**X**	**X**	**X**						**5.13**
	Cultural Heritage									
	Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc. and impacts on the setting of coastal historic environmental assets and loss of access.	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**5.4, 5.8**

5.3 Noise

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Behavioural and physiological effects on marine mammals, fish and other organisms from seismic surveys	X	X	X					
Behavioural and physiological effects on marine mammals, fish and other organisms from other geophysical surveys	X	X	X	X	X	X	X	X
Behavioural and physiological effects on marine mammals, fish and other organisms associated with construction phase noise	X	X	X	X	X	X	X	X
Behavioural and physiological effects on marine mammals, fish and other organisms associated with operational noise	X	X	X	X	X	X	X	X
Behavioural and physiological effects on marine mammals, fish and other organisms associated with decommissioning noise	X	X	X	X	X	X	X	X

5.3.1 Introduction

The study of ocean noise is a rapidly developing discipline with the number of peer-reviewed papers having increased exponentially in the last two decades. The focus of research has broadened from naval applications and studies of physical acoustics to investigations of the effects of a variety of anthropogenic sources on a diversity of ecological receptors (Williams *et al.* 2015, Duarte *et al.* 2021).

Sound is generated in the marine environment by a number of natural processes with a physical (e.g. wind, waves, rain, lightning, earthquakes) or biological origin (e.g. communication and behaviour) as well as being ubiquitous to all human activities, either as their by-product (e.g. shipping, fishing, construction) or as the key element of the activity itself (e.g. sonar and geophysical exploration). The potential effects of sound on marine organisms depend on the characteristics of the sound (e.g. type, intensity, spectra, duty cycle, duration), the physical characteristics of the environment in which sound propagates, the acoustic sensitivity of the receiver, and their interaction in space and time. Potential effects range from masking biological communication and causing small behavioural reactions, to chronic disturbance, injury and mortality (e.g. OSPAR 2009); these are described in Section 5.3.3.

Sound is a disturbance in pressure that propagates its energy as a mechanical longitudinal wave in fluids. Sound can only exist in a medium such as a fluid (gas or liquid) or a solid but not in a vacuum because it relies on the interaction of particles vibrating around their fixed position. The sound wave moves through the medium as particles are compressed and released along regions of high and low pressure[96]. Therefore, changes in both pressure and particle motion are inherent to any sound wave. The unit of pressure is the Pascal (Pa) while particle motion, a vector quantity with both magnitude and direction, can be described in terms of particle displacement (m), velocity (m/s) and acceleration (m/s^2). International standards for underwater acoustic terminology have been published (ISO 2017[97]); if adopted widely, these will succeed in reducing misinterpretation and improving comparability among studies, something which has been a hindrance in the past (Hawkins *et al*. 2015).

By convention, sound levels are expressed in decibels (dB) relative to a fixed reference pressure (the reference value for sound in water[98] is 1μPa). The decibel scale is a logarithmic scale (to base 10) which has been historically adopted as a scale compression method to deal with the very wide range of pressures encountered (from μPa to MPa). Commonly used metrics and their quantities expressed in levels are given in Boxes 5.2 and 5.3.

The other fundamental characteristic of a sound wave is its frequency, measured in Hertz (Hz) where 1 Hz represents one wave per second. Frequency is inversely related to the wavelength (the distance between two peaks) for a constant speed of sound within a medium: a low frequency sound wave has a long wavelength, while a high frequency wave has a short wavelength. Any complex acoustic waveform contains several frequencies which can be represented by its spectrum (amplitude as a function of frequency). Detailed spectra can be obtained (e.g. using Fourier analysis) to represent the signature of a sound; however, since amplitudes can vary rapidly with frequency, detailed spectra are difficult to use in comparisons. More commonly, levels are calculated within third-octave bands which represent a standard set of frequency bands[99].

Sound broadly falls into two types (Southall *et al.* 2007, Robinson *et al.* 2014) (see figures in Box 2). Impulsive (pulse) sound is characterised by a short burst of acoustic energy of finite duration; it is transient in nature, with rapid rise in amplitude, wide bandwidth and short duration (<1 sec). With relevance to offshore energy developments, pulses are generated from explosions, impact pile-driving, seismic air-guns and sub-bottom profilers. Continuous sound occurs when the acoustic energy is spread over a significant time (several seconds to hours); it may contain broadband noise and/or tonal (narrowband) noise at specific frequencies and its amplitude may vary. Relevant examples include shipping, drilling, dredging and operational noise. The distinction of pulsed sound from continuous sound is important because pulses generally have a different potential to cause effects, particularly on mammalian hearing with respect to injury (e.g. Ward 1997). However, pulses lose their impulsive character as sound propagates from source; in the case of impulsive sounds repeated at intervals (duty cycle), such repetition may become diffuse with distance and will become indistinguishable from continuous noise at a distance of several kilometres (Southall *et al.* 2007, EU TSG Noise 2014b).

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[96] Refer to the DOSITS website https://dosits.org/science/sound/what-is-sound/ for helpful illustrations, further details and additional resources.

[97] ISO 18405:2017 Underwater Acoustics - Terminology https://www.iso.org/obp/ui/#iso:std:iso:18405:ed-1:v1:en

[98] The reference value in air is 20 μPa so comparisons of sound levels in air and water are not straightforward.

[99] An octave represents a doubling in frequency and each octave contains three third-octave bands; each third octave band is a frequency ratio corresponding to a ratio of 21/3 ≈ 1.2599. An alternative expression for "third-octave" is the 'deci-decade' which is defined as one tenth of a decade or $10^{0.1}$ ≈ 1.2589 (smaller than one third of an octave by 0.08%). The former is favoured in Robinson *et al.* 2014 while the latter is the convention used in EU TSG Noise (2014c). The nominal central frequencies of each band are practically the same as listed in IEC 61260:1995.

Box 5.1 - Relevant acoustic metrics

sound pressure (or "instantaneous sound pressure"): the difference between instantaneous total pressure and pressure that would exist in the absence of sound. This is in effect the quantity represented when a sound pressure waveform is plotted as illustrated below.

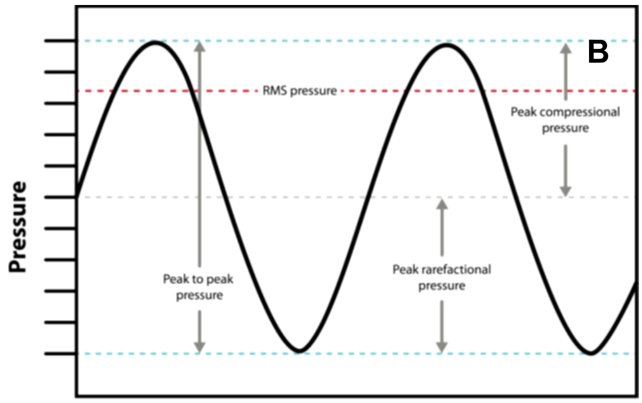
peak sound pressure (or zero-to-peak sound pressure), p_{peak}: the maximum sound pressure during a stated time interval. A peak sound pressure may arise from a positive or negative sound pressure.

peak to peak sound pressure, p_{pp}: the sum of the peak compressional pressure and the peak rarefactional pressure during a stated time interval.

root mean square (RMS) sound pressure: the square root of the mean square pressure, where the mean square pressure is the time integral of squared sound pressure over a specified time interval divided by the duration of the time interval. The RMS sound pressure is calculated by first squaring the values of sound pressure, averaging over the specified time interval, and then taking the square root.

sound exposure, E: the integral of the square of the sound pressure over a stated time interval or event (such as an acoustic pulse). The quantity is sometimes taken as a proxy for the energy content of the sound wave. When applied to an acoustic pulse, the integration time is the pulse duration and the quantity is sometimes called "single pulse sound exposure". Pulse duration is commonly defined as the time occupied by the central portion of the pulse, where 90% of the pulse energy occurs. This is useful because it can be difficult to determine the exact start and end of the pulse when the waveform contains noise; as illustrated below. When applied to an extended period or sequence of pulses/events, it is called "cumulative sound exposure" and it is important to specify any other relevant information such number of pulses, total time duration, duty cycle of any sampling.

A



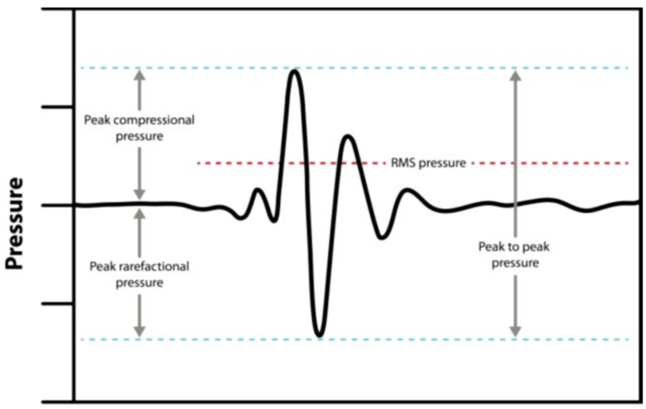
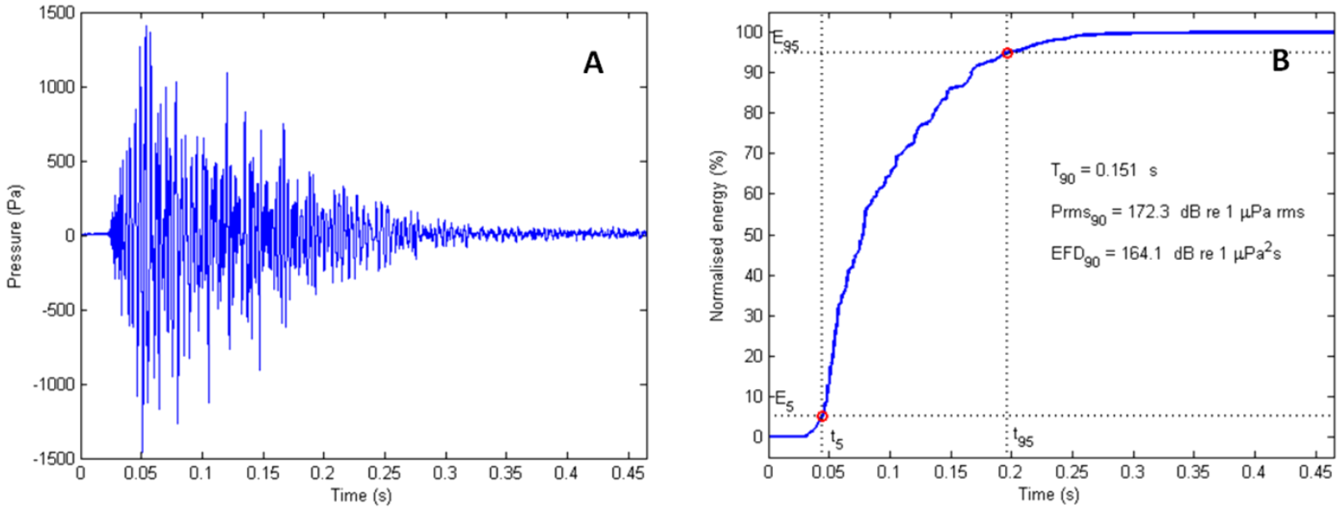


Illustration of metrics for sound pressure illustrated for a sound pulse (A) and for a periodic form (B)



illustrative examples of pulsed waveform from a measurement of marine pile driving (A) and calculation of pulse duration (B).

Source: Robinson *et al.* 2014

Box 5.2 - Relevant acoustic quantities expressed as levels

peak sound pressure level (or zero-to-peak sound pressure level), L_{peak}**:**

$$L_{peak} = 20\log_{10}\left[\frac{P_{peak}}{P_0}\right]$$

where p_{peak} is the peak sound pressure and $p_0$is the reference value, of 1 μPa in water. Units are dB re 1 μPa

It was common use to abbreviate peak sound pressure level to "peak SPL"[100]. However, since SPL generally refers to a time-averaged quantity, the meaning was ambiguous - it could be interpreted at "peak sound pressure expressed as a level", or as the "peak (or maximum) of the SPL". It is now recommended that peak sound pressure level is not abbreviated to "peak SPL".

peak to peak sound pressure level, L_{pp}**:**

$$L_{pp} = 20\log_{10}\left[\frac{P_{pp}}{P_0}\right]$$

where p_{pp} is the peak to peak sound pressure and $p_0$is the reference value, of 1 μPa in water.
Units are dB re 1 μPa.

sound exposure level, SEL:

$$SEL = 10\log_{10}\left[\frac{E}{E_0}\right]$$

where E is the sound exposure and E_0 is the reference value, of 1 μPa²s in water. Units are dB re 1 μPa²s.

Note that the sound exposure level is a useful measure of the exposure of a receptor to a sound field, and a frequency weighting is commonly applied. If a frequency weighting is applied, this should be indicated by appropriate subscripts.

sound pressure level, *SPL*:

$$\boldsymbol{SPL = 10\log_{10}\left[\frac{\hat{p}^2}{p_0^2}\right] = 20\log_{10}\left[\frac{\hat{p}}{p_0}\right]}$$

where $\hat{p}$ is the root mean square (RMS) sound pressure and $p_0$is the reference value, of 1 μPa in water.
Units are dB re 1 μPa. Note that the time interval used in the calculation of SPL must be stated.

Source: Robinson *et al.* 2014

[100] For example in Southall *et al.* 2007

Sound is altered as it radiates away from its source. The amplitude of the wave generally declines with distance from source with several factors at play, including geometrical spreading, absorption, reflection, refraction, scattering and reverberation (see Box 5.4). With the exception of geometrical spreading, the factors that influence propagation are frequency (wavelength) dependent and as a consequence the spectral component of sound is also altered with distance. Variations in seabed topography (depth, aspect, slope) across space are among the key characteristics of the environment that influence sound propagation; for example the presence of sand banks and shallow coastal areas can significantly reduce transmission, increase pulse duration and affect frequency content. In very shallow water, the tidal cycle may have an important influence on sound propagation. Within the water column, the presence of stratification (e.g. caused offshore by increased surface temperature during the summer or by low salinity at the mouth of rivers) may result in the formation of sound ducts and enhance propagation (see Box 5.4). Seabed sediment type can affect sound propagation, with sand for example being more reflective of sound than clay or mud. Different wind conditions (sea state) will also have an influence.

Overall, modelling sound propagation is a complex endeavour and its complexity depends on the required accuracy as well as the environmental conditions encountered. Several modelling approaches have been developed, each with its own assumptions, strengths and weaknesses (Etter 2013, Spiga 2015). Models based entirely on geometric spreading laws are commonly used and computationally simple. They may offer a suitable approximation in some situations but their limitations must be carefully considered (Robinson *et al.* 2014, Ainslie *et al.* 2014). Especially in the case of heterogeneous shallow environments, these models may introduce substantial errors because they assume that sound levels decrease at a constant rate with range and do not take into account spatial variability in the environment and frequency-dependent effects (Fracas *et al.* 2016). More computational complex models use various mathematical approaches such as ray theory, normal modes and parabolic equations; originally limited to the research community, they are now commonly applied. No single model is applicable to all environmental conditions and acoustic frequencies, and care should be taken in choosing the model most suitable to the task; in particular, range dependent models should be considered when propagating sound over significantly changing bathymetry and models capable of coping with frequency dependence should be investigated when accuracy over considerable distances is required. More complex models require more input data and at times the limiting factor is not the model but the availability of suitable environmental data at the appropriate scale. In all cases, models require validation against experimental data to ensure accurate predictions.

A common use of sound modelling in environmental impact assessment is to predict how much noise generated by a particular activity will be received by marine organisms at one or more locations in the surrounding area. For this, the source level of the activity must be known. In underwater acoustics the source level has been used traditionally as a measure of the output of a transducer; the pressure in the far-field of the source is measured under free field conditions (i.e. large body of water to minimise reflections) and back calculated to 1m range assuming spherical spreading. It has been quoted as dB re 1 μPa @1m (or as dB re 1 μPa.m) but the reference to 1m does not imply a measurement was made at 1m or indeed that the value is expected to be accurate at 1m. Such an approach to determine source level has also been applied to large sound sources such as from a seismic array or during impact pile-driving; caution should always be applied when interpreting these results as they represent only a modelled hypothetical level, higher than what can be encountered in practice (see Section 5.3.2.3.1 for seismic array example). The reasons for this discrepancy are several but all relate to the fact that spherical spreading back-calculations ignore the complexity of sound propagation in the near-field. These include the distributed and complex nature of the sound source (not the infinitely small point source assumed in the propagation model), the presence of reflections at the sea surface and at the seabed, spatial heterogeneity of physical parameters that influence sound propagation. Such estimated source level is appropriate as input to modelling when the focus is in the far-field. However, when the aim is to accurately predict the sound field close to the source, more sophisticated near-field models should be used, ideally benchmarked with near-field measurements.

Finally, ambient noise, also referred to as 'background noise', is the sound field against which signals must be detected (Hildebrand 2009). Ambient noise is a complex combination of several natural and anthropogenic contributing sources, influenced by sound propagation laws (see Appendix Section A1d.2.10). There is relatively large spatial and temporal variability in UK waters which affects signal to noise ratio and hence the range at which a sound may be audible to a receiver may vary significantly (e.g. EU TSG 2014c).

In the next section, sources of noise associated with each element of the draft plan/programme are described. For each element, the potential for noise generation of each main stage of development is considered.

Box 5.3 - Factors influencing propagation

The term **geometric spreading** is used to describe the decrease in intensity and apparent weakening of the signal due to the spreading of the energy as it gets farther from the source. From a point source, the sound wave propagates as spherical waves of increasingly larger diameter and its pressure will decay at a rate proportional to the inverse of the distance (e.g. spherical spreading). In shallow water, the initial spherical propagation may continue as cylindrical spreading once the physical boundaries of surface and seabed have been encountered.

Absorption of sound is caused by both viscosity (where some energy is converted to heat) and a number of chemical relaxation processes due to dissolved salts; the rate of absorption increases with frequency (high frequency sound will travel shorter distances before being reduced to the level of background noise). Absorption is relatively low for low frequency sound; for example at 1kHz absorption is less than 0.1 dB per kilometre.

Reflection of sound waves occurs at physical boundaries such as the sea surface (known to act as a very good 'mirror' for sound waves) and the seabed; multiple reflections may occur as the sound reflects alternatively from the sea surface and the bottom. The result is that a sound may be received at a distance not just from the direct path between source and receiver, but also as multiple signals from the additional reflections. The sea surface is known to act as a very good 'mirror' for sound waves. At the seabed, different sediment types (e.g. clay, gravel) reflect sound to different extents. Depending on a variety of factors, constructive or destructive interferences may be created between signals, reducing or enhancing the decay of sound (e.g. Lloyd mirror effect, 'ghost' reflections). Further signal distortions are introduced through **scattering** when boundaries are rough rather than smooth surfaces (e.g. surface with waves or complex bathymetry) and through **reverberation** depending on the angle at which sound encounters the boundary. Reflection may occur also within the water column, at the boundary between water masses with different physical characteristics.

The path of a sound wave in the ocean follows a straight line only when conditions are constant, allowing the speed of sound to remain the same. However, the sound speed depends on density which in seawater is mainly a function of temperature, salinity and pressure. If any of these variables change, the sound will be refracted and the path will bend towards the area of minimum sound speed. The sound speed is such an important oceanographic parameter that it is routinely measured as a function of depth, either directly or indirectly calculated using a CTD probe. In certain conditions, **refraction** allows so called 'shadow zones' and 'sound channels' to exist in the ocean. 'Shadow zones' are areas where sound from a particular source does not penetrate. Conversely, 'sound channels' act like ducts that tend to focus sound energy, allowing more efficient propagation over that from simple geometrical spreading. The global example is the Deep Sound Channel (or SOund Fixing And Ranging channel), first discovered in the 1940s as part of submarine warfare efforts, where low-frequency sounds have been recorded across entire ocean basins. It is centred at the depth where sound speed is at its minimum, due to a combination of temperature decrease and pressure increase with depth (it occurs between 600 and 1200m at low and middle latitudes but becomes progressively shallower at higher latitudes and reaches the surface in the polar oceans). Smaller sound channels can develop at

varying depths but due to mode-stripping, not all frequencies will be transmitted equally; each channel has a cut-off frequency which depends on its thickness and propagation only of frequencies above that cut-off will be enhanced.

5.3.2 Sources of potentially significant effect

Sources of potentially significant effect are grouped by the element of the draft plan/programme that they are more directly or historically associated with even though it is recognised that many noise generating activities (e.g. vessel traffic, geophysical surveys) are common across all elements. Noise generated during pile-driving and disposal of UXO are described under 'offshore wind farms' together with operational wind farm noise. Operational noise generated by wave and tidal energy devices is the focus of 'wave and tidal power'. Noise from seismic surveys, other geophysical surveys, production platforms, drilling, pipe laying, helicopters, support vessels and decommissioning are under 'Oil & Gas'.

5.3.2.1 Offshore wind farms

Pile Driving

Wind farms constructed in the UKCS to date have primarily relied on monopile technology and percussive methods for installation of turbine foundations, i.e. hammering a steel cylinder into the seabed, known as "pile-driving" (Elmes *et al*. 2013). Other techniques, generating less sound may also be available or in development, see Section 5.3.4.

The understanding of sound generated by impact pile-driving is growing (Nedwell *et al.* 2003, Nedwell & Howell 2004, Madsen *et al*. 2006a, Nedwell *et al*. 2007, Thomsen *et al*. 2006, Lüdemann & Koschinski 2013) and modelled predictions are increasingly in good agreement with acoustic measurements, even in topographically complex coastal environments (e.g. Schecklman *et al*. 2015). Pile-driving of monopole foundations generates a pulsed sound, qualitatively similar to pile-driving resulting from harbour works, bridge construction and oil and gas platform installations. The primary source of underwater sound is associated with the compression of the pile by the hammer strike; as the compressional wave travels through the pile, sound radiates across air, water and sediment and back into the water column with the direct water path being the dominant one (Nedwell *et al.* 2003, OSPAR, 2014). The sound pulse produced with each strike lasts between 50 and 100ms and a common rate of hammering involves 30-60 strikes per minute; it usually takes between 1-2 hours to drive one pile into the seabed (Thomsen *et al*. 2006).

The single pulse has very high energy; in a review of measurements from earlier UK constructions, Nedwell *et al*. (2007) indicated source levels (peak to peak sound pressure level, L_pp) to range between 189 and 257 dB re 1µPa @1m mainly as a function of pile diameter (0.5 to 4.7m). It is important to bear in mind the difficulties with extrapolating far-field sound measurements back to the concept of 'source' (see Ainslie *et al.* 2010) and while very high source levels have been reported (e.g. L_pp > 270 dB re 1µPa @1m) these should be interpreted with care (e.g. Norro *et al*. 2010). Using the energy source level (SLE) as the metric to describe the sound, Ainslie *et al*. (2010) obtained values ranging between 204.5-213.5 and 215-220 dB re µPa2m2s for a 2m pile at a UK site and a 4m diameter pile at a Dutch site, respectively. Pile diameter is largely dictated by the type of foundation required, with monopole foundations relying on single large diameter piles (>3.5m) while jacket foundations commonly use 3 or 4 smaller piles. There are several other factors which influence the levels of underwater sound generated during piling; these include blow energy, size of the hydraulic hammer and sediment type so that considerable variability in sound levels are reported from installation of comparably sized piles (DECC 2011). In terms of frequency spectrum, sound generated from impact pile-driving ranges from less than 20 Hz to more than 20 kHz but most energy is concentrated between 100-500 Hz (e.g. Thomsen *et al.* 2006, Ainslie *et al*. 2010).

Given the high levels, noise from piling can be detected above ambient noise to a range of 25km – 100km, with the latter being characteristic of quiet background conditions (see Nedwell *et al.* 2007 and references therein, Bailey *et al*. 2010).

Operational Noise

Underwater noise during operation of wind turbines is generated mainly by mechanical vibrations in the gear-box and generator inside the nacelle; these vibrations are coupled to the water column and the seabed through the turbine foundations. Noise is also produced in air by the air flow and turbulence from the blades but this is almost completely reflected at the water surface and does not contribute to underwater noise. Sound emitted by turbines in operation is continuous, relatively low in amplitude, broadband and characterised by a series of tonals mostly below 700 Hz The frequency content of the tones is a function of the mechanical properties of each turbine; since turbines are maintained at a constant rate of revolution independent of wind speed, only the height of the peaks and not their location on the frequency axis is affected by increased wind speed (Madsen *et al.* 2006a; Tougaard *et al.* 2009, Marmo *et al.* 2013). Foundation type influences the amplitude and frequency of operational noise; a modelling comparison concluded that monopile foundations have higher acoustic output than gravity or jacket foundations in all wind conditions (Marmo *et al.* 2013).

A review of earlier recordings from operational turbines in Denmark, Sweden and Germany reported considerable variations, especially in the tonal content, but overall received levels dropped to <120 dB re 1 µPa (SPL_{RMS}) at a distance of 100m even in the case with the highest recorded tonal (Whalberg & Westerberg 2005; Madsen *et al.* 2006a). Nedwell *et al.* (2007) reported from operational wind farms in the UK; the noise could be recognised by the tonal components caused by rotating machinery, and by its decay with distance. Typically, even in the immediate vicinity of the wind turbines, the underwater noise dominated over the background noise only in a few limited bands of frequency. Even within this range, the noise was usually only a few dB above the background noise. In some cases, the tonal noise caused by the wind farms was dominated by the tonal noise from distant shipping. In some cases, such as North Hoyle and Kentish Flats, the level of noise measured within the wind farm was slightly greater, by up to 10dB or more, than that measured outside. However, in other cases, such as Barrow and Scroby Sands, the level of noise measured within the wind farm was lower than that measured outside. Similar results were obtained by Tougaard *et al.* (2009) undertaking recordings from different types of wind turbines (450 kW – 2 MW), under different wind conditions in three offshore wind farms; turbine noise was clearly identifiable above background noise at distance where measurements were undertaken (14-40m). Absolute noise levels (SPL_{RMS}) were low, ranging between 109 and 127 dB re 1 µPa; in terms of frequency, turbine noise above ambient was recorded across the 1/3-octave bands between 12.5 and 500 Hz.

As part of a modelling study to predict the large-scale consequences of offshore wind turbine array development (van der Molen *et al.* 2014), an acoustic energy flux model was constructed; large turbines (5 MW) with an equivalent broadband source level energy of 167.6 dB re 1 µPa.m (SPL_{RMS}) resulted in broadband noise levels reaching 113 dB re 1 µPa (SPL_{RMS}) between turbines (800m spacing) and dropping down to 102 dB re 1 µPa (SPL_{RMS}) between farms (5km spacing). Notwithstanding uncertainties and constraints inherent in the model, it was concluded that large arrays of farms of many thousands of turbines offer the potential to make relatively small (a few dB) increases in average ambient noise over large areas. Tougaard *et al.* (2020) reviewed the available literature on measurements of underwater noise from turbines and concluded that the combined source level of a large wind farm is smaller or comparable to that of a large cargo ship. However, they note that wind turbine noise could be significant in areas with low ambient noise and low levels of ship traffic, possibly sufficient to raise concern about negative effects on fish and marine mammals. Similarly, that the cumulative contribution to the soundscape from multiple turbines and multiple wind farms in an area should not be ignored. The five-year project, PrePARED (Predators and Prey Around Renewable Energy Developments) under the Offshore Wind Evidence and Change Programme can be expected to provide evidence on such effects on fish and marine mammals, although distinguishing operational noise effects from those of installation presence may be a challenge.

Airborne operational noise from wind energy developments in the terrestrial environment has received considerable attention in relation to issues of disturbance to nearby residents, particularly where turbines are located in rural areas with low ambient noise levels. Noise assessment criteria (*ETSU-R-97*[101]) provide guidance on the assessment and mitigation of such effects from wind farm developments. Noise emissions from turbines are dominated by aerodynamic noise caused by the interaction of the turbine blade with the turbulence produced both adjacent to it and in its near wake. This is of low frequency and broad band in nature, i.e. it does not contain a distinguishable note or tone. The dominant character of aerodynamic noise is perceived as a ‘swish’ and fluctuates at the rate at which the blades pass a fixed point (typically about 1 blade pass per second); these fluctuations are known as Amplitude Modulation of aerodynamic noise (AM). In some situations, AM can become a source of unacceptable annoyance for neighbouring residents. Airborne operational noise from offshore wind farms is not widely documented, and is currently not considered to be a major source for concern for wind farms located well offshore as the distance between turbines and coastal settlements will allow for sound attenuation between source and receptor.

UXO

Large amounts of legacy unexploded ordnance (UXO) are present in UK and adjacent waters (see Appendix Section A1h.13.2). Sources of the munitions vary, ranging from munitions dumps, wrecks/crashes, weapon firing ranges or mines, torpedoes and depth charges dating from WWI and WWII. Most reported UXO have in the past been detonated in a controlled way out of concern for the safety of fishers and other users of the sea.

UXO detonations have the potential to cause significant injury or death and project developers are bound by health and safety legislation to manage and reduce this risk. For example, in early 2014 three WWII bombs found during development of the Gwynt y Môr offshore wind farm led to a 250m exclusion zone until they were destroyed by controlled explosion (Appleyard 2015) involving the attachment of a small explosive charge to the munition.

In-water explosions create spherical shock waves that travel at faster than the speed of sound in water. Immediately around the source there is a pressure rise followed by an exponential decay and a large oscillating gas bubble is also produced that radiates sound. The explosion itself generates low-frequency shock waves and subsequent pulsations of the bubble sphere at high pressure which propagate over long distances. Water depth affects the sound propagation characteristics, particularly of low frequency sound. Actual recording of noise levels from underwater explosions are sparse but Hildebrand (2009) states that a MK-46 torpedo detonation

[101] ETSU-R-97: The assessment and rating of noise from wind farms.
http://webarchive.nationalarchives.gov.uk/+/http:/www.berr.gov.uk/files/file20433.pdf

with 44kg (of TNT equivalent) explosive would produce a total source level of 289 dB re 1 µPa at 1m (including the initial shock and bubble pulse), with an almost constant frequency content between 10 and 200 Hz. Salomons *et al.* (2021) provide measured and calculated SEL spectra from detonations of two UXO in the North Sea of 325 and 140kg TNT equivalent, with10 kg donor charges; the results indicated for weighted SELs an effects range for harbour porpoise of 2.5–4 4km for PTS and a range 10–15km for TTS.

In the southern North Sea mainly within the Dutch Continental Shelf, controlled explosions of UXOs carried out by the Royal Netherlands Navy during 2010 and 2011 were examined by von Benda-Beckmann *et al.* (2015). It was found that there was a distinct seasonal pattern to the explosions, with a peak in March of 49 explosions and smaller peaks in August and November. The peak in March coincides with a peak of fishing activity, and therefore an increase in encounter rate of UXO. Explosive charge masses reported ranged from 10 to 1,000kg, with most between 125 and 250kg. Large variations in received levels were measured during explosions, at different depths in the water; the minimum SEL measured within 2km was 191 dB re 1 µPa^{2}s and SEL levels of 179[102] dB re 1 µPa^{2}s were estimated to vary between hundreds of metres and 15km.

5.3.2.2 Wave and tidal power

The available information on underwater noise associated with wave and tidal energy devices remains limited; this is partly due to the relatively early stage of development and deployment and partly to the wide variety of technical designs, each potentially providing unique sources of noise (Copping *et al.* 2013, Robinson & Lepper 2013).

The construction phase may include several activities that generate underwater sound, including dredging, vessel traffic, cable laying, drilling and/or piling during device installation; none of these are unique to this industry and are discussed in Sections 5.3.2.1 and 5.3.2.3. Among them, impact piling represents the noise source of most concern, but in practice this is unlikely to occur extensively. Most tidal stream devices are deployed in areas with rocky seabed and as a consequence, they are commonly fixed to the seabed by drilling rather than by piling; offshore wave developments may be installed by drilling on rocky seabed or may use gravity based anchors in areas of sediments (Robinson & Lepper, 2013). When pile installation is necessary, smaller diameter piles (e.g. 1m pin-pile) tend to be used, thus resulting in lower sound levels than commonly associated with the offshore wind industry (Copping *et al.* 2013).

During operation, sound generation will depend on the design of the device as well as on operating conditions (i.e. wave height and/or tidal state). The overall sound output will be a combination of several sources including noise generated by the device itself (e.g. rotating machinery, joints etc.) and by its interaction with water (e.g. turbulence, vortex shedding); many of these mechanisms are not yet well characterised and more direct measurements are required. However, accurate measurements of the acoustic environment are technically difficult to achieve within fast flowing conditions, such as tidal streams, and novel measurement techniques may need to be explored (Robinson & Lepper, 2013). In addition, wave and tidal energy devices have the potential to generate complex particle velocity fields in the near-field; while this is of relevance to many organisms, particle velocity is not typically measured (Robinson & Lepper, 2013).

The SeaGen 1.2MW tidal energy convertor was installed in the Narrows of Strangford Lough in April 2008; a comprehensive Environmental Monitoring Plan covering all phases of this

[102] Updated injury criteria for harbour porpoise

demonstrator project was implemented as part of the licence conditions (Royal Haskoning, 2011). Noise associated with SeaGen was first reported by Nedwell & Brooker (2007) and summarised in a biological noise assessment by SMRU (2010). Noise measurements of SeaGen carried out with high-precision instruments from a drifting boat showed that it produces narrowband, tonal components as well as broadband noise. The main narrowband components are tones at frequencies of 110-120Hz, 750Hz and 1500Hz. The maximum measured power spectral density at 49m distance was 153dB re 1 µPa/Hz2 and originates from the 750Hz tone. At close ranges, the power spectral density of the broadband noise is generally 40dB below that of the tones. The 'source level' of SeaGen was back-calculated from field measurements using a simple geometric propagation model and estimated to be 174dB re 1µPa. Ambient noise levels were also characterised at the site under different environmental conditions; measurements at slack tide and low sea state appear to be less than 80dB re 1 µPa/Hz2 at frequencies higher than 20-30Hz, but in conditions with strong tidal currents and slightly higher sea state, ambient noise levels increase by 15-20dB in a frequency range between 0.1kHz and 10kHz and remain high even at frequencies above 10kHz, most likely the result of moving stones on the seafloor (Nedwell & Brooker 2007).

As part of The Crown Estate's Pentland Firth and Orkney Waters Enabling Actions programme, Robinson & Lepper (2013) reviewed available evidence on noise radiated by wave and tidal stream energy devices. Information was obtained from publicly available resources as well as directly from manufacturers, developers, regulators and their advisers. Broadband 'Effective Radiated Noise Level' obtained for tidal energy converters ranged between 166 and 174 dB re 1 µPa referred to 1m. Measurements of operational noise for wave energy converters showed a range in broadband source level between 120 and 180 dB re 1 µPa2/Hz between low and high sea state and received levels SPL at 10-20m were 126-129 dB re 1 µPa. While an accurate comparison was difficult because of the use of different acoustic output metrics, the authors concluded that noise radiated during operation is comparable to that of a modest size vessel at moderate speed (e.g. a trailing suction hopper dredger during operation). Of key relevance to assessing impact, noise radiated during operation is likely to be below ambient noise levels beyond a limited range from the device (a few hundred metres to a few kilometres). This may occur both at low and high sea states as a strong correlation is likely between operational and ambient noise, for example in the case of wave energy converters, a high sea state will result in both an increase in operational noise and ambient noise (Robinson & Lepper 2013).

Noise recorded from the Wavestar wave energy converter installed on the Danish North Sea coast indicated noise levels at 25m from the converter were 1-2 dV above ambient in the range 125-250 Hz but undetectable at other frequencies. These results may not be directly transferable to all wave energy converters as the low emissions recorded here are most likely due to the specific construction design used, where all moving parts, except for the absorbers, are placed above water on a jack-up rig (Tougaard 2015).

5.3.2.3 Oil & gas

Seismic survey

Seismic surveys are commonly used during the exploration, development and production of oil & gas to map hydrocarbon bearing formations and their geologic context. The technique is based on the determinations of the time interval between the initiation of a seismic wave and the arrival of reflected or refracted impulses at detectors. The most common seismic source is the air-gun, typically used in tuned arrays; the receivers are usually hydrophones, detecting the reflected sound waves as pressure fluctuations in water. A brief summary of categories of seismic survey operations common in the UKCS are given below and a detailed overview can be found in OGP (2011).

- A two dimensional (2D) seismic survey involves a survey vessel towing a single airgun array and a single streamer, containing several hydrophones along its length. Streamers are typically 3-8km long (up to 12km). Repeated parallel lines are run at intervals of several kilometres (minimum 0.5km) and a second set of lines at right angles to the first is used to form a grid pattern.
- In a three dimensional (3D) seismic survey, a vessel tows two or more airgun arrays and several streamers (up to 16). Because the streamers are close to each other (typically 25-75m), data density is much improved with respect to 2D. These surveys may take several months to complete and cover areas of 300-3,000km^2.
- When a 3D survey is planned to be repeated over time (e.g. for reservoir management), it is referred to as a 4D seismic survey.
- Site surveys are carried out to obtain high resolution maps of the seabed surface and near subsurface. To achieve such high resolution, a similar technique to 2D seismic is used but crucially, a much smaller seismic source (a four air-gun cluster of 160 in^3 is typical or alternatively a mini-gun, 'sparker' or 'boomer' device) and receiving streamer (600-1200m in length) are deployed. Typically the area covered is 2-3km^2 and the survey lasts four or five days. Site surveys once a platform is in place may require the use of 'undershooting' whereby the sub-surface beneath an obstruction can be imaged by deploying the source and the receiver on separate vessels.
- Vertical Seismic Profiling (VPS) is employed to assist with well evaluation, by linking rock strata encountered in drilling to seismic survey data. A number of geophones are lowered into a well while the airgun array is deployed from either the rig itself, or from a vessel which may be stationary or moving. Sound source volumes are typically around 500 in^3, with a maximum of 1200 in^3 (Stone 2015b). Survey duration is short (one or two days at most).
- Ocean bottom seismic techniques, including ocean bottom seismometers (OBS), two-component (2C) and four component (4C) techniques, rely on acquisition of information by sensors placed directly on the seabed (either within cables or within sensor nodes). In addition to hydrophones, ground motion sensors (geophone or accelerometer) are used in 2C and 4C. The seismic source is deployed as in 2D or 3D surveys. This type of survey is favoured to accurately monitor reservoir depletion.

Airguns are among the highest energy anthropogenic sound sources in the sea (Richardson *et al.* 1995); when an airgun fires, part of the energy is converted to sound and generates a seismic signal that travels into the earth's subsurface. Single airguns may be used but only in specific instances (e.g. site surveys); to achieve the required high amplitude and low frequency ideal seismic wavelet (perfect impulse) airguns are combined into arrays i.e. strings of multiple airguns supported by towed floating tubes (Dragoset 2000). Tuned airgun arrays consist of many guns of different, carefully selected volumes fired simultaneously; sound pressure is proportional to the cube root of the volume so that several small guns are more effective than a few large ones. The volume of a single air-gun varies between 30 and 800 in^3, while whole arrays, typically involving 12-48 guns (up to 100 are used), have a volume of 3000-8000 in^3. In the UKCS for the period 1998-2010 Stone (2015a) reported a yearly mean array volume between 2000-4000 in^3 and maximum volumes between 4000-7000 in^3, with the largest volume of 10,170in^3 used on a 2D survey in 2006. Airgun arrays are towed generally at 6m (5-10m) below the surface. During normal operations guns are fired every 10-15s at a typical operating pressure of 2000 psi.

Several array geometries can be deployed, with horizontal arrays of 3-6 sub-arrays being common. Thus an array is not a point source but spans a small area (e.g. 15x16m, 30x15m) (Caldwell & Dragoset 2000). From a test measurement, energy output can be back-calculated assuming that the array is a point source; these values are commonly presented as 'nominal peak source level' but they do not accurately resemble energy at a short distance from the array (i.e. 'near-field'). While each airgun is an omnidirectional sound source, an airgun array does not behave as a point source; in the near-field, the horizontal configuration of the guns in the array is such that the outputs of each gun interfere destructively with one another, so that peak pressures are significantly lower than the output of the largest individual gun. This is done purposefully to concentrate the radiation pattern downwards; hence amplitude levels emitted vertically below the array tend to be at least 15-24 dB larger than levels emitted horizontally (Cadwell & Dragonet 2000). Back-calculated sound levels measured in the far-field from arrays have exceeded >260 dB (e.g. Wyatt 2008 and references therein) but for reasons given above, these values are only theoretical and should not be confused with the true maximum amplitude. More sophisticated modelling is used by the industry to accurately model array output; Cadwell & Dragonet (2000) estimated that despite the myriad array geometries deployed, overall output levels (RMS peak-to-peak amplitudes) tended to be 240-246 dB re 1 µPa vertically downward and 220-230 dB re 1 µPa in the horizontal plane. Differences in the horizontal plane have also been observed (Breitzke *et al.* 2008); likely due to a shadowing effect of the vessel, levels recorded during vessel approach were lower than during departure from the hydrophone.

Given the high source level and low frequency dominance, seismic sound can propagate large distances and ensonify areas on scales of ecological importance. The exact propagation is case specific but representative studies are informative; peak sound pressure levels are commonly reported to have decreased below 200 dB re 1 µPa at a range of 100-1000m and below 160 at a range of 10-11km (e.g. Breitzke *et al.* 2008, Kongsberg 2010). Acoustic detection of seismic survey noise above ambient occurs regularly at distances of hundreds or even thousands of kilometres from the location where firing is taking place (Nieukirk *et al.* 2012); during surveys, average ambient levels in the low-frequency 20-50 Hz band most important to whales can be raised by 10-25 dB over large areas (e.g. 7500nm^2) as reported by Clark & Gagnon (2006).

Frequency influences how far sound may travel and only low frequencies can penetrate the seabed to the depths (several kilometres) required in many oil & gas activities. Airguns produce most of their energy in the low frequency, centred around 50Hz and mainly below 200Hz but nonetheless a very broad frequency spectrum is produced and energy up to at least 15kHz has been recorded (Goold & Fish, 1998; Madsen *et al.* 2006b); while amplitude at higher frequencies is low relative to that at the peak frequency, it may still be loud in absolute terms given the overall high energy generated. In addition, the spectral signature of sound changes as it propagates away from source, depending on the environmental conditions encountered; for example in shallow coastal water low frequencies propagate poorly. This has been confirmed by Hermannsen *et al.* (2015); the authors studied characteristics and propagation of airgun pulses and made recordings (10Hz up to 120kHz) from single air-guns (10-40 in3) in a sandy area with a uniform depth of 15m at different distances (up to 1300m). While most of the signal energy was found at frequencies below 1kHz, high frequency components were also present (up to 10kHz at 1300m) and crucially the ratio between high and low frequency noise changed with distance. The peak frequency increased with range as did the noise energy above 1kHz relative to the total broadband energy. Another instance when environmental conditions combine to proportionally increase the high-frequency content of airgun signals is surface ducting. This was observed by De Ruiter *et al.* (2006) modelling acoustic propagation of airgun array pulses recorded on tagged sperm whales in the Gulf of Mexico. Some arrivals recorded near the surface had energy predominantly above 500 Hz at the time and location when sound speed profile indicated the presence of a surface duct in the water column.

Waves degrade the seismic signal because the geometry of the array becomes less stable and because rough seas spread out the reflection of the sound (i.e. the ghost reflection) producing a composite smoothed pulse with much reduced amplitude (OGP 2011). Weather appears to be less of an operational constraint on VSP and OBC surveys than 2D and 3D surveys; in practice in the UKCS, Stone (2015b) observed a clear seasonal pattern in 2D and 3D surveys with more activity in summer, but not in VSP.

Seismic interference from other surveys reduces productivity and is therefore avoided (OGP 2011).

Other Geophysical Surveys

In addition to airguns, there are a variety of other equipment and sound sources used in geophysical surveys, including echosounders, side-scan sonars and sub-bottom profilers (pingers, boomers, chirp, sparkers). In comparison to airguns, such equipment use higher frequency sound and focus on surface or shallow seabed imaging (see Zykov 2013, DECC 2011b). Most information of noise exposure during these surveys is modelled and direct measurements are limited. Sub-bottom profilers generate sound from about 500Hz to 10-300 kHz; their use by industry requires regulatory consent and is monitored through the UK Marine Noise Registry. There are several different types of echosounders, resulting in a variety of outputs in terms of power, frequency and directionality (single to complex beam patterns) but for those most commonly used on site surveys, the expectation is that sound levels drop off very quickly with distance due to a combination of high frequency (>10kHz) and high directionality. Side-scan sonar are also characterised by very high frequency output (>100kHz).

Drilling

Available measurements indicate that drilling activities produce mainly low-frequency continuous noise from several separate sources on the drilling unit (Richardson *et al.* 1995, Lawson *et al.* 2001). The primary sources of noise are various types of rotating machinery but the overall acoustic output depends on the type of operation (Wyatt 2008). When drilling from semi-submersible rigs, noise is transmitted from the rig to the water column through submerged parts of the drilling unit hull, risers and mooring cables, and (to a much smaller extent) across the air-water interface. If position is maintained by dynamic positioning, noise from thrusters may dominate the lower frequency band (Wyatt 2008). Noise transmission from jack-up drilling units used in shallower water is less because of reduced surface area contact between the water column and submerged parts of the rig. Sound pressure levels of 120dB re 1µPa in the frequency range 2-1400Hz (Todd & White 2012) are probably typical of drilling from a jack-up rig and is of the same order and dominant frequency range as that from large merchant vessels (e.g. McCauley 1994). Drilling duration may range from a few weeks for an exploration well, to several years in the case of a large development programme.

Pipe laying

The overall source levels resulting from pipe laying operations on the UKCS are not typically measured; however, near-field cumulative sound levels associated with pipe lay for the Clair project were predicted to be a maximum of 177dB (Lawson *et al.* 2001), with a duration of weeks or months. Pipelines can either be laid directly on the seabed or trenched and buried. Noise levels will likely be dominated by the vessel noise associated with installation (Genesis 2011). A pipeline installation which includes trenching and backfilling activities, is likely to be comparable to dredging activities, particularly cutter trailing dredgers and trailing suction hopper dredgers (Genesis 2011). Dredging generates underwater sound during sediment excavation, transportation and placement. This can originate through a variety of sources including movement of material, engine and mechanical sound, propellers, pumps, cutting and digging of material. Underwater sound caused by dredging activities is typically of low frequency, with strongest sound below 1 kHz (de Jong *et al.* 2010). However, relatively high source levels can be generated above 1 kHz (Robinson *et al.* 2011). Sound source levels typically range from 168 to 186 dB re 1 µPa (Genesis 2011). The levels and frequencies generated depend on the type of dredger, operational status and sediment type. Robinson *et al.* (2011) found that source levels were approximately 5 dB higher during dredging of gravel compared with sand.

Production platforms

Although there is little published data, noise emission from production platforms is qualitatively similar to that from ships, and is produced mainly by rotating machinery (turbines, generators, compressors). The compression required for gas export may be a significant source of noise, but propagation into the water column will be limited. Gas storage developments are predicted to be very similar, in terms of noise, to existing gas production.

Helicopters

A further source of noise associated with all stages of the offshore oil industry is helicopter overflights. There is relatively little quantitative information on the transmission of helicopter airborne noise to the marine environment (Richardson *et al.* 1995). Measurements of an air-sea rescue helicopter over the Shannon estuary (Berrow *et al.* 2002) indicated that due to the large impedance mismatch when sound travels from air to water, the penetration of airborne sound energy from the rotor blades was largely reflected from the surface of the water with only a small fraction of the sound energy coupled into the water.

Support Vessels

Noise from marine vessels represent numerous, widespread and relatively loud individual sources which combine to form by far the dominant anthropogenic source of continuous low frequency sound in the marine environment. Several factors play a role in determining the exact characteristics of radiated vessel noise, including vessel type, size, age, mode of propulsion and speed (OSPAR 2009). For example, Abrahamsen (2012) found dominant noise radiation from low powered vessels to be from on-board machinery, such as hydraulic systems, gears and compressors. Propellers and/or thrusters were the strongest noise source for many vessels, particularly high powered or high speed vessels. Noise was measured from a survey vessel at two different operating conditions; machinery noise dominated at a speed of 8 knots and propeller noise dominated at 13 knots (Abrahamsen 2012). Peak amplitude of machinery noise was found to be generated by the gears. Most support vessels are medium-size ship (50-100m length); typical broadband source levels are within the 165-180 dB re 1 µPa range and although there is considerable variability in associated frequency spectra, they tend to be similar to large vessels with dominant frequency below 1kHz (OSPAR 2009). Support vessels may be stationary for large periods of time, either at anchor or through dynamic positioning (DP) thrusters. Noise generated from DP is not well documented but it likely to be less than that generated during transit.

Decommissioning

Noise will be generated during decommissioning works and potential effects will depend on the type and duration of activities undertaken. In many instances, decommissioning requires a similar set of activities and associated noise emissions to construction and installation, with the exception of an absence of extensive seismic surveys and pile-driving activities. The main sources of noise are rigs and vessels as well as mechanical cutting techniques. Underwater noise emissions from cutting tools (operated by divers or remotely) are unlikely to result in sufficient levels of noise to cause significant disturbance to marine life. The use of explosive cutting methods may produce high intensity impulsive noise, although such activities are infrequent and would be subject to activity-specific assessment and regulation, with alternative cutting methods sought where possible.

5.3.2.4 Carbon dioxide storage

Noise characteristics of potential carbon dioxide storage developments are likely to be very similar to existing oil and gas developments. Geophysical surveys, in particular 4D seismic surveys (i.e. repeated, high resolution 3D surveys), may be necessary to monitor CO_2 plume spread within the reservoir. This may involve the deployment of permanent seabed geophone arrays. The frequency and cumulative acoustic disturbance associated with geophysical monitoring of carbon dioxide storage is not clear.

5.3.2.5 Gas storage

As with carbon dioxide storage, noise associated with gas storage in depleted reservoirs or salt caverns is predicted to be very similar to the survey, drilling and operational phases of conventional gas exploration and production.

5.3.3 Consideration of the evidence

Given the variety of sounds to which marine organisms may be exposed, potential effects are wide ranging, involving both physiology and behaviour (Kight & Swaddle 2011). In addition to direct effects on a receptor, indirect effects may also occur for example via potential changes to prey species.

The most acute effects can be lethal, involving the direct physical damage of body tissues and air filled cavities from rapid pressure change (i.e. barotrauma); these effects are spatially restricted to the immediate proximity of very high amplitude impulsive sounds (e.g. explosions, see Siebert *et al*. 2022) and are relatively well understood in part thanks to the interest in establishing safe levels for humans working underwater (Richardson *et al.* 1995, Parvin *et al.* 2007). In marine mammals, there is also a risk of nitrogen bubbles being formed, which may result in physiological effects similar to decompression sickness in humans. Although evidence on the exact mechanism remains equivocal, bubble formation has been suggested as causal mechanism between certain sound exposure (e.g. military sonar) and stranding events in beaked whales and other species (Southall *et al.* 2007).

The auditory system is most sensitive to sound and can be damaged by elevated sound (e.g. through damage and death of sensory hair cells in the ear). Depending on the exposure (e.g. sound type, amplitude, duration, kurtosis, duty cycle, frequency), damage may result in an irreversible loss of hearing functions (i.e. a permanent shift in hearing thresholds or PTS) or in a temporal loss of hearing functions (i.e. a temporal shift in hearing thresholds, or TTS) also called auditory fatigue, from which recovery is possible (e.g. Southall *et al.* 2007, 2019). Although not immediately fatal, the consequences of auditory damage are of concern given the importance of sound for marine organisms across a spectrum of activities, including communication, orientation, predator avoidance and foraging (e.g. OSPAR 2009).

There is also the potential for a pervasive role of noise as a chronic stressor given that in humans a variety of consequences on health, including cardiovascular disease, cognitive impairment and sleep disturbance have been identified (WHO 2011).

In addition to physiological impacts, behavioural changes can be induced in response to sound, resulting in disruption of normal activity. All types of behaviour may be affected including locomotion, communication, foraging and reproduction and while short-term effects are likely to have little ecological consequences, prolonged effects may be significant; the main concern is whether individual vital rates and ultimately population viability can be affected. Behavioural responses can be difficult to measure, interpret and predict; most importantly in relation to impact assessment, behavioural responses have been found to be strongly context specific depending on an individual's internal state, its perceived risks and habitat quality (Bejder *et al.* 2009, Gill *et al.* 2001). For example, avoidance of low-quality habitats may take place more readily because the immediate consequences to an individual are likely to be negligible.

Anthropogenic noise may mask important acoustic cues (Richardson *et al.* 1995); masking occurs whenever the presence of a sound reduces the animal's ability to hear a second sound (i.e. threshold of hearing for a second sound is increased). In the case of vocal communication involving a sender and a receiver, both may have their performance reduced through acoustic interference from anthropogenic noise. Masking is more effective the greater the overlap in frequency between signal and noise; temporal overlap also plays a role but the relative potential of continuous and pulsed sounds is currently still unclear (EU TSG Noise 2014c). The levels of sound involved in masking can be relatively low and as a consequence the spatial footprint can be very large; this rationale led to the development of the MSFD indicator 11.2.1 (Tasker *et al.* 2010).

As discussed above, the relationship between the type of effect elicited and sound level (or distance from source) is far from straightforward but nonetheless in many cases, it can be used as a valid approximation. The 'zone of influence model' of Richardson *et al.* (1995) was the first approach to assessing noise impacts on marine mammals largely on the basis of distance between source and receiver; four zones of influence were identified, each centred on the source and each of increasing size, determined by sound thresholds of decreasing amplitude: (1) zone of hearing loss, discomfort or injury, (2) zone of masking, (3) zone of responsiveness and (4) zone of audibility.

More recent developments establishing criteria for impacts have followed this original approach; efforts have focused on reviewing available evidence and establishing thresholds were meaningful to do so. For management, threshold criteria can be a useful and relatively simple tool to apply because they reduce the complexity of judging impact to whether sound produced exceeds a given level. However, in so doing, the complexity is shifted on to the process of establishing criteria. Since the acoustic sensitivity and the behaviour of the receiver play a very important role in how sound may affect marine organisms, impact criteria are specific to each receptor and are introduced in the relevant sections below.

5.3.3.1 Marine Mammals

Marine mammals emit and hear sound across a very wide frequency bandwidth spanning from the low frequency calls of baleen whales to the high frequency echolocating clicks of dolphins. Hearing sensitivity is expressed in the form of a hearing curve (i.e. audiogram) where the lowest sound level detected is plotted as a function of frequency; an audiogram commonly exhibits a U-shaped form with greater sensitivity (lower sounds detected) in the middle of a specific bandwidth. In marine mammals, audiograms have been obtained for several species of odontocetes and pinnipeds using either behavioural or electrophysiological (AEP) methods, mainly with captive individuals but also with wild animals temporarily captured and restrained (see Castellote *et al.* 2014, Finneran 2015 and references therein). No measurement has yet been made for any baleen whale and their sensitivity is derived from knowledge of the acoustic properties of emitted signals and anatomical features. Southall *et al.* (2007, 2019) considered the differences and similarities in auditory capabilities between species and grouped marine mammals into functional groups; cetaceans were divided into low-, mid- and high- frequency while pinnipeds were treated differently with respect to whether they were in water or air. These groups are currently considered relevant to noise impact assessment in UKCS and provided for reference in Table 5.1.

Table 5.1: Marine mammal functional hearing groups, estimated hearing ranges and relevant species regularly present in UK waters.

Functional hearing group	Estimated hearing range (region of greatest sensitivity) [frequency of peak sensitivity]	Species in UK waters
Low-frequency cetaceans	7 Hz to 35 kHz (200 Hz to 19 kHz) [5.6 kHz]	Minke whale *Balaenoptera acutorostrata* Fin whale *Balaenoptera physalus* Humpback whale *Megaptera novaeangliae* Sei whale *Balaenoptera borealis* Blue whale *Balaenoptera musculus*
High-frequency cetaceans	150 Hz to 160 kHz (8.8 kHz to 110 kHz) [58 kHz]	Bottlenose dolphin *Tursiops truncatus* Short-beaked common dolphin *Delphinus delphis* White-beaked dolphin *Lagenorhynchus albirostris* Atlantic white sided dolphin *Lagenorhynchus acutus* Risso's dolphin *Grampus griseus* Striped dolphin *Stenella coeruleoalba* Long-finned pilot whales *Globicephala melas* Beaked whales *Mesoplodon spp., Ziphius spp. Hyperodon spp.* Killer whale *Orcinus orca* Sperm whale *Physeter macrocephalus*
Very high-frequency cetaceans	275 Hz to 160 kHz (12 kHz to 140 kHz) [105 kHz]	Harbour porpoise *Phocoena phocoena*
Phocid seals in water	50 Hz to 86 kHz	As above

Functional hearing group	Estimated hearing range (region of greatest sensitivity) [frequency of peak sensitivity]	Species in UK waters
	(1.9 kHz to 30 kHz) [13 kHz]	

Source: Southall *et al.* (2019). Notes: The region of greatest sensitivity represents parameters f1 and f2, which are the bounds of the flat, central portion of the frequency-weighting curve region; the frequency of peak sensitivity represents parameter f0.

The most significant contributions to the development of threshold criteria for the management of noise-generating activities with respect to marine mammals was provided by Southall *et al.* (2007, 2019, 2021). They reviewed available science on the impact of noise on the hearing of cetaceans and pinnipeds and their behaviour and proposed noise exposure criteria which are now the most commonly used in the UK[103]. Another approach used in environmental statements in the UK was proposed by Nedwell *et al.* (2007); because of its wider application with respect to fish it is described in Section 5.3.3.2.

Southall *et al.* (2007) distinguished anthropogenic sound sources according to their acoustic and operational features into 'single pulse', 'multiple pulses' and 'non-pulses' and established criteria for each. With regard to metrics, since damage to auditory capabilities can occur from instantaneous exposure to a very intensive sound as well as to cumulative exposure over time of sound of lesser relative intensity, they proposed a dual-criterion approach based on both pressure and energy (i.e. the relevant threshold in any one case is the first one to be exceeded). The chosen metrics were zero-to-peak sound pressure level, L_{peak}[104] and cumulative sound exposure level, SEL_{cum}. The former being best suited to single pulses and for all sounds which include intense peak pressure components while the latter is favoured when assessing cumulative exposure as it allows sounds of different durations to be compared in terms of total energy. SEL_{cum} is the cumulative exposure over a 24h period calculated by simple summation of multiple exposures (assuming no recovery of hearing). To compensate quantitatively for the differential frequency response between functional groups, Southall *et al.* (2007) proposed frequency weighting functions (M-functions) to be applied in the calculation of SEL. These were derived following the approach of C-functions[105] for human hearing. The authors recognised that injury and behavioural disturbance as very different effects and dealt with them separately. Data on non-auditory injury (e.g. gas bubble growth) was insufficient to allow formulation of quantitative criteria, so the focus of injury criteria is on auditory injury.

Southall *et al.* produced a recent comprehensive review of information on hearing, sound production and the effects of noise on hearing in marine mammals (Southall *et al.* 2019). Injury criteria from Southall *et al.* (2019). are given in Table 5.2; they are the received level of sound which corresponds to the estimated onset of PTS.

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[103] These criteria have been recommended in the guidance for the protection of marine European Protected Species from injury and disturbance (JNCC, NE & CCW 2010, Marine Scotland 2020b)
[104] Southall *et al.* (2007) used to abbreviate zero-to-peak sound pressure level to SPL_{peak} but L_{peak} is now preferred.
[105] The C-weighting function is based on equal loudness contours and used in human audiology to quantify the loudness of more intense sounds.

Table 5.2: Marine mammal injury criteria

Functional hearing group	Dual-criteria	PTS Onset - Impulsive noise	PTS Onset - Non-impulsive noise
Low-frequency cetaceans	peak sound pressure level (peak SPL) unweighted	219	
	sound exposure level (SEL) weighted	183	199
High-frequency cetaceans	peak sound pressure level (peak SPL) unweighted	230	
	sound exposure level (SEL) weighted	185	198
Very high frequency cetaceans	peak sound pressure level (peak SPL) unweighted	202	
	sound exposure level (SEL) weighted	155	173
Pinnipeds in water	peak sound pressure level (peak SPL) unweighted	218	
	sound exposure level (SEL) weighted	185	201

Source: Southall *et al.* (2019). Notes: SEL thresholds in dB re1 μPa^{2}s under water, SPL thresholds in dB re 1 μPa under water

Since PTS has not been measured directly in any experiment on marine mammals, but only extrapolated from TTS measurements, the process of developing these criteria relied on several assumptions. Inevitably choices with respect of which evidence to use were made at several steps in the process and the authors purposefully and consistently erred on the conservative side. The following aspects are highlighted by way of example:

- SEL is calculated over a 24hr period assuming no recovery between sounds, even when large intervals may occur. This is a practical approach to deal with the difficult issue of interval and hearing recovery but it is flawed as recovery during intervals between sounds plays a crucial role in the growth of TTS; depending upon the temporal pattern of the activity, this assumption may have a potentially minor or large consequence in overestimating the potential for injury (e.g. Hastie *et al.* 2015).
- SEL is calculated assuming the Equal Energy Hypothesis to be valid and yet as more evidence becomes available it is clear that this is not always the case; fatiguing sounds induce different TTS depending not just on total amount of energy but on the interaction between level, duration of exposure, rate of repetition and frequency (Kastelein *et al.* 2012, 2014; 2016, Popov *et al.* 2014). The concept of 'effective quiet' is also ignored i.e. the maximum sound pressure level that will fail to produce any significant threshold shift despite duration of exposure and amount of accumulation.

- SEL is frequency weighted to account for species differences when evaluating impact; the choice of weighting curve can have important consequences on SEL calculations and there are concerns that the M-weighting curve adopted by Southall *et al.* 2007 may not be the most appropriate (Tougaard *et al.* 2015, NOAA 2015, Houser & Moore 2014).

It follows that these injury thresholds are precautionary and should be interpreted as the sound levels above which a risk of PTS occurring becomes increasingly likely and below which there is no scientific basis for expecting auditory injury to occur; it would be an over- simplification of their report to state that PTS is induced as soon as thresholds for injury are reached.

Southall *et al.* (2007) presented their criteria as 'preliminary', being well aware of the fast pace of current research and the need to improve and update these criteria as soon as new evidence becomes available. Since 2007, much of the evidence on TTS in mid-frequency cetaceans and harbour seals has tended to corroborate earlier findings. On the contrary, recent research on harbour porpoise warrants a revision of thresholds for high-frequency cetaceans. The early suggestion that harbour porpoises were more sensitive to noise than other cetaceans (as reported by Southall *et al.* (2007) in light of preliminary results by Lucke *et al.* (2007)), has been corroborated. Lucke *et al.* (2009) measured the auditory evoked potentials of an adult male harbour porpoise exposed to single airgun pulses and recognised the onset of TTS to occur at received sound pressure level (L_{pp}) of 199.7 dB re 1 μPa and a sound exposure level (SEL) of 145 dB re 1 μPa^{2}s. Kastelein *et al.* (2010, 2012a, 2013b, 2014, 2020) carried out several tests, also on an adult male harbour porpoise, to quantify TTS and hearing recovery after exposure to fatiguing continuous sound (octave band white noise centred at 4kHz); TTS was observed across a range of SEL 151-175, depending on SPL, duration and interval between exposures. While differences in sound types and methodologies make comparison between these studies difficult, there is now agreement that harbour porpoises are more sensitive to sound than other species previously tested.

A report for SNH on sensitivity of cetaceans and seals to acoustic deterrents (Lepper *et al.* 2014), applied the procedure proposed by Southall *et al.* (2007) to the results obtained by Lucke *et al.* (2009) and revised injury thresholds for harbour porpoise accordingly for continuous and pulsed sounds. (Table 5.3).

Table 5.3: Revised injury criteria for harbour porpoise

Dual-criteria	Multiple pulses	Non-pulsed
sound pressure level L_{peak} dB re 1 μPa	200	200
sound exposure level SEL_{cum} dB re 1 μPa^{2}s	179	184

Source: Lepper *et al.* (2014) based on the threshold for TTS onset reported in Lucke *et al.* (2009)

The US National Oceanographic and Atmospheric Administration (NOAA) has updated acoustic threshold levels as part of 'acoustic guidance for assessing the effects of anthropogenic sound on marine mammal species'[106]. The guidance proposes criteria for injury based on an approach similar to that of Southall *et al.* (2007) and incorporating recent research results. In addition to high-frequency cetaceans being recognised as a particularly sensitive group, the main

[106] http://www.nmfs.noaa.gov/pr/acoustics/guidelines.htm

innovation is a new set of marine mammal auditory functions constructed by Finneran (2015)[107]. Kastelein *et al*. (2020) investigated noise-induced temporary hearing TTS in a harbour porpoise exposed to impulsive sounds from airguns while both stationary and free-swimming for up to 90 minutes. In a previous study, ~4 dB TTS was elicited in this porpoise, but despite 8 dB higher single-shot and cumulative exposure levels (up to 199 dB re 1 lPa^{2}s) in the study, the porpoise showed no significant TTS at hearing frequencies 2, 4, or 8 kHz. There were no changes in the animal's audiogram or significant differences in the fatiguing sound between the studies, but audible and visual cues may have allowed the porpoise to predict when the fatiguing sounds would be produced. This may have allowed self-mitigation by the porpoise resulting in reduced hearing sensitivity, achieved via changes in the orientation of the head, or by alteration of the hearing threshold by processes in the ear or central nervous system.

With respect to behavioural effects, criteria based on exposure alone have been much more difficult to extrapolate, mainly because behavioural responses are often affected by individual history and exposure context. For single pulses, Southall *et al.* (2007) assumed that significant behavioural disturbance could occur if noise exposure was sufficient to elicit a measurable transient effect on hearing or TTS-onset. However, for multiple pulses (e.g. seismic survey) and continuous sounds, behaviour was assumed to be affected at sound levels below TTS onset. A systematic assessment of available behavioural disturbance studies was carried out by assigning severity scores to the relevant received sound level, on the basis of a simple 'behavioural response severity scale', ranging from minor behaviours with negligible and brief effects (scores 0-3) to those affecting vital rates (scores 7-9). Due to various statistical and methodological problems, much of the data were not considered to provide sufficient scientific credence for establishment of exposure criteria. The results suggested the presence of dose-response relationships between noise exposure and behaviour but the very high variability observed meant that no single threshold could be reasonably justified. Instead Southall *et al.* (2007) noted the importance of contextual variables in determining behavioural response; together with the presence or absence of acoustic similarities between the anthropogenic sound and biologically relevant natural signals (e.g. calls of conspecifics, predators, prey). Overall, caution was recommended in the application of the severity analyses and careful consideration of 'the overall context of exposure relative to that shown in the studies reviewed'. Further empirical evidence has been collected over the last ten years providing a stronger basis for comparison; key studies are presented below. In the UK, European Protected Species Guidance (JNCC 2010) recommends that disturbance as described in Regulations 39(1), 39(1)(b) and 39(1A)(a) of the HR and OMR is interpreted as sustained or chronic disruption of behaviour scoring 5 or more in the Southall *et al.* (2007) behavioural response severity scale.

The behaviour of marine mammals introduces uncertainty and complexity not just in terms of response (see Kastelein *et al.* 2020 & Southall *et al*. 2021) but also in the calculation of exposure. The position in the water column and the movement of an animal with respect to the direction (and movement) of a sound source influences its overall exposure. To cope with large uncertainties in these respects, a comparison of predictions based on different expected behaviour (e.g. static, transiting and fleeing animals) is often included in noise assessments. More complex models are capable of including specific details for both source and receiver

[107] The shape of the function has changed from the M-weighting function (resembling the human dB(C) approach) to a function based on a generic band-pass filter that resembles the much more commonly applied human dB(A). Function parameters are derived for each hearing functional group from available data including behavioural audiograms, equal latency contours, TTS measurements and predicted audiograms from anatomically based models.

(speed, direction, diving pattern, expected response to sound) and simulate relative source and receiver movement.

Taking all of the above in consideration, the EU MSFD Technical Subgroup (TSG Noise) under the Working Group on Good Environmental Status has developed an indicator (Indicator 11.1.1) on low- and mid- frequency impulsive sounds defined as: "*The proportion of days and their distribution within a calendar year, over geographical locations whose shape and area are to be determined, and their spatial distribution in which source level or suitable proxy of anthropogenic sound sources, measured over the frequency band 10 Hz to 10 kHz, exceeds a value that is likely to entail significant impact on marine animals.*"

This indicator aims to address the cumulative impact of impulsive sound generating activities in terms of 'considerable' displacement, described as 'the displacement of a significant proportion of individuals over a relevant time period and spatial scale' (EU TSG Noise 2014a). To make the indicator operational, Member States have been instructed to establish a Registry of the occurrence of all relevant low- and mid-frequency impulsive sounds. Minimum noise thresholds were established as a basis for including sources in the Register and are shown in Table 5.4 (EU TSG Noise 2014a). These thresholds were purposefully low; the aim being to ensure that all sources that have the potential for significant population level effect are included in the Register and only sources unlikely to have significant impact are excluded. As a consequence the sources included vary widely in their potential for impact.

Table 5.4: Sound level thresholds for inclusion into the MSFD Noise Register

Sound type	Activity	Sound level threshold for inclusion into Register	Proxy threshold for inclusion into Register (if relevant)
Non-pulse	Sonar	SL = 176 dB re:1 μPa	
Non-pulse	Acoustic deterrent	SL = 176 dB re:1 μPa	
Multiple impulsive	Impact pile driving	SL_E = 186 dB re:1 μPa²s	E_{hammer} = 1.1 kJ [108]
Multiple impulsive	Seismic survey (airgun array)	SL_E = 186 dB re:1 μPa²s	SL_{zp} = 209 dB re:1 μPa m
Single impulsive	Explosions	SL_E = 210.3 dB re:1 μPa²s	m_{TNTeq} = 8 g

Source: EU TSG Noise 2014a

Thresholds for inclusion into the Register were formulated as a combination of sound level and spatial range across which the sound level was exceeded; this was done to ensure that the effect of displacement elicited by the sound generating activity could be considered 'significant' from an ecological perspective. A range of 1000m was agreed thus the threshold proposed corresponded to the sound at source that would exceed the level identified for displacement over a range of at least 1000m.

Offshore wind farms – construction and operation

[108] The hammer energy threshold for pile driving is much less than what is routinely used in construction therefore no minimum threshold is valid and all pile-driving activities need to be registered.

Several empirical studies of marine mammal behaviour have been carried out during construction and operation of offshore wind farms in the North and Baltic Seas; piling sounds during construction have also been used for playback studies in wild and laboratory conditions. It is important to note in the following review that mitigation measures in Denmark and Germany promote the use of harassment devices (pingers and seal scarers) prior to impact piling; while studies have focused on the effect of piling, harassment devices may partly confound the results by contributing, at least close to the piling site, to influencing animal responses.

Tougaard *et al.* (2009b) measured the acoustic activity of harbour porpoises at Horns Rev using passive acoustic monitoring devices (T-PODs) and found clear evidence for a negative effect of pile driving. Waiting time between echolocation events increased significantly from an average of 5.9h during the construction period as a whole to an average of 7.5h between the first and second encounters after piling. No difference was observed in later inter-encounter intervals, suggesting the negative effect of piling was of limited duration. In terms of spatial extent however, the study concluded that the entire area was affected; this is because T-POD location (within the 4x4km^2 of the wind farm, at 7.5km east and at 21.5km west of the wind farm) did not have any effect on the outcome of the analysis. However, given the relatively small sample size, it might be possible that the analyses did not have enough power to detect a gradient.

A decrease in acoustic activity associated with pile-driving was reported also by Carstensen *et al.* (2006) at the Nysted wind farm; the interval between echolocation encounters increased from 6 hours in the baseline period to 3 days during the construction period within the wind farm area, but not at the reference area (10km east of the wind farm). A further construction activity involving prolonged ramming and vibration of steel sheet piles into the seabed for stabilisation was associated with an effect in both construction and reference areas. Measurements made 6-7 years after construction showed that echolocation activity had not yet fully recovered to pre-construction levels within the wind farm, while the reference area had remained unaffected (Teilmann & Carstensen. 2011). This is the only record available so far of a negative long-term effect and contrasted with the experience at Horns Rev and Egmond aan Zee; several differences exist between sites (e.g. turbine type, ship traffic) but a possible explanation put forward by the authors is that the area at Nysted is a less important habitat to harbour porpoises, consistent with the lower density observed.

In the Moray Firth, Thompson *et al.* (2010) found some evidence that harbour porpoises responded to disturbance from installation activities; in July and August 2006, the period in which the main installation work was carried out, porpoises were detected for significantly fewer hours per day when compared with a similar period in 2007, whereas similar comparisons for the adjacent months of June, September and October did not show significant differences in porpoise detections. Analysis of a different variable, the waiting time until the next porpoise detection, showed variable results, with waiting times within the typical distribution for the piling of the first sub-structure, and an extreme outlier of zero porpoise detections during piling of the second structure. Several factors, mainly small sample size and high variability between areas, limited the power of this study to draw firm conclusions; however, the experience was pivotal in proposing improvements on experimental design, such as the use of a gradient design to look for an effect of impact instead of relying on a BACI comparison. The latter is particularly difficult to establish whenever temporal/spatial variability is high and whenever ‘control’ sites may differ in several characteristics other than just the lack of impact as it’s often the case in marine mammal field studies.

The gradient approach was successfully adopted in studies at Horns Rev II (Brandt *et al.* 2011) and Alpha Ventus (Dähne *et al.* 2013). At Horns Rev II, T-PODs were deployed at 6 positions along a gradient ranging from 2.5 to 21.2km from the centre of the wind farm. Porpoise activity was found to be negatively affected by pile driving out to a distance of 17.8km; at the closest T-POD site the effect was stronger (reduced by 100% during 1 h after piling) and stayed below normal levels for longer (24-72h); with increasing distance, the duration of this effect gradually decreased. In contrast, activity at the furthest location was found to be higher than elsewhere (up to 30 h after piling). Overall, out to a distance of 4.7km, recovery time was longer than pauses between piling so that the end result was a reduction in activity throughout the construction period. At Alpha Ventus, C-PODs were deployed at 12 locations, extending up to 50km from the construction area, and information on acoustic activity was combined with sighting data from aerial surveys. Overall, harbour porpoise densities were found to be lower during construction period; a comparison of distribution patterns obtained on two aerial surveys three weeks before and exactly during pile-driving shows a strong avoidance response within 20km from the noise source. Analyses of acoustic detections using generalised additive modelling, identified a reduction in detection rate within 11km and an increase at the positions further away (25 and 50km); it was also noted that duration of pile-driving had a large impact, with longer pile-driving durations leading to a longer displacement. Brandt *et al*. (2018) describe porpoise reactions to piling noise during the construction of the first seven wind farms in German waters (generally with noise mitigation systems in place during piling); they found porpoises reacted to piling above a noise threshold level of 143 dB SEL_{05} re 1 μPa^2s and noted that spatial and temporal planning of simultaneous construction activities in the North Sea be as important as noise mitigation efforts.

A controlled exposure study was carried out by Tougaard *et al.* (2012) within a coastal area frequented by harbour porpoises where visual tracking by theodolite is possible from a nearby cliff top. Pile-driving sounds were played back from underwater loudspeakers and porpoises were clearly observed to avoid the area up to about 200m from the speaker. At that distance, received levels were on average 140 dB re 1 uPa (peak-peak).

Kastelein *et al.* (2015) used pile-driving playbacks to test hearing frequency thresholds on a captive harbour porpoise using a well-established psychoacoustic technique. Total exposure of 180 SEL_{cum} (146 SEL per pulse over 60 mins) resulted in a statistically significant TTS at 4 and 8 kHz but not at any of the other frequency tested, including no effect on the high frequencies used in echolocation. The magnitude of the effect was small (<4 dB) and full recovery was achieved within 48mins. In addition, the behaviour of the experimental porpoise was affected by the 60mins exposure: there were changes in swimming patterns, increased swimming speed and surfacing rate resulting in effects on the level of exertion and anxiousness. The carefully controlled and particularly quiet conditions of the test pool were important in being able to measure such a small TTS; the response may differ within an open water situation.

Graham *et al.* (2019) investigated harbour porpoise behavioural responses to piling noise using echolocation detectors (C-PODs) and noise recorders during the 10-month foundation installation of a wind farm in the Moray Firth. A 50% probability of response was recorded within 7.4 km at the first location piled, decreasing to 1.3 km by the final location. This is in marked contrast to current UK guidance which assumes total displacement within 26 km of pile driving. Because individual porpoises were not followed, it could not be determined whether or not the decline in response during construction resulted from habituation, but it was certain that porpoises showed a smaller response to pile driving noise at the end of the construction period than at the beginning. Importantly, acoustic deterrent device (ADD) use and vessel activity increased response levels, emphasising the need to consider the trade-offs between efforts to reduce far-field behavioural disturbance and near-field injury through ADD use.

In summary, all studies have shown clear evidence for some displacement of harbour porpoises in response to pile-driving. Variation between studies was observed in the magnitude of the effect, its spatial extent and its duration once construction was completed. This is not surprising given the number of factors at play when drawing such comparisons: site conditions (sound propagation characteristics, ambient noise, vessel traffic but also ecological importance of the area), use of different mitigation measures (soft-start, acoustic deterrents), experimental protocols (BACI, gradient design) and sample size.

Low relative abundance of cetaceans other than harbour porpoises has limited the opportunity to study responses of other species, but studies have been conducted on harbour seals. At Horns Rev wind farm satellite telemetry showed that harbour seals were still transiting the farm during periods of piling but no conclusive results could be obtained from analysis of habitat use with regard to a change in response to piling (Tougaard *et al.* 2006). Evidence of a response was obtained by Eden *et al.* (2004) at a haul-out site 10km away from the Nysted wind farm; during piling, numbers hauling out were reduced by 10-60% but the effect was only of short duration since the overall number of seals increased slightly during the whole construction phase. Hastie *et al*. (2015) reported the results from a large satellite telemetry tracking effort to elucidate the potential for sound exposure of harbour seals during the construction of the Lincs Offshore wind farm. All seals (n=24) were observed to spend time offshore during at least one pile driving event but none of the tagged seals were observed any closer than 4.7km.

Empirical observations with respect to operational turbines are limited but the available evidence suggests that harbour porpoises and harbour seals routinely enter wind farms and in some cases show attraction and behaviours consistent with foraging. In particular, Scheidat *et al.* (2011) studied acoustic activity of harbour porpoise in the area of the Dutch wind farm Egmond aan Zee and were able to compare patterns collected before construction with a later period when the farm was fully operational, both within the farm and at two reference sites, 10km north and south of the farm. No data were collected during construction. There was an overall increase in harbour porpoise acoustic activity from baseline to operation in line with the increase observed in this southern region of the North Sea; however, the increase was significantly higher within the operating wind farm than at the reference sites; the exclusion of most ship traffic from the farm, including fishing vessels, and the potential for the farm to act as an area of increase food availability are suggested as a reasonable explanations. For harbour seals, satellite telemetry tracking data has provided the clearest proof yet of individual seals not only regularly entering operational wind farms but concentrating their foraging activity at individual turbines, following a grid-like pattern to move between turbines (Russell *et al.* 2014). Russell *et al.* (2016) from a telemetry study on harbour seals in The Wash found that during piling, seal usage (abundance) was significantly reduced up to 25 km from the piling activity, and within 25 km of the centre of the wind farm, there was a 19 to 83% decrease in seal usage compared to during breaks in piling. However, there was no significant displacement during construction as a whole and within 2 hours of cessation of pile driving, seals were distributed as per the non-piling scenario.

Underwater detonations have the potential to cause lethal injury to marine mammals (see for example Siebert *et al.* 2022) as well as a range of physiological and behavioural effects. Acoustic impairment or behavioural response to a series of underwater explosions was linked to a mass stranding event of long-finned pilot whales in Scotland (Brownlow *et al.* 2015). The potential impact of explosive clearance activities of historical UXO on harbour porpoises in the Southern North Sea has been studied by von Benda-Beckmann *et al.* (2015). For recorded explosion events, impact areas were modelled and the number of animals likely to have suffered injury (PTS) was estimated using injury thresholds and aerial survey-based estimates of concurrent abundance. It was estimated that the 88 explosions between March 2010 and March 2011 were very likely to have injured 1,280 and possibly up to 5,450 animals.

Uncertainties in these predictions were acknowledged, such as difficulty of predicting underwater shock waves in shallow water, lack of data on the response of harbour porpoise to explosion shock and lack of knowledge on habitat use and movement patterns; nonetheless, the study identifies the need to consider this activity as part of cumulative assessments for the harbour porpoise in the North Sea. Based on measured and calculated noise levels from two UXO detonations in the North Sea, Salomons *et al.* (2021) indicated porpoise permanent-threshold-shift effect distances ranging from 2 to 6 km. The distance varied depending on the use of unweighted or weighted SEL values, and comparison of measured peak sound pressures with threshold values from Southall *et al*. (2019), indicated a PTS effect distance of about 4 km.

Oil & Gas – exploration (seismic surveys and other geophysical surveys)

Research on the potential effects of seismic airgun pulses focused initially on baleen whales, because of their greater acoustic sensitivity to low frequency sounds. Most early studies relied on visual observations and in several instances evidence for localised avoidance was obtained for species such as grey, bowhead and humpback whales (e.g. Richardson 1995). For example, in a comprehensive study of reactions of gray whales to seismic noise along their migration route off the Californian coast, Malme *et al.* (1983) found definite avoidance reactions by gray whales within a range of 5km from seismic array source; off Western Australia, McCauley *et al.* (2000) observed localised avoidance (~3km) by migrating humpback and a more pronounced response (avoidance at 7-12km range) for pods with cows involved in resting behaviour in key habitats (McCauley *et al.* 2000). In contrast, marine mammal observations during seismic surveys off Angola, concluded that the effects were small or negligible for humpback whales (Weir 2008); encounter rate (sightings/h) of humpback whales did not differ significantly according to airgun operational status; mean distance to humpback whale sightings was greater during full-array operations than during guns off, but this difference was not significant; no evidence for prolonged or large-scale displacement from the region during the 10-month survey duration was found.

Overall, the magnitude of response has been found to vary between studies, with several factors likely to be at play including species, actual received sound exposure levels, biological and social status of individuals (e.g. age, sex, single males vs. mother-calf units) and behavioural state and activity (e.g. migrating, foraging, resting) (e.g. Richardson 2002, McCauley *et al.* 2000). In addition, the behaviour of the sound source may also influence response; in a study to determine the short-term behavioural responses of bowheads to various industrial activities in the Canadian Beaufort Sea, Richardson *et al.* (1985) found no obvious reaction by the whales to seismic vessels operating as close as 6km to them but observed much stronger behavioural reactions to rapidly changing situations, including approaching boat, aircraft and a brief playback experiment. An analysis of bowhead behavioural data collected in the Beaufort Sea from 1980-2000, demonstrated seismic operations to have an effect on surfacing and dive durations but these changes in behaviour were found to be largely dependent on both circumstances and whale activity (Robertson *et al.* 2013).

Evidence of changes in vocalisation in response to seismic noise has been obtained from passive acoustic monitoring studies in several baleen whale species. Numbers of singing humpback whales (breeding displays) were found to decrease with increasing received levels off the coast of Northern Angola (Cerchio *et al.* 2014). In bowhead whales during the westward autumn migration in the Alaskan Beaufort Sea, calling rate is known to decrease in proximity (41-45km) to seismic operations (Blackwell *et al.* 2013); a more detailed study was able to differentiate between an initial increase in calling rate as soon as airgun pulses became detectable and decreased calling rates as exposure levels increased until all whales were virtually silent (Blackwell *et al.*2015). Extreme sensitivity has been suggested in sperm whales in the Southern Ocean, where vocalisation was observed to cease in some cases when a seismic survey vessel at range >370km was heard firing (Bowles *et al.* 1994). Other studies on this species have shown much greater tolerance both in terms of avoidance and acoustic behaviour (Madsen *et al.* 2002; Miller *et al.* 2009).

Observations by Marine Mammal Observers during seismic surveys on the UKCS are particularly valuable to infer potential effects on relevant species and an analysis of 16 years of data from seismic survey vessels highlights the variability of behavioural responses, although some general patterns are apparent (Stone *et al.* 2017). For larger airgun arrays (≥500 in^3), most species showed reduced detections when airguns were active vs inactive; such effects were less evident for smaller arrays (<500 in^3), although detection rates for harbour porpoise were also significantly lower for smaller arrays in use. While the median closest distance of approach to airguns was greater when active vs inactive for most species, this was statistically significant in less than half the species for which sufficient data were available (including harbour porpoise, bottlenose dolphin, white-beaked dolphin, white-sided dolphin and killer whale). Although the sample size was low, a strong effect was reported for common dolphin (median 150m closest approach when airguns were inactive vs 1,500m when active). Several species, including harbour porpoise and minke whales, showed significantly more avoidance (e.g. travelling away) from larger arrays when active.

The effects of seismic surveys on odontocetes and pinnipeds have been less thoroughly investigated but studies are addressing the gap, with several relevant to species in the UKCS. In the Moray Firth, a 2D seismic survey over 10 days (in September 2011) exposed a 200km^2 area with regular noise throughout the period; source levels were estimated to be peak-to-peak source levels 242–253 dB re 1 µPa at 1m and received levels within 5-10km from the source were estimated to be received peak-to-peak SPLs varied from 165 to 172 dB re 1 µPa, whereas SELs for a single pulse were 145–151 dB re 1 $µPa^2s$, and rms. levels were 148–155 dB re 1 µPa. (Thompson *et al.* 2013a).

Changes in the behaviour of harbour porpoises were measured (Thompson *et al.* 2013a). Observed waiting times derived from passive acoustic monitoring increased following the start of the survey; this effect diminished with distance from source and with time (suggesting some degree of habituation) but it was short-lived as porpoises returned to impacted areas within 19h. Detection rates from digital aerial surveys showed a decrease during the survey period within 10km of the vessel and an increase at greater distance; this supports the assumption that changes in acoustic detections corresponded to changes in abundance. Further analyses of acoustic recordings (occurrence and type of inter-click intervals or ICIs) provided more evidence regarding sub-lethal effects, such as possible disruption of social or foraging activities (Pirotta *et al.* 2015); porpoises remaining in the impact area reduced their buzzing activity by 15% during the seismic survey and the probability of detecting buzz ICIs increased with distance from the source vessel. In addition, Thompson *et al.* (2013a) explored the potential for broad-scale displacement by comparing control and impact sites between 2010 and 2011 (BACI design); statistically, a significant effect was identified but the effect size was small and entirely within seasonal and inter-annual variability. The authors concluded that while short-term disturbance was induced, this seismic survey did not lead to long-term or broad-scale displacement.

Bottlenose dolphins are more commonly observed in the inner Moray Firth and along the southern Moray Firth coast and occurred only rarely in the impact area, creating a challenge for analyses. Passive acoustic monitoring provided evidence of short-term behavioural responses in the part of their range closest to the seismic survey. The occurrence of dolphins at PAM sites in the southern Moray Firth increased during the survey, most likely the result of animals being displaced inshore, away from the survey vessel (Thompson *et al.* 2013b). However, there was no evidence for an overall reduction in dolphin occurrence and photo-identification estimates of the number of dolphins using the SAC remained similar throughout the period 2009-2012.

Common dolphins off the coast of Wales were monitored acoustically during a three month period before, during and after a 2D seismic survey; results from this study suggested localised avoidance but overall tolerance to the sound exposure outside a 1km radius of the guns (Goold 1996).

A meta-analysis of observer data from seismic surveys (primarily large or very large arrays) undertaken in the Gulf of Mexico and off West Africa and Australia (Milne *et al*. 2019) reported similar findings to those of Stone *et al.* (2017). While there was some variability in results between regions and species groups, there was a general pattern of reduced sighting rates and increased distances from the seismic source during periods of full power airgun activity compared to when the airguns were inactive.

Kavanagh *et al*. (2019) used seismic vessel MMO data to examine cetacean sighting rates during 10 surveys conducted between 2013-2016, together covering some 880,000 km^2 of the north-east Atlantic west of Britain and Ireland. A three-way comparison was made between active and inactive airgun periods from seismic vessels and also independent control data, collected by observers on 16 research cruises across the same region from 2015-2017. Relative to the control data, modelled sightings were significantly lower during active airgun firing periods for both baleen and toothed whales. Information on source characteristics was not provided, although the distribution of seismic surveys suggest that they were primarily regional-scale 2D/3D.

The analyses by Stone *et al*. (2017) of MMO data, provides evidence of effects of airgun firing also on odontocetes and pinnipeds. Beaked whales were also included in the analysis, although sample sizes were low and all species of beaked whale had to be combined; detection rates of beaked whales were significantly lower when 'large arrays' were active. Beaked whales are a particular concern because of the high sensitivity they display to another anthropogenic underwater source, military sonar (de Soto *et al*. 2016). Although no causal link has yet been established between seismic surveys and strandings (of beaked whales or other species), the possibility has been raised (Castellote & Llorens, 2016).

The effects of a large 3D seismic survey in the North Sea on harbour porpoise echolocation activity were investigated by Sarnocińska *et al.* (2020). The source was a 3,570 in^3 airgun array and the survey lasted 103 days, with seismic activity occurring on all but 17 days, covering an area of 1,121 km^2. Acoustic loggers were deployed inside and adjacent to the seismic survey area, before, during and after the survey over a total duration of 9 months. Harbour porpoises were detected at all stations throughout the study period. Three different measures of porpoise activity showed a dose-response effect, with the lowest activity closest to the source vessel increasing up to a range of 8-12 km, beyond which baseline acoustic activity was attained; no general displacement was detected compared to reference stations at 15 km from the seismic activity. The lowest porpoise acoustic activity was recorded at $L_{E,p}$ for a single pulse of 155 dB re 1 μPa^2 s, a similar but slightly higher level to that estimated by Thompson *et al*. (2013a) at distances where harbour porpoise detections were reduced. In line with Pirotta *et al*. (2014) and Thompson *et al*. (2013a), the study found no long-term and large-scale displacements of porpoises throughout the survey. The authors noted that it was not known if the same animals remained in the area during the survey or if displaced animals were continuously replaced by a flux of new animals moving into the area.

Responses of five harbour porpoise tagged in Danish waters to a brief exposure of pulses from a 10 in^3 airgun were reported by van Beest *et al*. (2018). At the time of exposure, porpoises were between 420-690m range from the source, and received $L_{E,p}$ of between 135-147 dB re 1 µPa^2 s. Results further highlight the variability of responses between individuals, with no quantifiable responses in three individuals, and shorter and shallower dives in two individuals for up to 8 hours post-exposure, one of which also exhibited rapid and directed movements away from the exposure site.

While seismic surveys (and other anthropogenic underwater noise e.g. vessels, Wisniewska *et al.* 2018; pile-driving, Graham *et al.* 2018) may disrupt foraging behaviour, very little is known of the energetic consequences of this in terms of impact on survival and reproduction, and the broader implications of such effects at the population-level. Using inputs on estimated levels of disturbance, stochastic population models can be used to assess subsequent effects on population parameters. The Interim Population Consequences of Disturbance (iPCoD) model (King *et al*. 2015) is one such approach, where, for several UK species, expert elicitation has been used to derive probability distributions of the effects of noise-related behavioural disturbance on vital rates such as adult and calf survival. These probability distributions were updated to reflect new empirical data and improved elicitation methods (Booth *et al*. 2019). Alternative approaches to estimating population-level effects include models based on animal's movement alongside foraging and energetics, as demonstrated by Nabe-Nielsen *et al*. (2018) for North Sea harbour porpoise and wind farm construction noise.

Potential effects from exploratory sound sources other than airguns have received limited attention. DiIorio and Clark (2010) reported on a study to investigate vocal behavioural response of blue whales to a low-energy sparker source during a seismic reflection survey; increased call production was detected on days with sparkers in operation even though exposure was relatively low and estimated at 131 dB re 1 µPa (peak to peak) (30–500 Hz) with a mean sound exposure level of 114 dB re 1 µPa^{2}s.

A high-powered 12Hz multi-beam echosounder system (MBES) has been implicated as the only plausible behavioural trigger of a highly unusual mass stranding of melon-headed whales in Madagascar in 2008 (Southall *et al.* 2013).

Oil & Gas – drilling and production

Evidence is relatively limited with regard to the effects of noise during production, but observations at installations in the North Sea have shown harbour porpoises regularly frequenting and actively foraging around platforms (Todd *et al.* 2009), implying that noise during production is either negligible or not a sufficient deterrent given the foraging opportunities provided.

There is evidence that vessel traffic may influence marine mammals in several ways, reported responses include avoidance, changes in swimming and surfacing patterns, alteration of the intensity and frequency of calls and increases in stress-related hormones (Veirs *et al.* 2016, Rolland *et al.* 2012, Dyndo *et al.* 2015, Wisniewska *et al*. 2018). In UK waters, results of a modelling study indicated a negative relationship between the number of ships and the distribution of harbour porpoises in the Celtic/Irish Sea and the North Sea (Heinänen & Skov, 2015).

Wave and tidal power

Potential biological effects of noise produced by the SeaGen 1.2MW tidal energy convertor in Strangford Lough were initially assessed by SMRU (2010). Monitoring for effects included shore based surveys, passive acoustic monitoring (using TPODs) of harbour porpoises, harbour seal tracking by telemetry (for more details see also Royal Haskoning 2011). During the short installation of the turbine (drilling), a large and rapid decline in acoustic activity was observed at short-range (i.e. within the Narrows but not in the inner Lough). This was short-lived and levels of activity recovered immediately after installation; it is unclear if the cause was the noise during drilling or the increased vessel activity.

SMRU (2010) used underwater sound propagation models to predict potential exposure of animals at increasing distance from SeaGen; these were combined with information on marine mammal hearing abilities and likely behavioural responses to predict potential effects as a series of influence zones (audibility, behavioural response). During strong tidal flow when ambient noise and turbine activity are highest, noise from SeaGen was predicted to be audible to marine mammals up to 1.5km. Two models were developed to evaluate the potential behavioural effects of the different components of the operational noise (tonal peaks and broadband) on marine mammals; together these results suggested that behavioural responses would most likely occur within a zone between 77m and 610m from SeaGen but could potentially extend up to several kilometres. These predictions must be viewed in the context of the actual observed behaviour of marine mammals around the turbine. Land-based observations, telemetry derived data on seal movements and TPOD detections of harbour porpoise echolocation all indicated that seals and porpoises continued to frequent the Narrows and the inner Lough throughout the operational phase within the distances within which they were predicted to display behavioural avoidance responses (Savidge *et al.* 2014). The use of harbour seal haul-out sites was not affected by SeaGen, nor was there any evidence to suggest a barrier effect or a significant displacement of seals and porpoises. The only changes detected in any of the metrics monitored were of a small magnitude relative to the natural variation explained by tidal cycle, time of day and season. Overall the observations are suggestive of small-scale local redistribution (250m) in relation to the SeaGen presence and operation with the likelihood of little ecological significance (Savidge *et al.* 2014).

Conclusions on the likely impact of operational noise from wave and tidal stream developments were drawn by Robinson & Lepper (2013) and Copping *et al.* (2013). The risk of injury to marine mammals is highly unlikely from operational noise even in close proximity to the device. Behavioural responses may be induced but significant behavioural effects are also unlikely at long-ranges from the development site.

Among the gaps in knowledge identified, Robinson & Lepper (2013) emphasised the importance of improving understanding of the potential influence of changes in radiated noise relative to background noise on the risk of impact; the relative signal-to-noise ratio will influence perception capability, on one hand minimising behavioural responses but on the other potentially increasing the risk of collision with the devices. Finally, because current understanding is limited to experience with single devices or small arrays, there is still high uncertainty with respect to effects of large scale arrays.

Efforts are on-going to improve knowledge base; for example, at the four test sites of the European Marine Energy Centre Ltd (EMEC) in the Orkney Islands the potential for displacement effects by wave and tidal stream devices is being monitored.

5.3.3.2 Fish

Fish exhibit large variation in their ability to emit and detect sound, largely dependent on great diversity in anatomical features, hearing physiology and behaviour (see Hawkins & Popper 2017; Popper & Hawkins 2018, 2019). The otolithic organs of all fishes respond to particle motion but in addition some fish have adaptations that make them sensitive also to sound pressure; these are gas-filled structures near the ear or connected to it and extensions of the swim bladder able to functionally influence the ear. It follows that understanding the effects of sound on fish requires measurements of particle motion and not only pressure; however, technology to make measurements of particle motion is still in development and while some devices are available, field measurements are very limited (Hawkins *et al.* 2015, Cefas 2015, Popper & Hawkins 2018).

Hearing sensitivity is expressed using audiograms as the lowest level (either as particle acceleration or sound pressure) detected as a function of frequency. Species sensitive to both particle motion and pressure show an increased hearing sensitivity and wider hearing bandwidth than species which rely exclusively on particle motion but overall, variability among species is high and difficult to predict from anatomical knowledge alone. Most species are sensitive to sound from below 50Hz to 500Hz, with most pressure-sensitive species detecting up to 2kHz but a few exceptions have been identified with some species of herring-like fishes capable of detecting sounds above 20kHz. However, the number of species for which accurate data are available is still small and measuring the hearing abilities for a wider range of species has been recommended as high research priority (Hawkins *et al.* 2015).

The susceptibility of fish to barotrauma (i.e. physiological trauma in response to sudden change in pressure) is also much greater in species with a swim bladder and other gas chambers.

A metric for the assessment of auditory and behavioural effects of underwater sound was first developed by Nedwell *et al.* (2007) together with relevant criteria. The aim of this work was to provide industry and regulators in the UK with an objective quantitative metric that would be simple to apply in practice, while accounting for the intrinsic complexity of the effects of different types of sounds across a range of species with widely different hearing abilities.

The metric proposed was dB_{ht} and corresponds to the amount of sound received above the hearing threshold; it is analogous to the dB(A) scale commonly used in human noise tests. It is not an absolute sound level unit, rather a 'prediction of the perceived loudness of the sound to the animal'. Since hearing threshold varies with frequency, dB_{ht} is calculated as an integral over frequency using a species-specific frequency dependent weighting obtained from good quality audiograms. Since different species have different hearing abilities, a given sound will have a different level on this scale for each species, hence the need to append the species name to the level e.g. dB_{ht}(*Species*). Validation of the metric and criteria combined evidence from three different sources; a re-evaluation of existing data from acoustic fish deflection systems, a set of laboratory reaction experiments to identify the onset of avoidance responses and re-interpretation of relevant literature including observations in the field during seismic surveys and studies on the onset of permanent threshold shift. On the basis of the information reviewed, criteria were suggested relative to specific effects (Table 5.5).

Table 5.5: Criteria developed by Nedwell *et al.* (2007)

Level in dB_{ht}(*Species*)	Effect
< 0	None
0-50	Mild reaction in minority of individuals, probably not sustained

Level in dB_{ht}(*Species*)	Effect
50-90	Stronger reaction by majority of individuals, but habituation may limit effect
90 and above	Strong avoidance reaction by virtually all individuals
Above 110	Tolerance limit of sound; unbearably loud
Above 130	Possibility of traumatic hearing damage from single event

Several limitations with this approach have constraint its broad application in noise risk assessments; Nedwell *et al.* 2007 used audiograms expressed only in terms of sound pressure so that validation with respect to particle motion is lacking; at present the quality of audiograms for many species is not satisfactory for calculation of dB_{ht}(*Species*) levels; reliance on audiograms may be appropriate for behavioural effects but should be considered with caution in respect to injury as also inaudible sounds can cause damage to tissues.

More recent efforts to establish broadly applicable sound exposure criteria for fish along the lines of those by Southall *et al.* (2007) for marine mammals have resulted in publication of guidance by Popper *et al.* (2014). Fish were classified depending as:

- Fishes without a swim bladder or other gas chamber (particle motion detection), e.g. elasmobranchs (sharks, skates and rays), jawless fishes, some flatfish, some gobies, some tuna and other pelagic and deep-sea species
- Fishes where swim bladder is present but not involved in hearing (particle motion detection and barotrauma), e.g. Atlantic salmon
- Fishes where swim bladder or other gas chamber is present and involved in hearing (particle motion detection, sound pressure detection and barotrauma), e.g. Atlantic cod, herring and relatives.
- Fish eggs and larvae

Sound from explosions, pile driving, seismic airguns, sonar and continuous sources were considered in turn. Potential effects were divided into: mortality and mortal injury, impairment effect (including recoverable injuries, TTS and masking) and behavioural effects (interpreted as substantial change in behaviour for a large portion of animals exposed). Exposure levels for the onset of any given effect are given either quantitatively (expressed in appropriate metrics) or qualitatively as a relative likelihood of effect occurring. These sound exposure guidelines should be treated as interim values and refined with the results from new research, which is strongly recommended (Popper *et al.* 2014). Guidelines for pile-driving are the more conservative ones and reported in Table 5.6 for reference.

Table 5.6: Sound exposure guidelines for pile-driving

Type of animal	Mortality and potential mortal injury	Recoverable injury	TS	Masking	Behaviour
Fish: no swim bladder	>219 dB SELcum or >213 dB peak	>219 dB SELcum or >213 dB peak	>>186 dB SELcum	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low

Type of animal	Mortality and potential mortal injury	Recoverable injury	TS	Masking	Behaviour
Fish: swim bladder not involved in hearing	210 dB SELcum or >207 dB peak	203 dB SELcum or >207 dB peak	>186 dB SELcum	(N) Moderate (I) Low (F) Low	((N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing	207 dB SELcum or >207 dB peak	203 dB SELcum or >207 dB peak	186 dB SELcum	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Eggs and larvae	>210 dB SELcum or >207 dB peak	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Notes: peak sound pressure levels dB re 1 µPa; SEL dB re 1 $µPa^2s$. All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist. Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I) and far (F). Source: Popper *et al.* (2014).

It is well established that underwater explosions can injure and kill fish; 'dynamite fishing' is practised (albeit illegally) in many parts of the world (McManus 1997) and several studies have reported on the effects (see Popper *et al.* 2014 and references therein). Models for predicting lethal impacts are considered to be robust for large juvenile and adult fish and are being further developed for larvae and young juveniles; evidence suggests larvae and juveniles are more vulnerable (Govoni *et al.* 2008).

Several studies have explored the effect of pile-driving on adult fish and demonstrated the potential for lethal injury on several species including Chinook salmon, (*Oncorhyncus tshawytscha*); these were reviewed by Popper *et al.* (2014) and used to set the guidelines discussed above. The extent of injury has been shown to increase with sound exposure level and duration (e.g. Halvorsen *et al.* 2012) but the lowest level found to induce injury (207 dB SEL cum) is relatively high and likely to be experienced only within a limited range of the source (<100m). Lethal effects on larvae have been examined by Bolle *et al.* (2012) in the common sole (*Solea solea*); sole larvae at different developmental stages were exposed to various levels and durations of exposure but no significant difference in mortality was observed between treatment and control groups. The highest cumulative sound exposure level applied was 206 dB re $1µPa^2s$ corresponding to 100 strikes at 100m from a typical North Sea pile-driving site.

Behavioural responses to pile-driving operations have been investigated as part of a COWRIE study (Mueller-Blenkle *et al.* 2010). Pile-driving noise was played back to cod and sole held in two large pens located in a quiet bay on the west coast of Scotland, with received SPL and particle motion measurements taken and the movements of fish analysed using a novel acoustic tracking system. There was a significant movement response to the pile-driving stimulus in both cod and sole at relatively low received SPL (sole: 144-156dB re 1µPa peak; cod: 140-161dB re 1 µPa peak, particle motion between 6.51x10-3 and 8.62x10-4ms^{-2}). Sole showed a significant increase in swimming speed during the playback period compared to before and after playback. Cod exhibited a similar reaction, yet results were not significant, although cod did show a significant freezing response at onset and cessation of playback. There were indications of directional movements away from the sound source in both species. Some observations suggested a level of habituation to the noise source but overall high variability across individuals was observed. Mueller-Blenkle *et al.* (2010) describe that their results further imply a relatively large zone of behavioural response to pile-driving sounds in marine fish, although note that it is difficult to explain the nature and biological significance of these responses. Many responses observed suggest avoidance reactions, although it was noted that in a wild marine environment a wider demographic of animals will be present, and there will be other ecological drivers (e.g. food, reproduction) at play, both of which will influence the nature of reactions.

Studies investigating fish mortality and organ damage from noise generated during seismic surveys are very limited and results are highly variable (Popper *et al.* 2014). Slabbekoorn *et al*. (2019) note that there are few good case-studies in the peer-reviewed literature that report on the impact of a seismic survey on the behavioural response of free-ranging fish or the direct impact on local fisheries. Existing studies do not yield completely coherent results but suggest that fish could stop foraging and move down in the water column. Such temporary displacement and/or altered feeding behaviour are likely to be responsible for the reduced catches reported in some circumstances. Popper *et al.* (2016) found no mortality or tissue damage in response to single airgun shot exposure even at high level (SPL 231 dB re 1µPa or SEL single shot of 205 dB re 1µPa^{2}s). On the other hand, behavioural responses and effects on fishing success ("catchability") have been reported following seismic surveys (Pearson *et al.* 1992, Skalski *et al.* 1992, Engås *et al.* 1996, Wardle *et al.* 2001, Bruce *et al*. 2018). MMS (2004) consider that the "consensus is that seismic airgun shooting can result in reduced trawl and longline catch of several species when the animals receive levels as low as 160dB".

One study showed long-term damage to the epithelial cells of the pink snapper (*Pagrus aurata*), (McCauley *et al.* 2003) while a similar experiment conducted in several species of riverine fish by Popper *et al.* (2005) found that the limited hearing loss incurred had recovered with 24 hours, with no apparent damage to hair cells.

Spawning and nursery grounds for most species are dynamic features and are rarely fixed in one location from year to year. Therefore, while some species have similar patterns of distribution from one season to the next, others show greater variability (Coull *et al.* 1998). Discrete banks of clean gravel found in the southern North Sea, Moray Firth and other UK coastal waters are used by spawning herring. The sub-populations of North Sea (and west coast) herring spawn at different times and localised groups of herring can be found spawning in almost every month (Rogers & Stocks 2001). The potential for seismic survey and piling activities to disturb or disrupt spawning shoals of herring (and other species) is recognised and mitigated through the activity consenting processes. Guidance on sensitive periods for fish spawning is available to developers, and may be incorporated into licence conditions, including prohibitions of some activities in certain months.

Less intense sounds of longer duration and potentially affect much larger areas also need considering. No associations of lower-intensity, continuous drilling noise and fishing success have been demonstrated, and large numbers of fish are typically observed around North Sea (e.g. Løkkeborg *et al*. 2002, Fujii 2015) and other production platforms (MMS 2004). Similarly, it has been suggested that wind farms and other renewable energy installations can act as artificial reefs once in operation (Inger *et al.* 2009). In addition to studies on masking, several recent experimental studies are improving the evidence base with regard to effects induced by low-level increases of ambient noise, such as from increased vessel traffic; changes to the behaviour of adults including effects on startle response, anti-predator response, ventilation rate and swimming speed, as well as changes to the behaviour, growth and development of larvae have been documented (Neo *et al.* 2014, Nedelec *et al.*, 2015, Bruintjes *et al.* 2016). Nonetheless it is still difficult to interpret many of these results, extrapolate to natural situations and place them within the context of potential population effects.

Potential effect on migratory species of conservation importance is also an area of significant interest for which empirical evidence is still needed (Gill & Bartlett 2010). Swim bladder in salmonids and eels is not involved in hearing (particle motion sensitive). Laboratory experiments carried out by Simpson *et al.* (2015) found that predator avoidance by juvenile European eels migrating to the continent from the Sargasso Sea was significantly impaired by the noise of vessel traffic in harbours. The migration route of older eels back to spawning grounds does not appear to be affected by noise generated by offshore wind farms in the southern Baltic Sea (Andersson *et al.* 2012). Gaps in knowledge with respect to Atlantic salmon are the focus of current research as part of Marine Scotland Science National Research and Monitoring Strategy for Diadromous Fish[109].

5.3.3.3 Aquatic birds

Aquatic birds are exposed to a variety of man-made noise sources, depending on their habitat. Offshore foraging species are those more likely to be exposed to noise from offshore energy development and shipping while inshore species may be exposed more often to recreational boating, coastal construction and even traffic noise if close to highly populated areas (Crowell *et al.* 2015). Increased ambient (in air) noise levels on birds have been linked to a variety of effects including masking communication signals, spatial avoidance, decreased reproductive success and increase physiological stress, with the hearing sensitivity of a species thought to determine the magnitude of the effect (Crowell *et al.* 2015).

Information on the underwater hearing abilities of diving birds and evidence of the effects of underwater anthropogenic noise is very limited. Unlike other receptor groups, no dedicated reviews on the effects of noise on diving birds have been undertaken; distillations of available evidence can be found in Hartley Anderson Limited (2020), U.S. Department of the Navy (2020) and the DOSITS website[110]. The exposure of shallow plunge-diving or surface-dipping aquatic birds to underwater noise is likely to be negligible due to the very short period of time they spend underwater (U.S. Department of the Navy 2020). Deeper-diving species which spend longer periods of time underwater (e.g. auks) are the most likely birds to be at risk of exposure to underwater noise, but all species which routinely remain underwater for a period of minutes in pursuit of prey and benthic feeding opportunities in marine and estuarine habitats may be exposed (i.e. also including divers *Gavia* spp., grebes, diving ducks, cormorant, shag, gannet and Manx shearwater). Based on this logic, Box 5.4 lists aquatic bird species occurring in the UK considered potentially vulnerable to underwater noise effects.

The reported in-air hearing sensitivity for a range of diving duck species, red-throated diver, gannet and puffin have been tested for tone bursts between frequencies of 0.5-6kHz; results revealed a common region of greatest sensitivity from 1-3kHz, with a sharp reduction in sensitivity >3-4kHz (Crowell e*t al.* 2015, Mooney *et al*. 2019). Similar results were observed for African penguin; tests of in-air hearing showed a region of best sensitivity of 0.6-4kHz, consistent with the vocalisations of this species (Wever *et al*. 1969). These results are comparable to the observed hearing sensitivity of numerous land birds (Dooling *et al*. 2000).

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[109] http://www.gov.scot/Topics/marine/marineenergy/Research/NatStrat/Theme1
[110] https://dosits.org/animals/sound-reception/how-do-aquatic-birds-hear/

Box 5.4: Migratory and/or Annex I aquatic bird species occurring in the UK considered potentially vulnerable to underwater noise effects

Divers and grebes	Diving ducks
Great northern diver *Gavia immer*	Pochard *Aythya ferina*
Red-throated diver *Gavia stellata*	Tufted duck *Aythya fuligula*
Black-throated diver *Gavia arctica*	Scaup *Aythya marila*
Little grebe *Tachybaptus ruficollis*	Eider *Somateria mollissima*
Great crested grebe *Podiceps cristatus*	Long-tailed duck *Clangula hyemalis*
Slavonian grebe *Podiceps auritus*	Common scoter *Melanitta nigra*
Seabirds	Velvet scoter *Melanitta fusca*
Manx shearwater *Puffinus puffinus*	Goldeneye *Bucephala clangula*
Gannet *Morus bassanus*	Red-breasted merganser *Mergus serrator*
Cormorant *Phalacrocorax carbo carbo*	Goosander *Mergus merganser*
Shag *Phalacrocorax aristotelis*	
Guillemot *Uria aalge*	
Razorbill *Alca torda*	
Puffin *Fratercula arctica*	

Note: Includes species which are known to engage in pursuit diving or benthic feeding in marine, coastal and estuarine waters at least during part of the year.

Some aquatic birds possess adaptations to their auditory system related to being underwater, which generally relate to protecting against damage from pressure changes (Dooling & Therrien 2012); these include barrier creation (e.g. auks), pressure regulation (e.g. penguins) or cushioning for species which plunge dive (e.g. gannet). Exposure of cormorant (*Phalacrocorax carbo*) to tones at frequencies of 1-4kHz suggested an underwater hearing threshold of $L_{p,rms}$ 70-75dB re 1µPa (Anderson Hansen *et al*. 2017). The authors argue that this underwater hearing sensitivity, which is broadly comparable to that of seals and small odontocetes at 1-4kHz, is suggestive of the use of auditory cues for foraging and/or orientation. However, tests on other species of diving bird have suggested less sensitive hearing abilities. Testing on the long-tailed duck underwater showed reliable responses to high-intensity stimuli (>117dB re 1µPa) from 0.5-2.9kHz (Crowell 2014). Preliminary results from the first underwater hearing tests on gentoo penguins (*Pygoscelis papua*) indicate consistent behavioural reactions to a broadband sound burst at modest levels, *above* $L_{p,rms}$ 110dB re 1µPa (Sørensen *et al*. 2019). A similar result was recently obtained for common guillemot (*Uriaa aalge*) in tank based playback experiments on 2 birds, with behavioural reactions to both broadband sound bursts (c. 0.5-7kHz) and sonar signals (c. 4kHz) observed at all tested received levels of $L_{p,rms}$ 110-137dB re 1µPa; the strongest reactions (startle, stop feeding, moving >0.5m from feeder) were most frequently observed at the highest received levels (Andersen Hansen *et al*. 2020).

Very high-amplitude low-frequency underwater noise may result in acute trauma to diving birds, with several studies reporting mortality of diving birds in close proximity (i.e. tens of metres) to underwater explosions (Yelverton *et al*. 1973, Cooper 1982, Stemp 1985, Danil & St Leger 2011). McCauley (1994) inferred from vocalisation ranges that the threshold of perception for low frequency seismic noise in some species (e.g. penguins, considered as a possible proxy for auk species) would be high, hence individuals might be adversely affected only in close proximity to the source. While published evidence is largely lacking, direct observations during extensive seismic and piling operations in the North Sea and elsewhere have not reported mortality. A study investigated seabird abundance over three years in Hudson Strait (Atlantic seaboard of Canada) during seismic surveys using either explosives or airguns (Stemp 1985): comparing periods of shooting and non-shooting, no significant difference was observed in abundance of thick-billed murre (Brünnich's guillemot), along with kittiwake and fulmar. While some mortality of birds in close proximity to explosive charges, none was associated with airgun use (Stemp

1985). Lacroix *et al*. (2003) monitored the number and diving behaviour of moulting long-tailed ducks (a period in which flight is limited and food requirements are high) before, during and after seismic survey activities in coastal waters of the Beaufort Sea, Alaska. Surveys had no noticeable impacts on the movements or diving behavior of birds, while a decline in numbers during the period of activity was observed in both seismic and control areas; however, the authors noted that methodological constraints limited their ability to detect more subtle disturbance effects. More recently, Pichegru *et al*. (2017) used telemetry data from breeding African penguins to document a shift in foraging distribution concurrent with a 2D seismic survey off South Africa. Pre/post shooting, areas of highest use bordered the closest boundary of the seismic survey; during shooting, their distribution shifted away from the survey area, with areas of higher use at least 15km distant to the closest survey line. However, insufficient information was provided on the spatio-temporal distribution of seismic shooting or penguin distribution to estimate a deterrence radius. It was reported that penguins quickly reverted to normal foraging behaviour after cessation of seismic survey activities, suggesting a relatively short-term influence of seismic survey activity on these birds' behaviour and/or that of their prey.

Studies of the responses of diving birds to other acoustic sources are similarly limited. In a playback experiment on wild African penguins, birds showed strong avoidance behaviour (interpreted as an antipredator response) when exposed to killer whale vocalisations and sweep frequency pulses, both focussed between 0.5-3kHz (Frost *et al*. 1975). The use of acoustic pingers mounted on the corkline of a gillnet in a salmon fishery, emitting regular impulses of sound at *ca.* 2kHz, was associated with a significant reduction in entanglements of guillemot, but not rhinoceros auklet (Melvin *et al*. 1999). Additionally, underwater playback of boat sounds (recorded from a bird-scaring chase vessel; no acoustic characteristics available) has been shown to reduce the abundance of eider and other sea ducks feeding on mussel farms by up to 80% (Ross *et al*. 2001). These vocalisation, pinger and vessel sounds all contained significant energy within the reported hearing range of diving birds.

A study in the Dutch North Sea attempted to investigate the potential impacts of wind farm pile-driving on seabirds (Leopold & Camphuysen 2009). Visual observation before and during piling operations did not detect any individuals of the potentially more vulnerable divers, seaduck and auk; this was attributed to the timing of operations being such that these species had largely left the area when piling commenced. Birds that did fly by the construction site (mainly gulls and terns) did not show a noticeable reaction to the activities. The authors suggested that any of the more vulnerable birds left in the area would likely have been displaced by associated shipping activities before piling commenced. Consideration of disturbance responses to vessels among divers, scoter and other diving waterbirds (e.g. Kaiser *et al.* 2006, Fliessbach *et al*. 2019, Mendel *et al*. 2019), which can be initiated at distances of up to several kilometres for individual birds, does suggest that birds respond to visual cues and are therefore likely to be displaced away from areas of the highest intensity of underwater noise.

In the case of piscivorous species such as divers and auks, indirect effects through acoustic disturbance of prey species could be postulated, although such effects are likely to be local and not significant at a population scale. It is therefore considered unlikely that offshore impulsive noise will result in significant injury or behavioural disturbance to seabirds.

5.3.3.4 Marine turtles

Interest in assessing the potential effects of anthropogenic sounds on marine turtles has recently come to the fore (Popper *et al.* 2014). Nonetheless, available information is very limited. Morphologically, sea turtles have a typical reptilian ear with few underwater modifications and they are able to detect sound pressure (see in Popper *et al.* 2014). A recent systematic review identified 29 references that provided information on marine turtles and their response to sound in comparison to 414 for marine mammals and 187 for fish (Nelms *et al.* 2016). Behavioural and auditory evoked potential studies have indicated the hearing range of cheloniid species is between 50-2,000Hz, with highest sensitivity below 400Hz (Ridgway *et al.* 1969, Martin *et al.* 2012, Lavender *et al.* 2012, all cited in Popper *et al.* 2014). Injury and death of turtles has been linked to the use of explosives, avoidance behaviour has been elicited by airgun exposures in experimental conditions (evidence is lacking during seismic survey observations), and no data on the effects of pile driving or sonar have yet been obtained (Popper *et al.* 2014). Concern of the potential impact of seismic surveys to turtle populations is not limited to the effect of sound but to entanglement in equipment during both towed or seabed deployed operations (Weir, 2007). In summary, there is potential for anthropogenic sounds to affect marine turtles but the extent to which this may result in impact still remains to be clarified. 'Interim' sound exposure guidelines have been published (Popper *et al.* 2014). Where turtle encounters are common (i.e. not the UK), time-area closures designed to avoid critical habitats at times of aggregations have been favoured as mitigation measures, while those based on direct observations (e.g. shut-down of operations if turtle is encountered) are thought to be ineffective due to difficulty in turtle detection (Nelms *et al.* 2016).

5.3.3.5 Invertebrates

Planktonic and benthic invertebrates generally do not have gas-filled body cavities and are considered less susceptible to acute trauma and behavioural disturbance resulting from noise and vibration but data are very limited, see reviews by Carroll *et al*. (2017) and Hawkins & Popper (2017). Cephalopods, with a well developed nervous system and complex behavioural responses, are a possible exception. Their primary sound detection organs are the statocysts (balance organs), although peripheral hair cells may also play a role in detecting local water movements. Cephalopods appear to detect the acceleration and particle motion component of the sound field, rather than pressure and are most sensitivity to low frequency (<400 Hz) sounds; thus their hearing ability has been described as comparable to those of elasmobranch and teleost fish that lack auditory specialisations. Hu *et al.* (2009) suggested that the octopus *Octopus vulgaris* and the squid *Sepia lessoniana* may detect sounds at higher frequencies (400-1000Hz and 400-1500Hz respectively) but Mooney *et al.* (2010) challenged that result, suggesting it might have been an artefact of the experimental procedure. Mooney *et al.* (2010) carried out a carefully controlled experiment to quantify the acoustic sensitivity of the longfin squid *Loligo pealeii* using auditory evoked potentials (AEPs); the responses to near-filed acoustic as well as shaker-generated stimuli were found to be limited within 30 - 500 Hz with highest sensitivity between 100 and 200 Hz. Of relevance to impact assessment, controlled exposure experiments have demonstrated that statocysts of several species can be damaged after exposure to low-frequency sound (Andre' *et al.* 2011; Solé *et al.* 2013a, b). Specific thresholds could not be extrapolated during these studies because of tank effects and lack of particle motion measurement. A link between seismic surveys and increased reports of stranded giant squids in Spain has been suggested (Guerra *et al.* 2004), while experimentally Fewtrell & McCauley (2012) showed that exposure to noise from a single airgun could elicit alarm responses of squid with increasing occurrence as noise levels increased. Behavioural responses of cuttlefish (*Sepia officinalis*) to pure-tone pips within a range of sound pressure levels and particle accelerations have been studied by Samson *et al.* (2015). Responses observed included escape (inking and jetting), changes in body patterns and fin movements; type and intensity of response was dependent on stimulus amplitude and frequency (e.g. inking observed only between frequencies of 80 and 300 Hz and at sound levels above 140 dB and 0.74 ms^{-2}).

For all other invertebrate taxa, studies are too few to reach conclusions even though several examples of effects have been obtained (Hawkins *et al.* 2015). For example, recent laboratory experiments on scallop larvae have shown that noise exposure to playbacks of seismic sounds can cause developmental delays and body malformations (Aguilar de Soto *et al.* 2013), while oxidative stress was reported in the mussel *Mytilus galloprovincialis* after prolonged noise exposure (Dinu *et al.* 2012). To sedentary invertebrates, seabed vibrations created during anthropogenic activities such as piling and seismic surveys may also induce a response. For example, the bivalve *Mytilus edulis* has been shown to respond to substrate-borne vibrations by partially or fully closure of their valve; depending on duration this may have consequences for their fitness (Roberts *et al.* 2015). In a similar experiment, the hermit crab *Pagurus bernhardus* was also found to respond behaviourally to substrate-borne vibrations (Roberts *et al.* 2015b). From these studies however, extrapolations of effects in the wild are limited by the challenges of reproducing, controlling and measuring exposure level in small tanks, especially with respect to particle motion (Popper & Hawkins 2018).

5.3.4 Controls and mitigation

Both planning and operational controls are currently in place to cover all significant noise generating activities on the UKCS, specifically including geophysical surveying and pile-driving.

The main focus is to ensure compliance with the Habitats Directive. The *Conservation of Habitats and Species Regulations 2017* ("the Habitats Regulations") and the *Conservation of Offshore Marine Habitats Species Regulations 2017* make provision for implementing the Birds Directive and the Habitats Directive in the UK and marine areas relevant to the draft plan/programme. All state that it is an offence to deliberately injure or disturb wild animals of any species listed on Annex IVa of the Habitats Directive (which includes all cetaceans), particularly where disturbance is likely to impair breeding, rearing, hibernation and migration or to affect significantly the local distribution or abundance of the species to which they belong. In addition, any proposed activity with a potentially significant acoustic impact on a designated SAC or SPA would also be subject to the requirement for Habitat Regulation Assessment (HRA) under the above Regulations.

To help avoid or minimise the risk by activities in the marine environment to kill, injure or disturb cetaceans guidance has been prepared by JNCC, Natural England and Countryside Council for Wales (2010), for the marine area in England and Wales and the UK offshore marine area and by Marine Scotland (2020b) for Scottish inshore waters. The guidance is based on a risk assessment approach, assessing the likelihood of a statutory offence, and then whether a licence to undertake the proposed activity should be sought. The likelihood of an activity resulting in injury or disturbance to a marine European Protected Species (EPS) will very much depend on the characteristics of the activity, of the environment and the species concerned, hence the need for a case-by-case approach when assessing the risk of it occurring.

The guidelines suggest that activities with the potential to deliberately injure or kill a marine EPS in areas can be long or short-lived, and include explosive use, seismic surveys, navigation by high speed vessels, and pile-driving. However, if mitigation measures are appropriate and effectively implemented, the risk could be reduced to negligible levels. In this respect, recommendations regarding mitigation measures for specific activities have been published and are available from the JNCC website on offshore industry advice (http://jncc.defra.gov.uk/page-4273); these are:

- JNCC guidelines for minimizing the risk of injury and disturbance to marine mammals from seismic surveys
- Statutory nature conservation agency protocol for minimizing the risk of injury to marine mammals from piling noise

- JNCC guidelines for minimising the risk of injury to marine mammals from using explosives.

The EPS guidelines also suggest that for most cetacean populations in UK waters, disturbance, in terms of the HR or OMR, is unlikely to result from single, short-term operations, e.g. a seismic vessel operating in an area for 4-6 weeks, or the driving of a dozen small diameter piles. Such activities would most likely result in temporary disturbance of some individuals, which on its own would not be likely to result in significant effects on the local abundance or distribution. Non-trivial disturbance, which would constitute an offence under the Regulations, would most likely result from more prevalent activities in an area, chronically exposing the same animals to disturbance or displacing animals from large areas for long periods of time. These considerations are assessed in the context of this SEA in Section 5.3.5 below.

All seismic surveys (including Vertical Seismic Profiling and high-resolution site surveys), sub-bottom profile surveys and shallow drilling activities carried out by the offshore oil and gas industry (including storage of gas and carbon dioxide) require an application for consent and cannot proceed without it. These applications are supported by an EIA, which includes a noise assessment. OPRED circulates each application to the relevant statutory consultees for advice and a decision on whether to grant consent is only made after careful consideration of their comments. Statutory consultees may request additional information or risk assessment, specific additional conditions to be attached to consent (such as specify timing or other specific mitigation measures), or advise against consent. It is a condition of consents issued under Regulation 4 of the *Petroleum Activities (Conservation of Habitats) Regulations 2001* (& 2007 Amendments) for oil and gas related seismic and sub-bottom profile surveys that the JNCC Seismic Guidelines are followed and the elements of the guidelines that are relevant to a particular survey are incorporated as a condition of consent.

Geophysical surveys carried out for renewable energy developments in Scotland will also need consent through the EPS licensing regime but in other parts of the UK, although a stage 1 risk assessment is required, a voluntary notification of intent to carry out the survey made to the Marine Management Organisation (MMO) will be sufficient, if the proposal does not carry a risk of disturbance or injury to any EPS. In practice, relevant JNCC mitigation guidelines are followed.

The mitigation measures recommended by JNCC and the SNCBs above represent best practice in the UKCS, primarily relevant to the prevention of injury (JNCC 2010). At the detail level there are important differences between mitigation measures (type and duration) to be applied during seismic surveys as opposed to impact piling or when using explosives; however, there are important commonalities too as the approach adopted is the same in all cases, mainly:

- The importance of the planning stage is emphasised; choice of location and timing (daily/seasonal) can be key to minimise risk, especially with respect to migration, breeding, calving or pupping. Moreover, an effort should always be made to minimise the amount of noise generated from any activity to the minimum level necessary to achieve the required outcome.
- During the operational stage, the main mitigation measure recommended is to monitor for the presence of marine mammals before the start of operations and only allow operations to commence if animals are not present. The duration of the pre-search and the size of the ‘mitigation zone’ depend on the activity and on its location. Different requirements are recommended with respect of the number of marine mammal

observers (MMOs), their degree of expertise and additional use of passive acoustic monitoring systems (PAM) to complement visual observers.

- The second key mitigation measure is to induce an avoidance response by animals, using a sound deterrent that is less acoustically injurious than the noise produced by the activity itself. The main measure recommended to achieve this is a so called 'soft-start' i.e. when the energy used for airguns and hammering piles or indeed the charge size for detonations is incrementally increased over a limited time period, just long enough to give time to animals to move away. In some cases, especially with explosives and potentially piling, the use of acoustic deterrent devices may also be recommended.
- Reports detailing the marine mammal mitigation activities as they happen must be prepared by the MMOs and sent to JNCC. These are regularly analysed and help inform on the effectiveness of the guidelines in practice and support revisions based on evidence (Stone 2003, Stone & Tasker 2005, Stone 2015a & 2015b, Stone *et al.* 2017).

The JNCC guidelines for minimising acoustic impacts from seismic surveys, first used in 1995 on a voluntary basis, were the first of their kind; as other countries have developed their own recommendations over time, the JNCC approach has been praised in many respects, but in comparison to some others it is perceived as incurring the least disruption to a survey (Weir & Dolman 2007) and has received some criticism (Weir & Dolman, 2007, Parsons *et al*. 2009, Wright & Cosentino 2015). The main points of concern raised are:

- the over-reliance on 'soft-start' procedure to ensure animals have moved away from the source, especially since MMOs and PAM are not always effective (e.g. at night, during low visibility, higher sea state or for species that don't vocalise regularly or can't be easily recognised). Critics argue the basis for the 'soft-start' procedure is theoretical and its effectiveness remains untested, while at the same time it introduces additional noise.
- the lack of shut-down of operations if a marine mammal is observed entering the 'mitigation zone' once the seismic survey is underway (as recommended in several countries).
- The focus on mitigating against risk of injury rather than disturbance.
- The 'soft' approach used in the guidelines; recommendations are made about what to take into consideration rather than mandatory, prescriptive requirements to be followed.
- The lack of incentive to ensure enforcement.

With respect to the first point, analyses of marine mammal observations during seismic surveys (Stone 2015a) found detection rates of cetaceans to be significantly lower during soft-start than when the airguns were not firing. While it has to be recognised that the soft-start may not be effective in all cases (e.g. occasional instances of white-beaked dolphins bow-riding have been recorded during the soft-start, Stone & Tasker 2006), these results provide some evidence that the soft start may indeed be a useful mitigation measure for some species. The importance of accurate MMOs reporting to gather evidence should be emphasised.

A modelling study by Hannay *et al*. (2011) assessed whether soft-start during a large airgun array operation might result in hearing damage to marine mammals. Sound exposure was compared to injury thresholds published by Southall *et al.* (2007); no instances were found in which injury threshold levels for cetaceans were reached during the initial stages of the soft-start sequence, but that for pinnipeds was approached in the worst case model. If the lower injury threshold proposed for harbour porpoises was to be applied (see Section 5.3.3.1), this may also be approached.

To reduce noise generation from pile-driving, several technical mitigation measures can be successfully applied during piling and alternatively, low-noise foundations can be chosen instead of those based on impact-piling. In the German EEZ, a mandatory noise limit has been set (dual threshold level of 160dB single event sound pressure level, SEL / 190 dB (peak-to-peak) at 750m from the source) which, in the case of commonly used pile foundations, can only be met by applying technical mitigation measures. The industry has responded with great efforts in developing new technologies and Ludemann & Koschinki (2013) collated examples of several mitigation measures and compared noise reduction potential and development status; these included bubble curtains, isolation casings, cofferdams and hydro sound dampers. Alternative foundation types were also reviewed such as the use of vibratory pile driving, foundation drilling, gravity base foundations, bucket foundations and floating turbines (i.e. tethered turbine technology). Mitigation measures that can reduce sound up to 40dB have been described, such as the use of stationary encapsulated gas bubbles (Lee *et al.* 2012). Further technological development is on-going but until a system has been routinely applied, it is difficult to predict with certainty the time required for its installation and how it may therefore effect operations layout and work schedule. This information is necessary to compare and evaluate options at the project level with respect to cumulative ecosystem impacts.

To reduce potential impacts from seismic surveys, technological developments are focusing on options either to improve the current efficacy of airguns (e.g. optimisation of airgun design, attenuation of unwanted high frequencies) or to develop alternative sound sources such as marine vibroseis (OSPAR 2009, LGL & MAI, 2011).

To support the MSFD goal of reaching Good Environmental Status in terms of noise pollution, OSPAR has been tasked to develop, review and support the application of mitigation measures (OSPAR 2010). An OSPAR inventory of measures to mitigate the emission and environmental impact of underwater noise has been published; the focus so far has been on pile-driving but other activities including seismic surveys, explosions, high frequency impulsive sources, dredging, sonar and shipping are also being planned (OSPAR 2014). OSPAR adopted the following in its new 2030 strategy last year: Strategic Objective 8: Reduce anthropogenic underwater noise to levels that do not adversely affect the marine environment; Operational Objectives S8.O1: By 2025 OSPAR will agree a regional action plan setting out a series of national and collective actions and, as appropriate, OSPAR measures to reduce noise pollution and S8.O2: By 2022 OSPAR will develop and implement a coordinated monitoring and modelling programme for continuous sound to support an assessment of anthropogenic underwater noise in the OSPAR maritime area.

5.3.5 Likelihood of significant effects

The following section considers the potential for significant effect, and potential for mitigation, under the following rationale:

- Definition of possible spatial effects ranges for injury and disturbance; based on synthesis of source level characterisation, propagation characteristics, effects criteria, and animal response observations discussed above
- Review of frameworks for assessment of long-term population effects

- Consideration of potential activity levels and specific sensitivities of individual Regional Seas
- Identification of specific geographical areas of concern
- Consideration of operational mitigation and potential for seasonal restrictions
- Consideration of potential cumulative effects

From the evidence described above, the following salient points have been identified.

It is appropriate to focus on marine mammals and in particular on the harbour porpoise in this SEA as they are appear to be more sensitive to sound than other receptors. Therefore if sufficient protection is offered to the harbour porpoise, it is assumed this would be sufficient for the marine environment as a whole.

Chronic exposure to increased levels of underwater noise has the potential to have long-term consequences for the health of marine species, as well as the potential to mask important biological signals but at present the evidence is insufficient to be able to set targets to ambient noise. The process established through MSFD, including noise indicators and noise registry, will help to improve our understanding.

Acute non-auditory physical damage, leading to death, is limited to the immediate vicinity (<10m) of impulsive, high amplitude sounds. Cetacean strandings may be the exception; a behavioural response (e.g. panic) to certain sounds may be the cause of abrupt change in diving behaviour, which in turn may result in decompression sickness and/or spatial disorientation leading in some instances to mass strandings. Beaked whales appear to be particularly at risk.

Southall *et al.* (2007 & 2019) thresholds for injury should be applied to estimate the onset of the risk of auditory damage. This estimate is recognised as highly conservative; efforts to incorporate new information into improved thresholds should continue at the international level with the aim to increase their accuracy and applicability. Thresholds for harbour porpoise (high-frequency cetacean) are the lowest; an assessment based on this species will therefore be precautionary for all other species.

Of the potential acoustic effects under consideration in this SEA, the most likely to be significant are considered to be the effects of pulse sources, associated in particular with seismic surveys, impact pile-driving, use of explosives and UXO clearance using detonation. Injury thresholds are likely to be exceeded only within a limited range from source. While in many instances the range will be <500m, this may not be necessarily true for all large 2D/3D seismic surveys, especially with respect to SEL_{cum} for high-frequency cetaceans.

Current mitigation measures as described in JNCC guidelines could be sufficient in minimising the risk of injury whenever carefully applied by industry for all regular marine mammal species that are common on the continental shelf. For deep-diving species and in particular for beaked whales (long dive duration, commonly silent, high risk of mass strandings) reliance on visual observers and PAM over a pre-search period is unlikely to be sufficient (even if extended to 60mins); it follows that risk from injury is still a possibility in these species. In particular with regard to beaked whales (in regions 9,10,11) further mitigation measures should be introduced to minimise any risk of behaviourally-mediated damage.

Establishing meaningful received sound levels to estimate the onset of disturbance has proved much more difficult, mainly due to the challenges with observing and measuring behavioural responses and due to the inherent variability of the behavioural context. Field observations during industrial activities are fundamental sources of information for assessment; however, such studies face many challenges and the statistical power associated with the analyses may be limited.

Precautionary effective deterrence ranges (EDR) are recommended in JNCC (2020b) and reproduced in JNCC (2021b) as a means of assessing the range of temporary habitat loss for harbour porpoise in relation to SACs established for the species. These EDRs do not apply to the waters of Scotland or Wales.

Table 5.7: Recommended Effective Deterrence Ranges (EDRs) for harbour porpoise.

Activity	EDR (km)	Source references
Monopile	26	Tougaard *et al.* 2013, Dähne *et al*. 2013
Monopile with noise abatement	15	Dahne *et al*. 2017, Rose *et al.* 2019
Pin-pile (with and without noise abatement)	15	Graham *et al*. 2019
Conductor piling for oil & gas wells	15	Jiang *et al*. 2015, MacGillivray 2018, Graham *et al.* 2019
UXO clearance	26	Based on monopile EDR
Seismic (airguns) survey	12	Thompson *et al*. 2013, Sarnocińska *et al.* 2020
Other geophysical surveys	5	Crocker & Fratantonio 2016, Crocker *et al.* 2019

Source: After JNCC (2020b)

JNCC (2020b) note that different EDRs and estimates of the duration of impact may be justified based on new peer-reviewed evidence on sound levels and propagation, harbour porpoise response, recovery and habituation. The EDRs shown in Table 5.7 are considered very precautionary particularly in the light of some of the evidence cited (e.g. effects distances reported by Graham *et al.* (2019)) and that a range of technical alternatives may be deployed to reduce the effects footprint such as vibropiling or drilling of foundations, and UXO clearance using low noise techniques (e.g. Robinson *et al*. 2020) and the avoidance of use of explosive scare charges (Robinson *et al*. in prep.).

Kastelein *et al*. (2019) report recent tests on captive harbour porpoise and harbour seal which have improved the reliability of the TTS onset curve for both species. Their results show harbour porpoise hearing to be slightly less susceptible to low-frequency sound, and much less susceptible to high-frequency sound, than formerly assumed. Harbour seal hearing is much less susceptible to low-frequency sound, and more susceptible to high-frequency sound, than formerly assumed.

The focus of most studies has been on individual effects and yet the likelihood of significant effects needs ultimately to be assessed in terms of long-term population consequences. Assessments at the population level must be able to consider the cumulative effects of several impacts likely to impinge on a population. This is a major challenge which continues to be the focus of much research effort, see below.

Modelling frameworks to assess population level impacts of harvesting and by-catch are well established (e.g. Wade 1998) but these are concerned exclusively with lethal impacts. A conceptual framework specific to acoustic disturbance, is the PCAD model (Population Consequences of Acoustic Disturbance) (NCR 2005); it proposes to evaluate how changes in behaviour caused by sound may result in population effects through clearly described steps and includes a series of transfer functions to link behavioural responses to sound with life functions, vital rates and population change. Using results from case studies, the structure of the PCAD model has been amended and its scope extended to include all possible forms of disturbance, hence it is referred to PCoD (Populations Consequences of Disturbance) and detailed by New *et al.* (2014). Although case studies have helped to estimate some parameters for some species, empirical data to inform most of the identified variables and transfer functions are currently limited or altogether missing for most species.

Using PCAD and PCoD as starting point, novel approaches have been developed to carry out assessment of acoustic impact while dealing with the current lack of data.

A transparent way of linking predicted individual impacts to vital rates was proposed by Thompson *et al.* 2013 in an effort to assess population-level impacts of proposed wind farm construction on protected harbour seals using the Dornoch Firth and Morrich More SAC, in the Moray Firth. Spatial patterns of seal distribution and received noise levels were obtained from high-quality telemetry data and noise propagation modelling; these were integrated with available data on potential impact of noise to predict how many individuals were displaced (using criteria from Nedwell *et al.* 2007) or experienced auditory injury (using injury criteria from Southall *et al.* 2007). It was assumed that any risk of direct mortality (due to high sound levels which were estimated to occur only <50m from source) could be avoided by mitigation. Expert judgement was then used to link these impacts to changes in vital rates and the rationale applied is clearly outlined; finally the results were applied to population models that compared population changes under baseline and construction scenarios over a 25 year period. At the individual level, up to 59% of the seals population could be affected by behavioural displacement and up to 15% suffer PTS. This translated at the population level, in a short-term reduction in abundance during and immediately after the construction period followed by recovery resulting in no observable difference between baseline and impact scenarios after 25 years. Conservative estimates were chosen for all individual parameters to ensure that worst-case impacts were assessed; this has led to more significant short term impacts being predicted than would likely be expected.

New *et al.* (2013) developed a model simulating the complex social, spatial, behavioural and motivational interactions of coastal bottlenose dolphins in the Moray Firth to assess the biological significance of increased rate of behavioural disruptions caused by vessel traffic. A scenario was explored in which vessel traffic increased from 70 to 470 vessels a year in response to the construction of a proposed offshore renewables facility. Despite the more than six fold increase in vessel traffic, the dolphins' behavioural time budget, spatial distribution, motivations and social structure remained unchanged. It was concluded that small-scale changes in behaviour should not be automatically associated with a need to limit anthropogenic activities without further investigation as to the cumulative effects of the disturbance.

Harwood *et al.* (2014) and King *et al.* (2015) developed and applied an approach termed 'interim PCoD' which also relies on expert elicitation to estimate parameters that transfer changes in individual behaviour and physiology to vital rates. Results are then incorporated into a stochastic population model to forecast the potential effects of disturbance on population size and structure. Expert elicitation helps to parameterise a statistical relationship between the number of days of disturbance and vital rates. As an example, the potential effects of noise from offshore wind farm construction on the North Sea harbour porpoise population were investigated; the risk was estimated to be low or negligible (<0.5% worst-case decline <0.5% of initial population size) but authors cautioned against the interpretation of this illustrative study as a prediction of actual effects because of the simplistic and likely unrealistic way that the numbers of animals disturbed was estimated.

In the Netherlands, the Framework for Assessing Ecological and Cumulative Effects (FAECE) has been drawn up for the cumulative ecological effects of the development of offshore wind farms in the southern North Sea (Rijkswaterstaat 2015a). For marine mammals, a phased approach which incorporates the interim PCoD model has been recommended (Heinis *et al.* 2015). An initial assessment by Heinis *et al*. (2015) of the possible extent of the cumulative effects of piling noise on the harbour porpoise population used a number of scenarios for both the construction of wind farms on the Dutch Continental Shelf (DCS) and in the rest of the North Sea and for seismic surveying between 2016 and 2022. Seventeen construction scenarios were compared; for the Dutch wind farms, based on two farms being built per year while international scenarios assumed a maximum of six wind farms being constructed (two of these being in the DCS). Different scenarios were provided by inclusion of seasonal restrictions (in DCS abundance is higher in spring and lower in the autumn), by the introduction of a sound standard as currently applied in Germany (SEL1 at 750m from pile = 160 dB re 1μPa^{2}s) and by varying assumptions about duration of piling and size of relevant sub-population (used mainly to test sensitivity of the model). The final outcome of the models was expressed as a change in porpoise population for the years 2022-2024. All scenarios with the exception of those where sound standards were implemented resulted in a considerable predicted reduction of the harbour porpoise population. The magnitude of the reduction ranged between ~66,000 and 100,000 individuals (5th percentile using 500 simulation results) in international scenarios and between 5,000 and 28,000 when only DCS wind farms were considered. In addition, the simulation for an international seismic survey scenario indicated that the effects of seismic surveys may be of the same order of magnitude as the effect of the worst case scenario for piling. To put the predicted reductions into a wider ecological context, the results were further assessed by comparison with the ASCOBANS standard for annual additional mortality (Rijkswaterstaat 2015b). The relevant ASCOBANS threshold was estimated at 6375 individuals (additional mortality per year); this was exceeded in the majority of scenarios, even when only the effects of construction phase of Dutch wind farms were considered. The conclusions reached were that the construction of wind farms in the North Sea will impose a considerable pressure on the harbour porpoise population, both at the national and international levels and that significant adverse effects can only be avoided by taking mitigation measures to reduce the sounds emitted during construction.

In the UK, the Habitats and Wild Birds Directives Marine Evidence Group (MEG) commissioned an expert group to provide an objective, scientific assessment of the potential impacts of planned large-scale offshore wind energy development on marine mammals in the North Sea (Tougaard *et al.* 2016). As in previous assessments, the long-term consequences of disturbance were the primary focus of the work as the risk of injury was assumed to be already minimised through current mitigation measures. The harbour porpoise was chosen as the test species being the most common species in the North Sea and because it appears to be the most sensitive in terms of direct effects on both hearing and behaviour. Hence an assessment based on harbour porpoise can be assumed to be precautionary for all other shelf species. Given the gaps in knowledge on how effects at the individual level are transferred to the population and the lack of input data and validation for agent-based models currently in development, the expert group chose to use a simplified population impact model. The model used a range of simplifying and worst-case assumptions; avoidance (as complete displacement from impacted area) was the response considered for acoustic disturbance. The construction scenario consisted of two pile driving operations occurring simultaneously and continuously over the next decade. A 26km effective deterrence radius was predicted around pile driving events and its effect at the population level was estimated in terms of absolute decrease in population size over the decade to range between <2% and <7%; the magnitude of this effect is small when compared to other known negative impacts on this species (e.g. by-catch in gill net fisheries) and therefore insufficient to threaten the long-term conservation status of the porpoise in the North Sea. The Expert Group concluded that under the modelled assumptions, the planned offshore construction activity will result in a non-trivial level of acute disturbance, but *'this will not compromise the long-term health of the population'*. Nonetheless, mitigation measures should be carefully considered and preferentially adopted; recommendations focus on reducing noise emissions through modifications to offshore wind installation as well as careful planning to minimise the impact from temporal and spatial overlap between harbour porpoises and construction activity.

The evidence obtained over the last 15 years has generally shown that harbour porpoise are more sensitive to underwater noise than previously thought. However, as revealed by the difference in outcomes from the modelling frameworks above, the degree of uncertainty in extrapolating from individual to population effects is still uncomfortably high. Nonetheless, these exercises have raised the theoretical possibility for temporal and spatial combinations of large seismic surveys and pile-driving operations to result in significant population disturbance.

In terms of noise exposure, what matters is the number of pile driving operations taking place simultaneously within a region or management unit; while project schedules are estimates and changes are possible, this SEA concurs with the assumption made by the Expert Group (Tougaard *et al.* 2016) that on average two pile driving operations will take place continuously in the North Sea over the next decade or more. If sound generated during pile-driving is assumed to affect an area with a radius of 20km, wind farm installations will disturb approximately 2500km^2 corresponding to ~1% of Region 1 & 2 combined.

Seismic survey coverage of the UKCS is extensive. As identified in previous offshore energy SEAs, the vast majority of seismic survey effort on the UKCS has been undertaken in the developed (in terms of oil and gas) areas of the northern, central and southern North Sea and the Faroe/Shetland Channel, the Channel, the western approaches and the Irish Sea. A GIS analysis carried out of all 3D surveys from the Oil & Gas UK database from 2000 to 2014, revealed a similar pattern with 92% of 3D surveys taking place across Regions 1, 8 and 9. A similar geographic distribution of seismic survey effort can be anticipated in the future, although limited activity in other parts of the UKCS cannot be discounted. In addition to this UK seismic noise budget, noise propagating from surveys in contiguous national waters (particularly Faroese and Norwegian waters) will be present.

Assuming that activity over the next 5 years will not exceed the yearly average of the last 10 years, an estimate of the total area affected by seismic surveys following the plan/programme may be calculated. The number of 3D surveys carried out per year between 2004 and 2014 is ~18. Assuming each survey requires 60 days of shooting and most of the seismic activity is concentrated between April and September, 6 surveys may take place at any one time (but not geographically coincident). If it is assumed that sound from seismic surveys affects an area of 10km radius, seismic exploration could acoustically disturb approximately 1885km^2. If it is assumed that all this activity is in Region 1 and 2, the area disturbed at any one time would correspond to 0.8% of the total area or <0.5% if Regional Seas 1, 2, 8 and 9 were combined.

To further inform regional considerations of the likelihood of impacts, marine mammal sensitivities of individual Regional Seas – based on Appendix 3a.8 – are summarised below:

Regional Sea 1 - The central and northern North Sea has a moderate to high diversity and density of cetaceans, with a general trend of increasing diversity and abundance with increasing latitude. Harbour porpoise and white-beaked dolphin are the most widespread and frequently encountered species, occurring regularly throughout most of the year. Minke whales are a seasonal visitor, regularly recorded in the summer months; killer whales are sighted with increasing frequency towards the north of the area and during the summer. Atlantic white-sided dolphin, Risso's dolphin and long-finned pilot whale can be considered occasional visitors, particularly in the north of the area. Coastal waters of the Moray Firth and east coast of Scotland support an important population of largely resident bottlenose dolphins. Large numbers of grey and harbour seals breed in the area, with high densities observed in many coastal waters and some areas further offshore; large declines in harbour seals numbers have been observed in this region.

Regional Sea 2 – compared to the central and northern North Sea, the southern North Sea generally has a relatively low density of marine mammals, with the likely exception of harbour porpoise. While over ten species of cetacean have been recorded in the southern North Sea, only harbour porpoise and white-beaked dolphin occur regularly throughout most of the year, and minke whale in summer. Important numbers of grey and harbour seals are present off the east coast of England, particularly around the Wash where harbour seals forage widely. The Southern North Sea SAC, designated for persistent high relative densities of harbour porpoise, encompasses a considerable proportion of the region, particularly in summer.

Regional Sea 3 – The eastern English Channel has a relatively low density and diversity of marine mammals; it is a transition zone between the communities of the southern North Sea and the western Channel/Celtic Sea. Harbour porpoise are the most frequently sighted species in coastal waters, followed by bottlenose dolphins. Further offshore, occasional sightings of long-finned pilot whales or common dolphins have occurred but numbers are much less than in the Western Channel. The area is not particularly important for seals, with no major colonies present on the English coast and very little activity recorded.

Regional Seas 4/5 – These regions experience a relatively high density and moderate diversity of marine mammals. Four cetacean species occur frequently: minke whale, bottlenose dolphin, short-beaked common dolphin, and harbour porpoise. Long-finned pilot whale and Risso's dolphin are also regularly encountered. Grey seals are present in the area, but in low densities relative to the rest of UK shelf waters. Harbour seals are rarely encountered.

Regional Sea 6 – Eighteen species of cetaceans have been recorded in this region with highest species diversity offshore around the Celtic Deep and close to the Isle of Man. Coastal waters off Wales, particularly Cardigan Bay, support relatively high densities of bottlenose dolphins. Other frequently encountered species are the harbour porpoise, the short-beaked common dolphin, Risso's dolphin and minke whale. Grey and harbour seals are also regularly present in certain areas.

Regional Sea 7 – the Minches and western Scotland support a rich diversity and high density of marine mammals. Harbour porpoise and white-beaked dolphins are widespread and numerous and encountered throughout the year, although most frequently during summer months. Common dolphins are also sighted throughout the year, although most regularly and in large numbers during summer. Risso's dolphins and minke whales are also sighted fairly frequently in the summer months. Small numbers of bottlenose dolphins also occur around coastal waters of the Hebrides. Killer whales are occasionally observed throughout the area, most notably around seal haul-out sites during summer. Both grey and harbour seals are abundant throughout the area. A majority of the region falls within the Inner Hebrides and the Minches SAC, designated for persistent high relative densities of harbour porpoise.

Regional Sea 8 – the waters north and west of Scotland support a rich diversity and density of marine mammals. Containing a variety of habitats, the region supports species commonly associated with shallower coastal areas, offshore shelf waters, and those occupying the deeper waters of the shelf edge and slope. Ten cetacean species are known to occur regularly in this area: harbour porpoise, white-beaked dolphin, Atlantic white-sided dolphin, Risso's dolphin, bottlenose dolphin, short-beaked common dolphin, killer whale, long-finned pilot whale, sperm whale and minke whale. Large numbers of grey and harbour seals breed in the area, with high densities observed in many coastal waters and some shelf areas further offshore; large declines in harbour seals numbers have been observed in this region.

Regional Sea 9 – the Faroe-Shetland Channel supports a rich diversity and high density of marine mammals. Most abundant species in the region is the Atlantic white-sided dolphin and other commonly sighted species include bottlenose dolphin, killer whale, long-finned pilot whale, and sperm whale. Beaked whales, common dolphins, Risso's dolphins, fin, sei and minke whales are also recorded regularly, while other species of baleen whale such as blue and humpback are occasionally observed. Grey and harbour seals are very uncommon.

Regional Seas 10/11 – knowledge of marine mammal occurrence in the deep waters beyond the shelf slope to the west of Scotland is poor relative to other areas in UK waters. However, available information suggests that this is an important area for cetaceans, with a variety of species and high densities recorded, both as residents and large whales on migration.

Key areas of marine mammal sensitivity therefore include:

- Fair Isle – Sumburgh Head (harbour porpoise, white-beaked dolphin, grey seal, harbour seal)
- North and east of Orkney (grey and harbour seals)
- The Moray Firth (bottlenose dolphin, harbour porpoise, minke whale) and coastal waters south to the North of England (bottlenose dolphin, white-beaked dolphin (further from shore)); including Smith Bank (grey and harbour seals, harbour porpoise), inner Firths (harbour seal), St Andrews Bay and outer Forth (grey seals)
- Areas adjacent to the Farne Islands and Donna Nook (grey seal)
- The Wash, outer Wash and off the Humber (harbour seal)
- Offshore areas of the southern North Sea (harbour porpoise)
- Western English Channel (common dolphin, minke whale)
- Coastal areas around Cornwall (bottlenose dolphin)
- Celtic Sea (common dolphin, minke whale)
- Coastal areas from Cardigan Bay to Liverpool Bay, including the Lleyn Peninsula (bottlenose dolphin, harbour porpoise, Risso's dolphin, grey seal) and adjacent Manx waters
- Coastal areas around Pembrokeshire (harbour porpoise, Risso's dolphin, common dolphin, minke whale, grey seal)
- Carmarthen Bay (harbour porpoise, grey seal)

- Hebridean Sea – Kintyre to Skye (harbour porpoise, bottlenose dolphin, common dolphin, minke whale, grey seal, harbour seal)
- Continental shelf edge – Barra Fan to Miller Slide (various cetaceans)
- Stanton Banks (grey seal)
- North Minch and Cape Wrath to North Rona (harbour porpoise, white-beaked dolphin, common dolphin, Risso's dolphin, minke whale, grey seal)
- Hebridean shelf – notably around Monarchs and Flannans (grey seal)
- Deep waters to the west of the UK (various cetaceans including beaked whales, migrating humpback and blue whales)

The evidence has highlighted the potential for noise generated during seismic surveys and impact pile driving to cause disturbance on a relatively large temporal and spatial scales. Several of these activities may take place across the UKCS and across neighbouring regions, leading to the potential for cumulative and trans-boundary effects. The most likely response by marine mammals is avoidance of an area, although other behavioural and physiological responses may also be involved. By assuming that acoustic disturbance equates to loss of foraging opportunities through avoidance, long-term population consequences can be calculated. Current understanding is that, in combination, noise generated from planned activities, are highly unlikely to result in a population level effect. Given the wide ranging distribution and individual movements of marine mammals, the relevant geographical scale for transboundary effects with respect to acoustic disturbance is that of the relevant management unit.

5.3.6 Summary of findings and recommendations

Considerable uncertainty surrounds many elements of our understanding of the effects of anthropogenic noise on the marine environment. Efforts to identify and address these gaps are ongoing through a variety of initiatives, including academic, government and industry projects.

It is accepted that marine mammals show the highest sensitivity to underwater sound, particularly the intense pulses associated with seismic surveys, impact pile-driving and of explosions. The severity of potential effect has therefore been related principally to marine mammal species composition and abundance in an area, although effects on fish (including spawning aggregations) and other receptors have also been considered. A major obstacle in understanding the effects on fish and invertebrates is the limited ability to measure the particle motion component of sound.

The nature of effects reviewed range widely, from masking of biological communication and small behavioural reactions, to chronic disturbance, injury and mortality. For marine mammals and fish, effects will generally increase in severity with increasing exposure to noise; a distinction can be drawn between effects associated with physical injury and effects associated with behavioural disturbance.

With respect to injury, this SEA concurs with the scientific consensus judgement that underwater sound generated during seismic and pile-driving operations has the potential to cause injury within a limited range (tens to hundreds of metres). Assessment of risk can rely on exposure thresholds but these a periodically updated to reflect the latest scientific findings as is further guidance on their application. In addition, current mitigation measures when carefully applied, are deemed sufficient in reducing the risk of injury to negligible levels for all species common on the continental shelf. More uncertainty on their efficacy exists for deep-diving species; a particular concern identified in this SEA is for beaked whales (deep water Regional Seas 5, 9, 10, 11) which are known to be highly sensitive to some underwater sounds.

For disturbance effects, there is little confidence in relying on criteria based on exposure alone as animal behaviour is largely dependent on context. Instead, field observations during industrial activities are fundamental sources of information for assessment. Impact pile-driving and seismic surveys have the largest disturbance footprint of any activity in the plan/programme. However, the main challenge when assessing the likelihood of significant disturbance effects stems from the need to assess these in terms of long-term population consequences while the available evidence relates to individual responses under relatively short-term conditions. Several modelling frameworks are being developed to assess population level impacts of acoustic disturbance. All frameworks rely on assumptions and on expert judgement to cope with the gaps in the data, but so far there are considerable differences in methodologies and outcomes, all of which need to be viewed with caution. The approach used by an expert group convened under the Habitats and Wild Birds Directives Marine Evidence Group led to the conclusion that planned offshore construction activity up to 2020 will result in a non-trivial level of acute disturbance, but *'this will not compromise the long-term health of the population'*. Since activities considered in this SEA are of a similar magnitude, the report's conclusions are considered to remain applicable.

Previous SEAs have recommended consideration of the establishment of criteria for determining limits of acceptable cumulative impact; and for subsequent regulation of cumulative impact. The SEA recognises the advances made in this respect through the establishment of the indicator on low- and mid- frequency impulsive sounds under the Marine Strategy Framework Directive. The establishment of a database to collate occurrences of 'noisy activities' (the Marine Noise Registry) represents an important contribution to understanding and management of activities.

Given the potential risk from chronic exposure to increased ambient noise level, the degree of uncertainty with population level assessment of acoustic effects and the need to achieve Good Environmental Status, this SEA recognises the importance of minimising underwater noise emissions and emphasises the value of further voluntary mitigation measures at the project scale, in particular technical noise emissions reductions and careful planning to reduce temporal and spatial overlap between activities and marine mammals.

5.4 Physical damage/change to features and habitats

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Physical effects of anchoring and infrastructure construction (including pipelines and cables), operation and maintenance, and decommissioning on seabed sediments and geomorphological features (including scour)	X	X	X	X	X	X	X	X
Physical damage to/loss of biotopes from infrastructure construction including seabed preparation, operation and maintenance, and decommissioning (direct effects on the physical environment)	X	X	X	X	X	X	X	X
Changes/loss of habitats related to the placement of structures on the seabed and related protection materials	X	X	X	X	X	X	X	X
Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc. and impacts on the setting of coastal historic environmental assets and loss of access.	X	X	X	X	X	X	X	X
Post-decommissioning (legacy) effects – cuttings piles, footings, foundations, *in situ* cabling etc	X	X	X	X	X	X	X	X
Offshore disposal of seabed dredged material	X	X	X	X	X	X	X	X

5.4.1 Introduction

Previous SEAs have compared the physical disturbance effects of oilfield activities and OWFs to those of fishing and natural events (e.g. storm wave action), concluding generally that effects are minor on a regional scale, although highly variable across the Regional Sea areas (DECC 2011, 2016). The most important human pressure in terms of its spatial extent and level of impact on the UK marine environment results from fishing (e.g. Dinmore *et al*. 2003, Gage *et al*. 2005, Eastwood *et al.* 2007, Stelzenmüller *et al.* 2008, Foden *et al.* 2010, 2011). With the exception of relatively few designated conservation sites which have fishery restrictions in place and temporarily or periodically closed areas (for fishery stock management purposes), trawling is effectively unregulated in the UK and can be of concern with regard to conservation of seabed habitats and species (e.g. Witbaard & Klein 1993, de Groot & Lindeboom 1994, Jennings & Kaiser 1998, Kaiser *et al.* 2002a, Kaiser *et al.* 2002b). In the UK, concern has focussed on the continental shelf, but with increasing concern in relation to deep water areas (Bett 2000, Roberts *et al*. 2000, Gage *et al.* 2005). ICES have calculated the area impacted by mobile bottom-contacting gears (based on Vessel Monitoring System (VMS) and logbook data for vessels >12m) to provide fishing abrasion maps[111]. Figure 5.2 highlights

[111] http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2015/2015/DCF_indicators_567.pdf

those areas where the seabed surface (upper 2cm) has been impacted by mobile bottom-contacting gears in 2017 (the latest year for which a figure is available). More recent data for the Greater North Sea region estimated that mobile bottom-contacting gears have been deployed over approximately 490,185km^2 of the region in 2018, corresponding to *ca*. 73% of the region's spatial extent (ICES 2021a). Fishery impacts were also widespread in the Celtic Seas ecoregion with an estimated 409,425km^2 (or 45%) of the region impacted by mobile bottom-contacting gear (ICES 2021b). The potential activities that could result from licensing, the installation of infrastructure (e.g. turbines, cables) in areas of dynamic, soft sediments and associated activities such as sandwave clearance and the addition of hard substrata (rock, concrete mattresses) to support and protect infrastructure has become a cause for concern. More recently, potential impacts of seabed disturbance on blue carbon stored in seabed sediments has become an area of research interest.

5.4.2 Sources of potentially significant effect

A number of sources of potentially significant effect associated with activities covered by the draft plan/programme have been identified which could cause physical damage/change to features and habitats. These are identified at the start of this section and in Table 5.8 below along with the main relevant source activities and pathways by which exposure of sensitive receptors might occur with links to where further information is provided.

Table 5.8: Physical damage/change to features and habitats: sources of effect, pathways and receptors

Source activity	Relevant aspects of plan	Pathways by which exposure might occur	Potential receptors
Construction phase			
Physical effects of anchoring and infrastructure construction (including pipelines and cables), operation and maintenance, and decommissioning on seabed sediments and geomorphological features (including scour) (see Section 5.4.3.1)			
Physical damage to/loss of biotopes from infrastructure construction including seabed preparation, operation and maintenance, and decommissioning (direct effects on the physical environment) (see Section 5.4.3.1)			
Changes/loss of habitats related to the placement of structures on the seabed and related protection materials (see Section 5.4.3.1)			
Offshore disposal of seabed dredged material (see Section 5.4.3.1)			
Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc. and impacts on the setting of coastal historic environmental assets and loss of access (see Section 5.4.3.2)			
Anchoring of vessels, semi-submersible rigs, floating production, wave, tidal and offshore wind installations	All	Anchor placement, dragging and chain abrasion	Seabed sediments and features, benthic habitats
			Submerged archaeological resource
Piling of monopile or jacket foundations	Oil and gas, gas storage, CO_2 storage, offshore wind, offshore hydrogen production	Remobilisation of sediments during piling	Water quality (increased turbidity)
			Seabed sediments and features, benthic habitats

Source activity	Relevant aspects of plan	Pathways by which exposure might occur	Potential receptors
	OWF	Loss of seabed and associated benthic habitats under footprint	Seabed sediments and features, benthic habitats
Pipeline, flowline and umbilical installation and trenching. Laying and trenching of cables	All	Disturbance and remobilisation of sediments during trenching and cable burial	Seabed sediments and features, benthic habitats
			Water quality (increased turbidity)
			Submerged archaeological resource and setting of coastal historic assets
Scour protection (rock dumping, concrete mattresses) on cable / infrastructure	All	Loss of seabed and associated benthic habitats under footprint	Seabed sediments and features, benthic habitats
		Creation of new habitat, hard structures/ substrate	Benthic habitats
Placement of wellheads, subsea templates and manifolds	Oil and gas, gas storage, CO_2 storage	Loss of seabed and associated benthic habitats under footprint	Seabed sediments and features, benthic habitats
Placement of jack-up rigs/barges (seabed disturbance by spud cans)	Oil and gas, gas storage, CO_2 storage, offshore wind	Loss of seabed and associated benthic habitats under footprint	Seabed sediments and features, benthic habitats
Placement of gravity base and suction caisson foundations	Oil and gas, offshore wind, tidal stream, wave	Loss of seabed and associated benthic habitats under footprint	Seabed sediments and features, benthic habitats
		Creation of new habitat, hard structures/ substrate	Benthic habitats
Placement of foundations and walls associated with lagoon construction	Tidal range	Loss of seabed and associated benthic habitats under footprint	Seabed sediments and features, benthic habitats
		Creation of new habitat, hard structures/ substrate	Benthic habitats
Works to level seabed and offshore disposal of seabed dredged material	All	Removal of seabed by dredging	Seabed sediments and features, benthic habitats
			Submerged archaeological resource
		Remobilisation of sediments during disposal	Water quality (increased turbidity)
			Seabed sediments and features, benthic habitats

Source activity	Relevant aspects of plan	Pathways by which exposure might occur	Potential receptors
Decommissioning phase			
Post-decommissioning (legacy) effects – cuttings piles, footings, foundations, in situ cabling etc (see Section 5.4.3.3)			
Decommissioning of infrastructure	All	Pathways the same as construction phase	Receptors the same as construction phase

5.4.3 Consideration of the evidence

5.4.3.1 Physical damage/change associated with construction phase

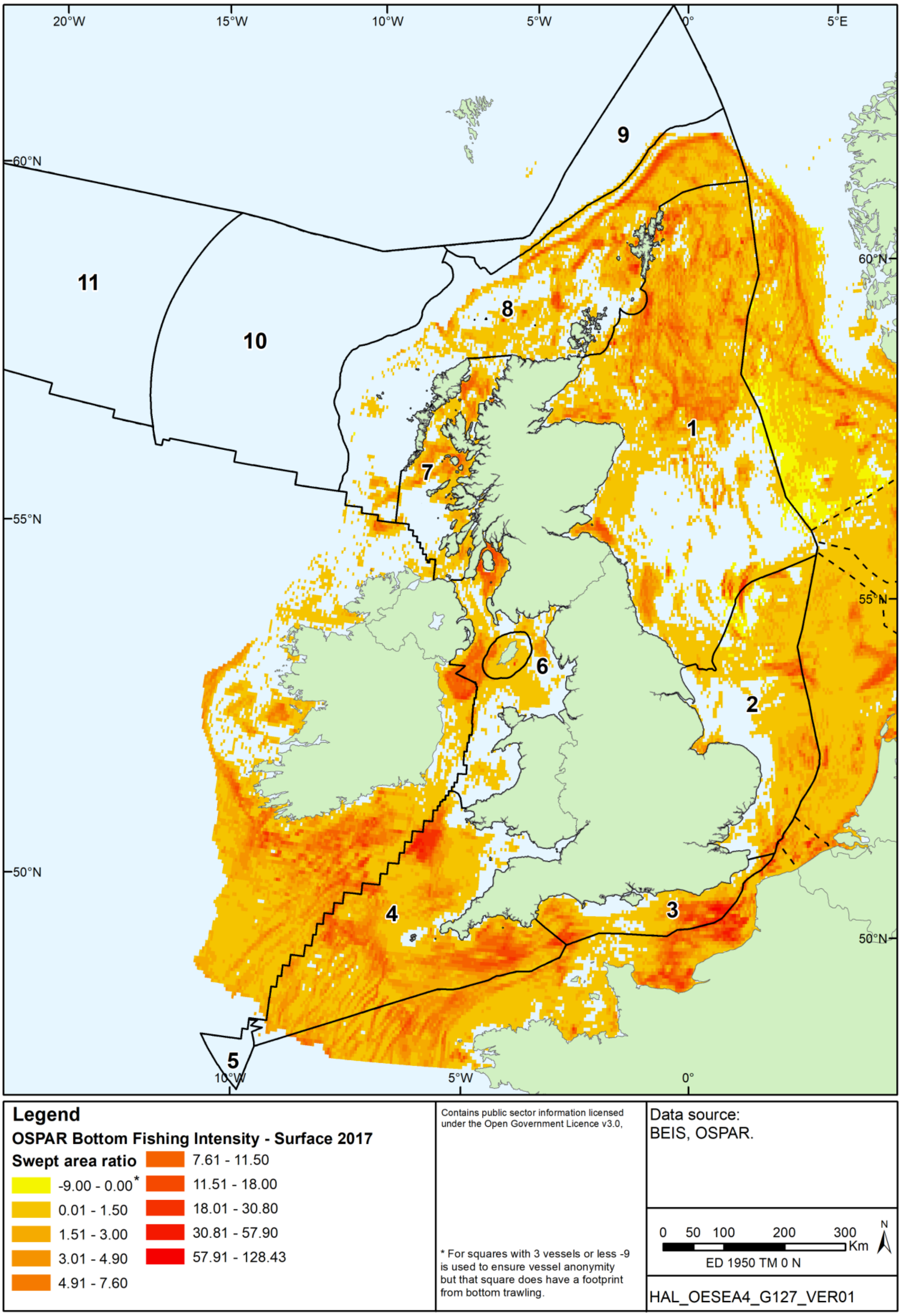
In general, physical damage to seabed features and properties, benthic populations and communities may result, which can be direct (from physical abrasion or discharges of particulate material causing smothering) or indirect (scour, or winnowing of disturbed material, causing smothering). The scale of direct damage to features and habitat loss associated with long-term placement of structures on the seabed is generally in proportion to the size of the object, and the duration of effect is equal to the operational lifespan of the structure – or may be indefinite if complete removal is not feasible or cost-effective. In the case of scour-related effects, the scale may be significantly greater than that of the fixed structure (see below).

Offshore wind farms

Physical effects associated with the installation of foundations

Round 1 and 2 OWF turbines exclusively used monopole-type foundations. However, as part of Round 3 and future development rounds, alternative foundation types for OWFs are being considered including steel jackets, gravity base foundations, suction caisson foundations and potentially floating structures for deeper waters, which have varying impacts on the physical environment. A review of Environmental Statements for a number of Round 3 wind farms and a floating wind demonstrator site for OESEA3 provided estimates of the seabed footprint associated with the different foundation types (Table 5.9). This table has been updated for OESEA4 and shows that monopiles and jacket foundations have been selected for recent wind farm projects and those that will be constructed in the near future. No gravity base foundations (which have the largest seabed footprint) have been installed to date on the UKCS.

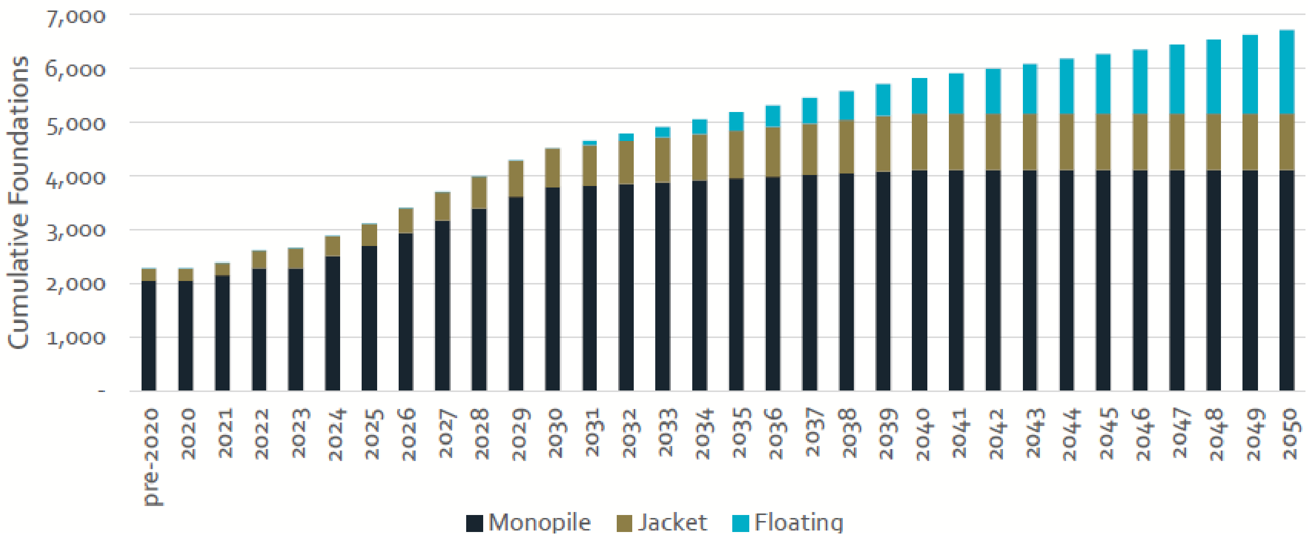
Figure 5.2: Surface abrasion from mobile bottom-contacting gears in 2017



This is reflected in the UK strategic capability assessment of offshore wind foundations for the Offshore Wind Growth Partnership (ORE Catapult 2020)[112], which indicates that (at that time) the UK had over 8.5GW of operational offshore wind farms with over 2,000 wind turbines. In terms of foundations, 90% of the installed turbines use monopile foundations with the remaining 10% being jacket foundations. The report forecasts that as deployment ramps up towards the 2030 target of 40GW, sites will be developed in deeper waters and jackets are expected to increase share to 22% compared to 78% for monopiles. Beyond 2030, it is expected that floating foundations will become cost-competitive and be used on the majority of UK projects (Figure 5.3).

In terms of seabed preparation, monopile and jacket structures have a localised impact on the seabed. There may be localised seabed clearance with monopiles either driven or placed into a drilled hole and cemented in place (where bedrock is closely subcropping with the seabed); piles for jackets are installed using similar methods, though these are smaller and more numerous than monopiles. Similarly, floating turbines are likely to require minimal seabed preparation although this will depend on the anchor system selected and the seabed conditions. Gravity bases and suction caisson designs may require preparation of the seabed through levelling, usually done by dredging and the removal of boulders and other obstructions (see Table 5.9 for estimates of seabed preparation areas and excavation volumes associated with these foundation types). They also potentially require a thin stone bed or further dredging to create an even horizontal surface. At present, there are no indications that a significant number of gravity bases will be used in the future development of UK offshore wind (see Figure 5.3).

Figure 5.3: UK foundations market forecast by foundation type



Source: ORE Catapult (2020)

As indicated above, monopiles are likely to be used as foundations where depths (up to 60m) and sediments are suitable. Steel piles are typically hammered to the desired penetration depth. However, in some cases the pile may reach a point of refusal and cannot be driven to the required penetration depth due to difficult ground conditions. In this event it is possible to drill out some or all of the volume of sediment inside the pile to reduce the driving resistance and allow the pile installation to be completed. Drilling of monopiles will result in the release of

[112] https://owgp.org.uk/wp-content/uploads/2020/01/UK-OSW-Foundations-Strategic-Capability-Assessment-2019-v04.03-1.pdf

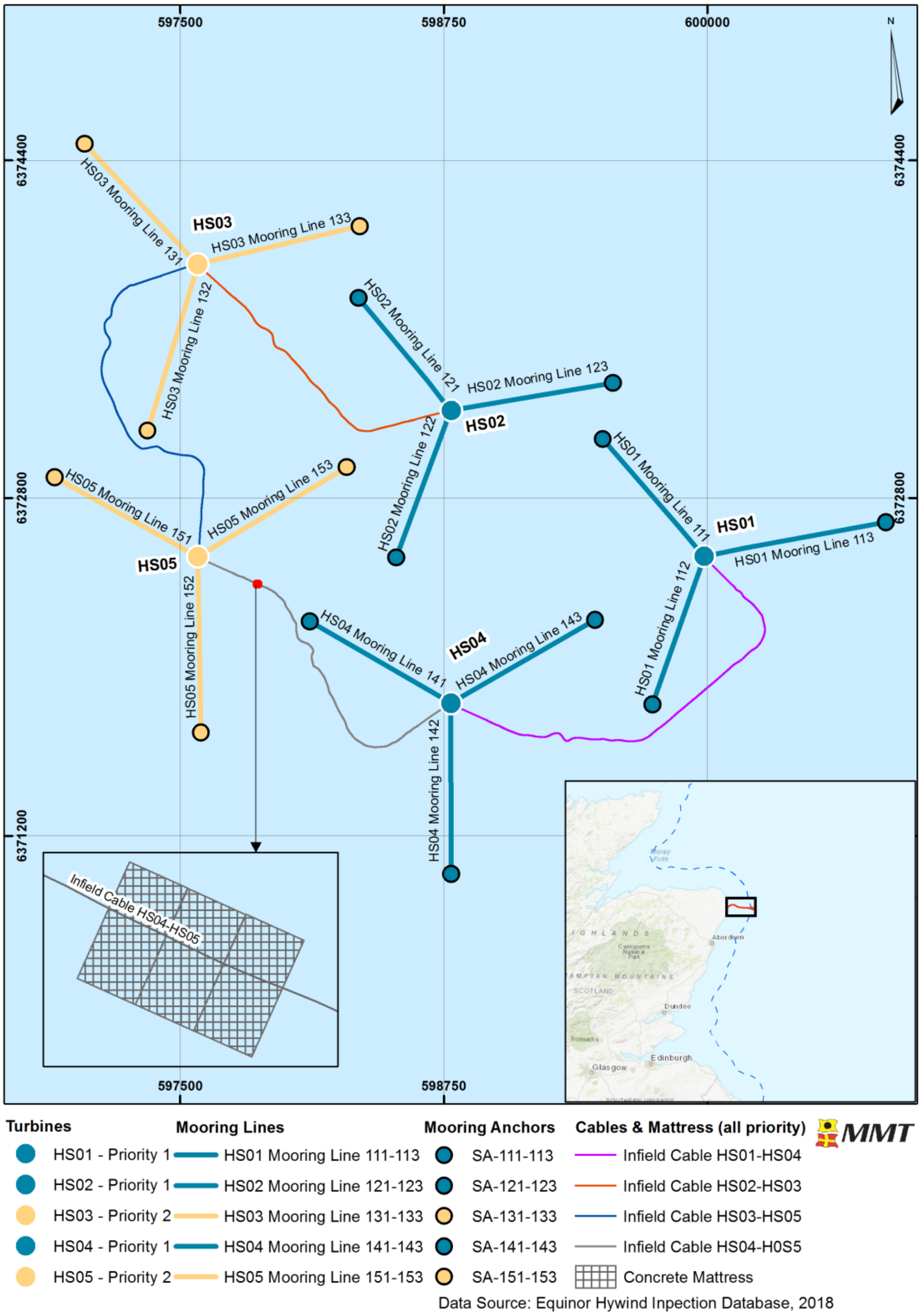
both fine material (silts) and granular material (sands and gravels) at the sea surface, which will deposit on the seabed (Table 5.9 provides estimates of potential drill cuttings for monopiles for projects associated with Round 3 leasing). Dispersion modelling of drill arisings from monopile drilling was carried out for Hornsea Project One and indicated a relatively rapid dispersion of fine material (less than 24 hours) with SSC increases of up to 10mg/l above background levels expected to be confined to an area close to the wind farm (Smart Wind 2013). The extent to which drilling of monopiles was used during foundation installation for Hornsea Project One is not clear.

The physical placing of a structure on the seabed, the installation of scour protection (see below), cabling and anchor structures all result in direct loss of habitat and sedentary species within the footprint (and any working area) of the structure. Table 5.9 shows broad estimations of the size of footprint (including allowance for scour protection) of different foundation types used to inform the EIA process of a number of offshore wind developments (as well as an update of the foundation types actually used). Any associated habitat loss is likely to be permanent for all foundation types apart from potentially suction caisson whereby the removal of the structure will allow the restoration of habitats within the footprint, although direct loss of organisms during installation will still occur. As with potential dredging effects, the physical habitat recovery and benthic recolonisation of the working area around the foundations after installation is likely to occur, again with the timescale dependent on the sedimentary regime, dispersal of individuals and seabed preparation methods. In terms of floating structures the physical footprint of the anchors on the seabed and therefore direct disturbance is likely to be small, depending on whether embedment anchors, piles or suction caissons are used, but spread out over a potentially large area (in the case of catenary structures), with large areas included in the overall device footprint that are essentially undisturbed. The calculation of the exact area of habitat affected by each individual structure reflects how much direct disturbance would potentially occur from each foundation type depending on the physical and biological characteristic of the site. For example, Hywind Scotland consists of five 6MW floating turbines deployed in the Buchan Deep, an area of deep water (95-120m) some 25km off the coast at Peterhead, north east Scotland. Figure 5.4 (from a recent 2020 survey of the park) shows the area of seabed occupied by the mooring system, suction anchors, inter-array cables and other associated cable protection, estimated at *ca*. 15km^2. However, the area of seabed on which project infrastructure is actually installed[113] is estimated at 0.275km^2 (Statoil 2015) or 1.8% of the area occupied.

The overall physical areas occupied by the latest OWF developments are very large e.g. 407km^2 for the Hornsea One wind farm in the southern North Sea, which began operation in June 2019[114] (see Figure 5.8 below for Hornsea One layout). However, the spacing between turbines (minimum *ca*. 900m along and between rows) means that there are large areas of undisturbed seabed within this wider footprint. Similarly, other recently consented projects will consist of a large number of turbines but these will be well spaced within the large development areas with the maximum development seabed footprint estimated at between 0.09 and 1.8% of the total development area (see Table 5.9).

[113] Total footprint which includes anchor installation, anchor chains, inter-array and export cable installation.
[114] https://hornseaprojectone.co.uk/news/2019/07/operations-start-on-hornsea-one---the-worlds-largest-offshore-wind-farm

Figure 5.4: Overview of the Hywind Scotland pilot park



Source: Equinor (2020). Environmental survey report – artificial substrate colonisation survey, Hywind Scotland Pilot Park

Table 5.9: Seabed footprints associated with previously proposed foundation types for consented fixed wind farms and demonstrator floating offshore wind sites and update on selected foundation types

Wind farm (potential WTG capacities)	Foundation type	Seabed preparation area (m^2) / excavation volume (m^3)	Drill cuttings (m^3)	Seabed footprint (m^2)	Seabed footprint (incl. scour protection) (m^2)	Development seabed footprint[1] (km^2) and as % of development area	Update (December 2021)
Recent fixed offshore wind farm sites							
Telford, Stevenson & MacColl (Moray Firth) (3.6-8MW WTG)	Concrete gravity base	12,265m²	-	3,316m²	7,085m²	2.4km² (0.8%)	Now Moray East. Final turbine installed September 2021. All of the 100 WTGs supported by tubular jacket substructures and foundation piles. Scour protection area per foundation, including foundations of 1,700m². Only 10 WTG estimated to require scour protection (total 17,000m²/ 0.017km²) [115].
	Steel jackets with pin piles	Limited or no requirement	-	20m²	201m²	-	
Seagreen Alpha & Brava (Firth of Forth)	Jacket (driven piles)	Limited or no requirement	-	28m²	-	-	Now Seagreen. First turbine installed December 2021. 114 of the WTGs will be supported by suction bucket caisson jacket foundations and 36 WTGs by piled jacket foundations[116].
	Jacket (suction piles)	Limited or no requirement	-	616m²	907m²	-	
	Gravity base	4,295m² (21,475m³ excavation volume)	-	4,295m²	5,780	0.9km² (0.2%)	
	Monopile[2]	Limited or no requirement	3,691-6,220m³	573-962m²	Gravity base worst case	-	Now Dogger Bank A & B. Offshore construction of

[115] https://marine.gov.scot/sites/default/files/moray_east_dslp_version_5.pdf
[116] https://marine.gov.scot/sites/default/files/owf_dslp.pdf

Wind farm (potential WTG capacities)	Foundation type	Seabed preparation area (m²) / excavation volume (m³)	Drill cuttings (m³)	Seabed footprint (m²)	Seabed footprint (incl. scour protection) (m²)	Development seabed footprint[1] (km²) and as % of development area	Update (December 2021)
Creyke Beck A & B (Dogger Bank) (4-10MW WTG)	Jacket	Limited or no requirement	3,691-6,220m³	707m²	Gravity base worst case	-	Dogger Bank A expected to begin 2022[117]. Dogger Bank A & B: 190 monopile foundations to be fabricated[118].
	Gravity base	3,844-4,900m² (2,883-3,675m³ excavation volume)	-	1,735-2,376m²	5,512-6,153m²	3.3-3.7km² (0.3%)	
Teesside A & B (Dogger Bank) (6-10MW WTG)	Monopile[2]	Limited or no requirement	4,752-6,220m³	707-962m²	Gravity base worst case	-	Teesside A, now Dogger Bank C. Teesside B, now Sofia. Offshore installation for Sofia expected to begin in 2023, with Dogger Bank C in 2024[119]. Sofia OWF array location and layout plan (July 2021)[120] indicates extended monopile foundations for all WTG (100 No.) with a seabed footprint (excluding scour protection) of up to 78.5m².
	Jacket[3]	Limited or no requirement	4,752-6,220m³	707m²	Gravity base worst case	-	
	Gravity base	4,225-4,900m² (3,169m³ excavation volume)	-	1,963-2,376m²	5,027-5,675m²	2-2.3km² (0.2%)	
Hornsea Project One	Monopile	Limited or no requirement	2,837m³	57m²	1,419m²	-	Hornsea One completed October 2019. All of the 174

[117] https://doggerbank.com/construction/offshore/
[118] https://doggerbank.com/project-news/sif-smulders-consortium-to-provide-foundations-for-first-two-phases-of-dogger-bank-wind-farm/
[119] https://www.rwe.com/en/press/rwe-renewables/2021-06-11-rwe-begins-construction-of-its-offshore-wind-farm-sofia-on-dogger-bank
[120] https://marinelicensing.marinemanagement.org.uk/mmofox5/download/parcel/64j3nvtclqrshuk61rl00j8krjjq9oopb9c3amqqso506b7rvf4pm5tkqm9stfscgoau5su4hev71phsqfuclgm46fepgi0dgjt9/a26873ce562d489535bbab1a3f876b8a/003455088-02-Management+Plans+-+SOWF+-+Array+Location+and+Layout+Plan.pdf?

Wind farm (potential WTG capacities)	Foundation type	Seabed preparation area (m^2) / excavation volume (m^3)	Drill cuttings (m^3)	Seabed footprint (m^2)	Seabed footprint (incl. scour protection) (m^2)	Development seabed footprint[1] (km^2) and as % of development area	Update (December 2021)
(3.6-8MW WTG)	Jacket (driven piles)	Limited or no requirement	2,121m^3	28m^2	707m^2	-	WTGs have monopile foundations[121]
	Jacket (suction caisson)	Limited or no requirement	-	707m^2	6,362m^2	-	
	Gravity base	3,846m^2 (17,839m^3 excavation volume)	-	1,963m^2	6,362m^2	2.1km^2 (0.5%)	
East Anglia ONE (3-8MW WTG)	Jacket (pin piles)	Limited or no requirement	-	20m^2	-	-	Installation completed May 2020[122]. 102 jacket-type foundations using pin piles[123]
	Jacket (suction buckets)	Limited or no requirement	-	78m^2	-	-	
	Suction caisson	9,025m^2 (11,500m^3 excavation volume)	-	490m^2	16,504m^2	-	
	Gravity base	14,400m^2 (22,500m^3 excavation volume)	-	1,962m^2	22,686m^2	5.4km^2 (1.8%)	
Rampion (3-7MW WTG)	Monopile	Limited or no requirement	1,824m^3	33m^2	1,600m^2	-	116 monopile foundations[124]

121 https://hornseaprojectone.co.uk/news/2017/06/update-on-hornsea-project-one-foundation
122 https://www.scottishpowerrenewables.com/pages/offshore_construction_update.aspx
123 https://www.scottishpowerrenewables.com/pages/east_anglia_one.aspx
124 https://www.rampionoffshore.com/about/key-facts/

Wind farm (potential WTG capacities)	Foundation type	Seabed preparation area (m^2) / excavation volume (m^3)	Drill cuttings (m^3)	Seabed footprint (m^2)	Seabed footprint (incl. scour protection) (m^2)	Development seabed footprint[1] (km^2) and as % of development area	Update (December 2021)
	Jacket (pin piles)	Limited or no requirement	976m^3	21m^2	1,200m^2	-	
	Suction caisson/bucket	962m^3 excavation volume	-	961m^2	8,700m^2	-	
	Gravity base	1,820m^3 excavation volume	-	907m^2	7,900m^2	1.4km^2 (0.8%)	
Floating wind demonstrator site							
Hywind Scotland Pilot Park (6MW WTG)	Suction anchors (3 per WTG)	Limited or no requirement	-	120m^2 (3 anchors) 150-850m anchor chain on seabed	2,700-3,000m^2 (3 anchors)	0.013-0.015km^2 (0.1%)	Each suction anchor has a height of 15.9m and diameter of 5m.

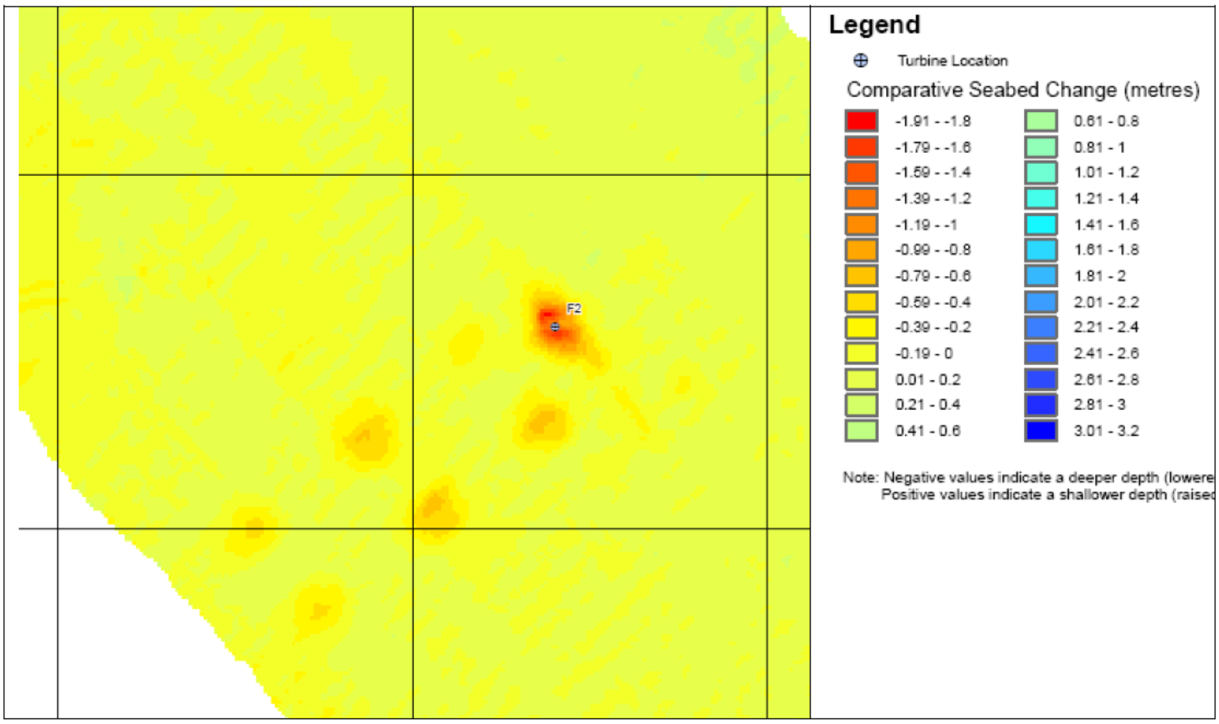
Notes: [1]Worst case development seabed footprint estimated primarily from gravity base foundation seabed footprint including scour figure multiplied by maximum number of proposed turbines from Environmental Statements. [2]Includes: monopile with steel monopile footing, monopile with concrete monopile footing, and monopile with a single suction-installed bucket footing. [3]Figures probably represent jacket with suction caisson foundations.

Sources: Moray Offshore Renewables Limited (2012), Seagreen Wind Energy Limited (2012), Forewind (2014), Smart Wind (2013), East Anglia Offshore Wind Limited (2012), E.ON Climate & Renewables UK Rampion Offshore Wind Limited (2012), Statoil (2015, 2017a).

Physical effects associated with construction vessels

Offshore construction activities will use a range of vessels including jack-up barges, which will cause seabed disturbance through spud can placement. For example, swathe bathymetry data collected as part of FEPA monitoring of the Kentish Flats wind farm indicated a set of six regular depressions in the seabed at each of the turbine locations resulting from jack-up operations (Figure 5.5). Immediately post-construction, a January 2005 survey recorded these depressions as having depths of between 0.5 and 2.0m. By November 2007, these depths had reduced by an average of 0.6m indicating that the depressions were naturally infilling (Vattenfall 2009). The impact of these spud can depressions on the seabed is therefore local and temporary; their duration depending on the rate of sediment transport in an area. The presently consented and future projects will require the installation of large numbers of turbines; the Hornsea ONE ES estimated that 341 structures (foundations and associated offshore structures would require jack-up barges for installation with each barge assumed to have a seabed footprint of 420m^2. However, the large distance between turbines (*ca.* 600->1,000m), the very localised nature of the seabed depressions and the relatively dynamic nature of sediment transport regimes within the project areas for former Round 3 and potential Round 4 projects, means that infilling of the depressions is likely to occur in the short to medium term. Year 1 post-construction bathymetry surveys in 2020 of Hornsea One indicate that areas of disturbance including jack up barge leg scars showed sediment accretion (Geophysical survey reporting - licensing summary - generation assets (dML 1-3)[125]). Turbine siting is informed by site survey which provides information on seabed topography and habitats, within the expected seabed footprint, allowing potentially sensitive features to be identified and reflected in the location selection.

Figure 5.5: Bathymetric comparison plot for Turbine F2 at Kentish Flats, March 2007



Source: Vattenfall (2009)

Scour associated with presence of foundations

Scour – a localised erosion and lowering of the seabed around a fixed structure – was recognised as an issue in relation to wind farm foundations at an early stage in the development of offshore locations, and has been subject to considerable research and monitoring. A two-

[125] https://marinelicensing.marinemanagement.org.uk/mmofox5/fox/live

stage project to identify, collate and review available field evidence for scour and scour protection from built Round 1 and other European sites was carried out for the UK Government RAG programme (ABPmer 2008, HR Wallingford 2008); these reports also provide a comprehensive bibliography of relevant literature. Five sites formed the principal datasets used in the study (Barrow, Kentish Flats, Scroby Sands, North Hoyle and Arklow Bank); all using monopile structures but representing a range of hydrodynamic conditions.

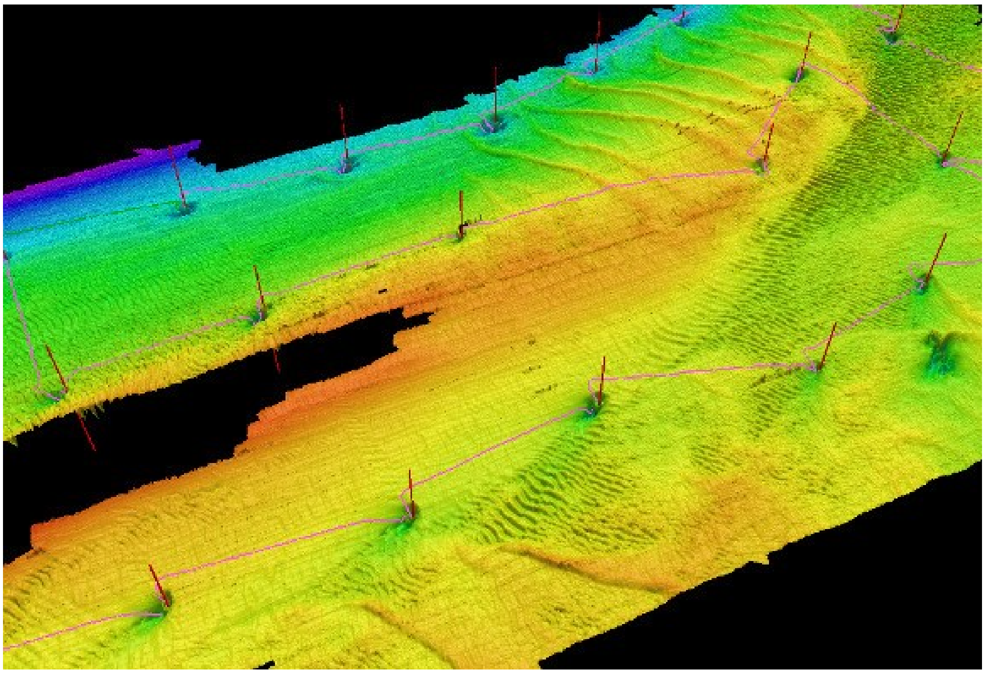
Scour is a complex process, involving various interactions between the structure and water flow patterns and with implications for stability of the structure and sediment transport in the vicinity. Scour depth around piles is often quantified in relation to the pile diameter (S/D): HR Wallingford (2008) reported significant scour at Barrow (up to 0.44D), Kentish Flats (up to 0.46D), Scroby Sands (prior to rock dump scour protection, up to 1.38D), and Arklow Bank (prior to rock dump scour protection, up to 0.8D). These values equate to a maximum scour depth of around 6m (at Barrow and Scroby Sands). At Scroby Sands and Arklow Bank secondary scour i.e. not adjacent to the foundation itself, followed the installation of scour protection. Little or no scour (<0.125D) was observed at North Hoyle – it is not clear whether this was due to the presence of scour protection, the redistribution of drill cuttings (resulting from pilot hole drilling for the piles) which arose during the installation process or natural infill (HR Wallingford 2008). Data for Robin Rigg (Carroll *et al.* 2010) indicated values from 1.3D up to 1.77D. The extensive data set for this site (at 1-10m water depth) and those at Princess Amalia wind farm (offshore Netherlands in 19-24m water depth) and the range of scour values described by the COWRIE report for the sites, highlights the need for scour calculations to include geotechnical conditions and how the seabed soil structure varies spatially and with depth.

In the context of physical damage to features and habitats, the key aspects are the spatial extent, severity and variability of scour, and of increased sediment deposition outside the scour footprint; together with whether the scour exposes seabed habitat which is significantly different from the original surficial sediment.

At Barrow, where the seabed consists mainly of sand overlying tillite and clays to a depth reaching 10m but including bedded muddy sands in this surface layer, the scour hole radius of individual piles varied from 0 to 15.7m at up to 62 days following pile installation. The typical total scoured area at this location was of the order of 50-100m^2, and exposed sediments differed to the pre-installation substrate (but typical of till exposures in the area). One year later, scour radii were much lower, with areas typically in the range 3-12m^2 (excluding the pile itself) and two years later scour depths for most piles were reduced to 0-4m in depth, with a trend for most scour holes to be backfilled to some extent (Carroll *et al.* 2010). The turbines which experienced greatest scour were located to the west of the wind farm area, where the bed consists of fine to medium sand and the thickness of the surficial layer was greatest.

At Scroby Sands, 30 monopiles of 4.2m diameter were installed between November 2003 and February 2004 with a minimum distance between monopiles of 320m. In addition to baseline and construction surveys, swathe bathymetric surveys have been carried out under previous FEPA licence monitoring conditions, providing a 4-year time series. Analysis by CEFAS (2006) indicates the development of scour pits associated with the monopiles (typical depths up to 5m and horizontal diameter 60m); and scour tails (trains of bedforms) extending from one monopile to the nearest downstream neighbour (Figure 5.6). Seabed biotope within the scour pits is likely to be significantly altered, whereas it is probable that the depositional and more extensive scour tails do not result in significant habitat alteration (note the whole area is characterised by active sandwaves, which do not appear to be influenced by the construction (CEFAS 2006)).

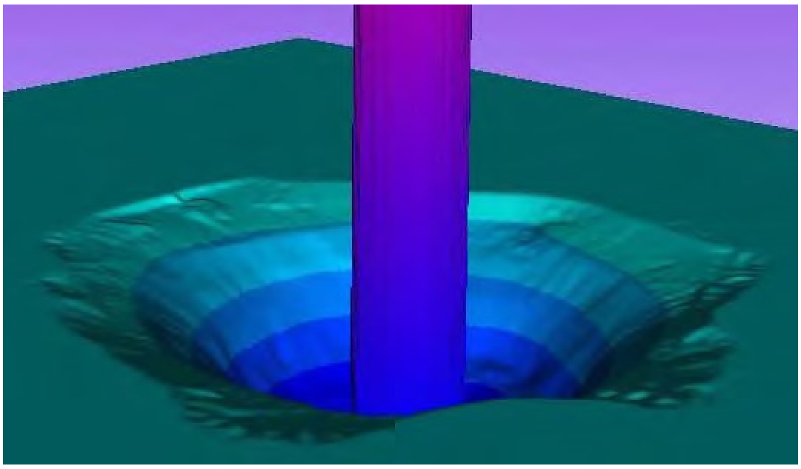
Figure 5.6: Swathe bathymetry image of February 2005 from the Scroby Sands OWF



Source: CEFAS (2006)

The seven wind turbine monopiles at Arklow Bank (eastern coast of Ireland) are influenced by strong currents (>2m/s) and design wave heights approaching 6m, with a water depth of 5m over the crest of the bank (wave-breaking occurs during storms). In the short delay between monopile installation and scour protection, scour holes (4m deep, 25m diameter, Figure 5.7) developed due to tidal current alone. Scour protection appears to have stabilised the bathymetry, with raised areas around some piles probably representing rock armour. The spatial extent of habitat modification is therefore around 450m^2 per pile (ABPmer 2008).

Figure 5.7: Contour plot of scour hole observed after monopile installation, Arklow Bank

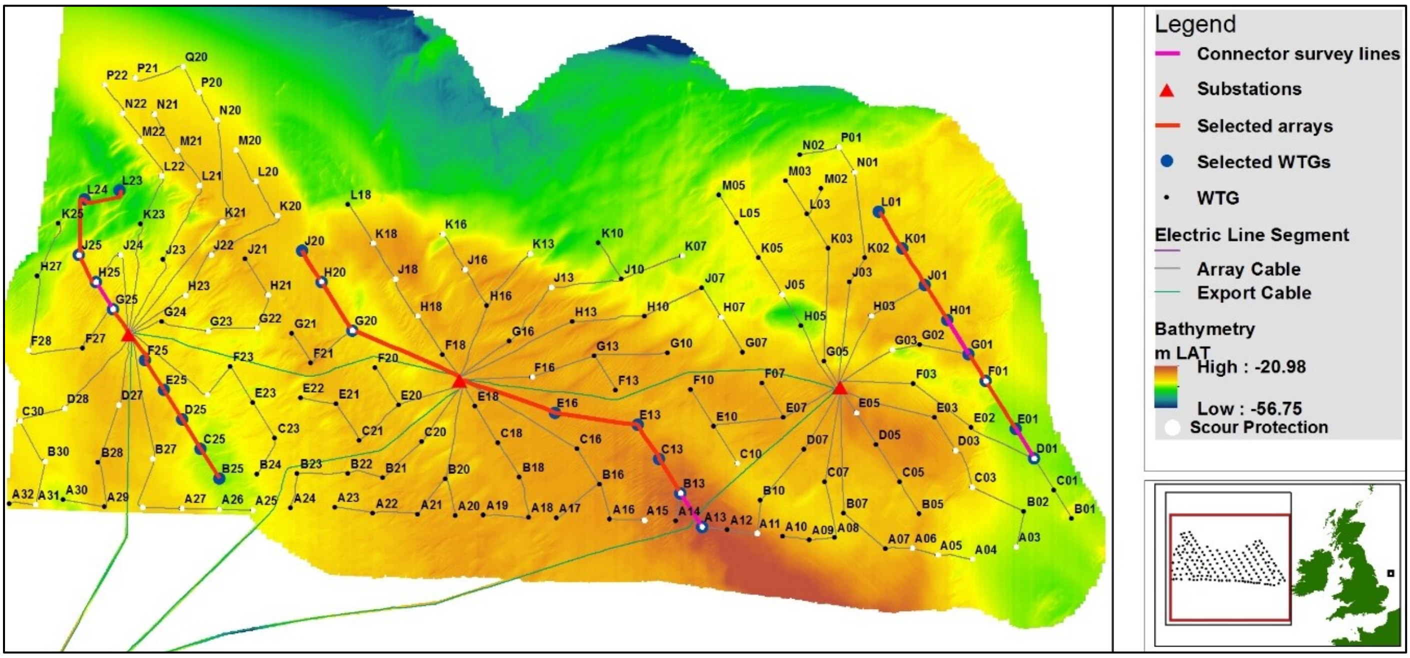


Source: HR Wallingford (2008)

The last review of post-consent monitoring of R1 and R2 windfarms (MMO 2014a), indicated that the rationale for scour monitoring of sites was not triggered specifically by sensitive environmental receptors but was typically undertaken to inform the structural and engineering integrity of structures including foundations and export cables. The extent of scour was over-predicted in the Environmental Statements reviewed. Modelling was based on the monopile diameter, but did not take into account the underlying substrate or thickness (or absence) of overlying mobile sediments. Where sandy sediments occur in greater thicknesses, these may be scoured to an equilibrium depth and width which is roughly proportional to turbine foundation diameter (on monopile foundation structures). For sites located on highly mobile sandbanks or in areas of large mobile bedforms, scour patterns may be more variable with secondary scour forming around any foundation protection and the formation of scour wakes (e.g. as occurs at Scroby Sands). The review of post-consent scour monitoring data did not identify any significant adverse impacts on sensitive physical receptors but indicated that scour monitoring may be required where seabed erosion is identified as a potential stressor to sensitive receptors including the benthos. The review recommended that the frequency of scour monitoring should be based on the geological and metocean characteristics, with areas covered by a thin veneer of mobile sediments requiring less monitoring than locations with large mobile bedforms, palaeochannels or sandbanks (MMO 2014a).

With respect to the consented Round 3 developments, desk-based scour assessments of the different potential foundation options above indicated that in general gravity base foundations represented the worst case scenario with respect to predicted scour depths and volumes (for example, scour depths of 9-12m and volumes of 26,663m^3 were estimated for the 65m diameter gravity base foundation option for the Moray Firth development projects). Year 1 post-construction bathymetry surveys carried out for Hornsea One were used to compare desk based assessments of predicted scour used to inform the environmental assessment with recorded scour around some of the monopile foundations (Geophysical Survey Reporting Licensing Summary Generation Assets (dML 1-3)). Twenty-six wind turbine locations and associated array cables were selected for monitoring to account for different water depths across the site; the presence of scour protection; different soil conditions, sediment availability, different size and orientation of bedforms (Figure 5.8).

Figure 5.8: Hornsea One scour monitoring survey locations



Source: Geophysical Survey Reporting Licensing Summary Generation Assets (dML 1-3)

Post-construction, the summary report of the 2020 survey indicated that the general trend across all sites surveyed was that areas of disturbed seabed were returning to their pre-installation state. At the turbine survey locations, the majority of the seabed had returned to natural seabed conditions as seen in the pre-construction data. Where scour protection had been installed around WTG foundations, this was still in place and showed no sign of settling or further erosion in comparison to the 2019 data set. Where no scour protection had been installed, the majority of turbine foundations showed no significant change in seabed levels

(within ±0.20m of last survey). The only exceptions to this were turbines C13 and E01. Maximum scour at C13 was -0.94m for an average of 20m around the turbine foundation, however there was a large sand wave moving through the area, which could be the cause. At E01, maximum scour was -0.66m at a radius of 12m from the WTG on an otherwise flat seabed. The summary survey report concluded that these two areas of scour were not indicative of any wider patterns of changing seabed morphology. Further analysis of the near-monopile-bathymetry showed the surface difference pre- (2016) and post-construction (2020) at two locations with (turbine J25, Figure 5.9a) and without (turbine E01, Figure 5.9b) scour protection, with bathymetry profiles running north to south and west to east at the turbines.
At all 26 WTG locations, the measured scour was significantly less than the worst case scenario predicted in the Environmental Statement for the development. The ES predicted a scour footprint of 14,257m^2 for a single monopile foundation but the average scour footprint for the 26 turbines surveyed in 2020 was only 1,294.84m^2. All inter-array cable trenches surveyed showed sediment accretion along their length, often combined with areas of erosion along the outside edge of the trench where the excavated material was piled up but was now backfilling the trench and returning to natural seabed. In some cable routes, the seabed had returned to pre-construction levels and there was no difference between the trenched cable route and the surrounding seabed.

Physical effects associated with the installation of cables

The likely future scale of offshore wind development along with on-going development of Round 3 related projects, Round 1 & 2 projects and extensions, and Scottish wind farm exclusivity zones means that further extensive cable laying operations are required to transfer the generated power from the OWF to the mainland. Table 5.10 provides a summary of the extent of export and inter-array cabling installed to date with relevant developments highlighted on Figure 5.10. There has been a clear increase in the average lengths of inter-array and export cables installed as the development rounds have progressed with most recent projects representing a marked increase over previous rounds.

Table 5.10: Extent of inter-array and export cabling currently installed

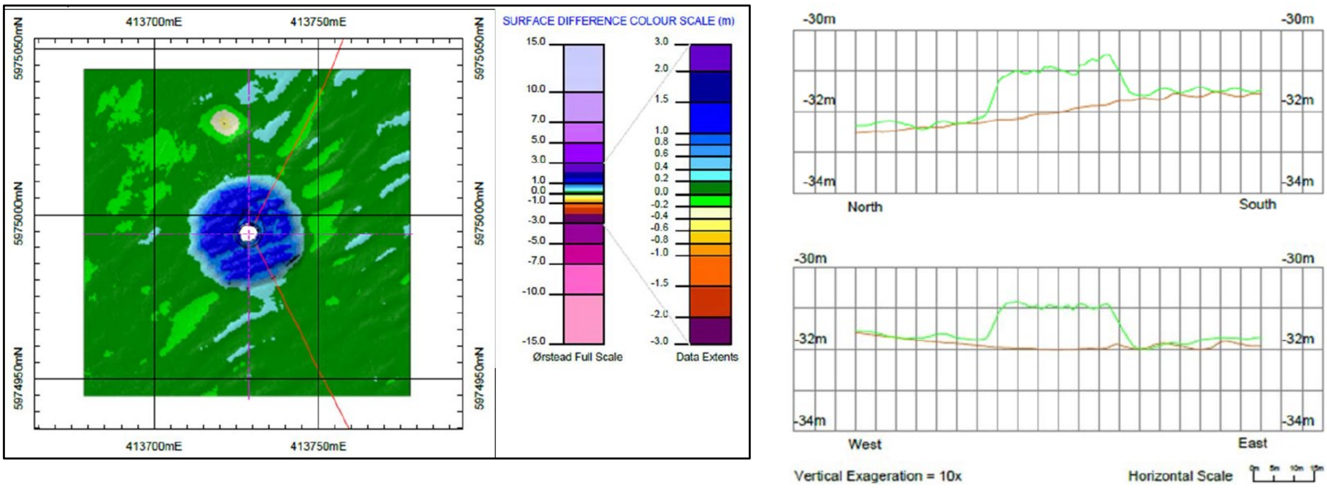
Wind farm leasing Round	Inter-array cables		Export cables	
	Total length (km)	Average length per project (km)	Total length (km)	Average length per project (km)
1	177	16.11	256	23
2	1,469	104.91	1,178	84
R1 & R2 Extensions	399	79.85	286	57
3	1,017	203.35	996	199
Scotland	231	57.73	238	60
Total	**3,293**	**84.43**	**2,955**	**76**

Source: KIS-ORCA

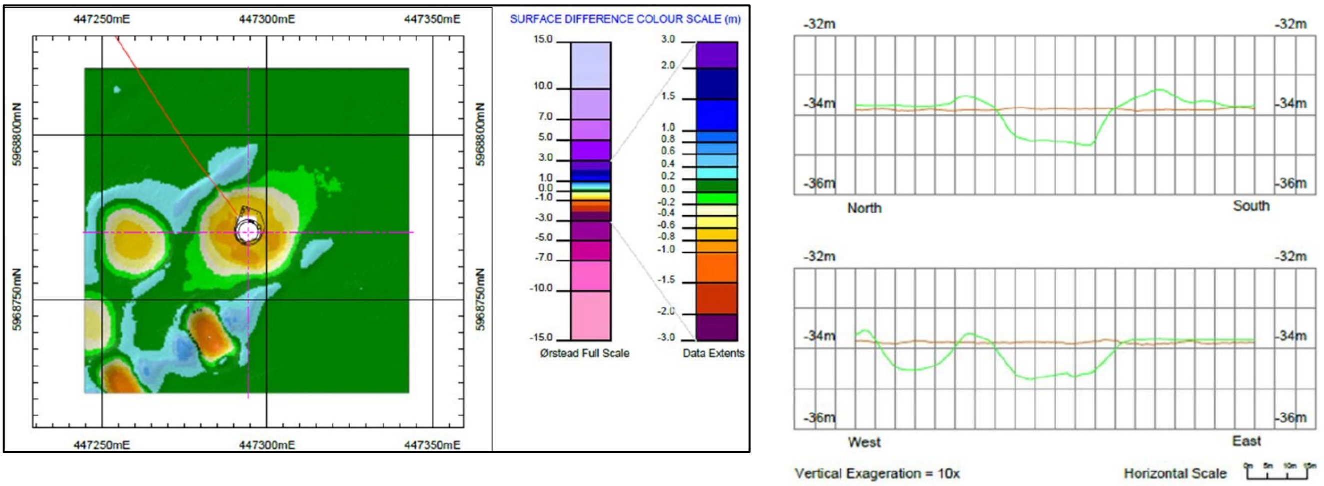
Figure 5.9: Near-monopile-bathymetry pre- and post-installation of wind turbines a) with and b) without scour protection

a) Turbine J25 with scour protection

Surface difference **Bathymetry profiles**

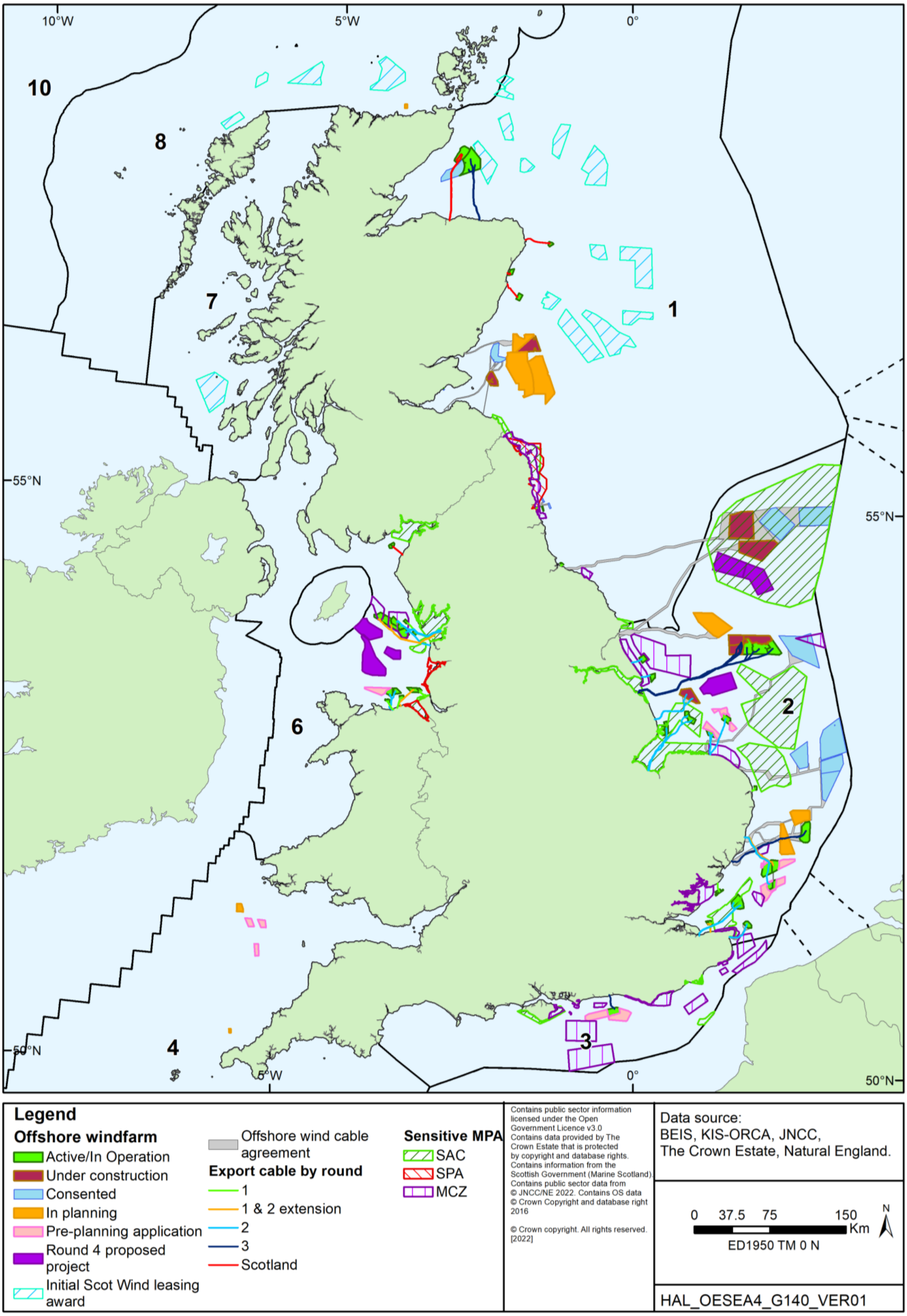


b) Turbine E01 without scour protection



Note: Surface difference and bathymetry profile comparison made between survey data from 2016 (brown line in bathymetry profiles) and 2020 (green line). Source: Hornsea One, Geophysical survey reporting licensing summary generation assets (dML 1-3)

Figure 5.10: Wind farm zones, and current and potential export cabling installed in relation to potentially sensitive MPAs

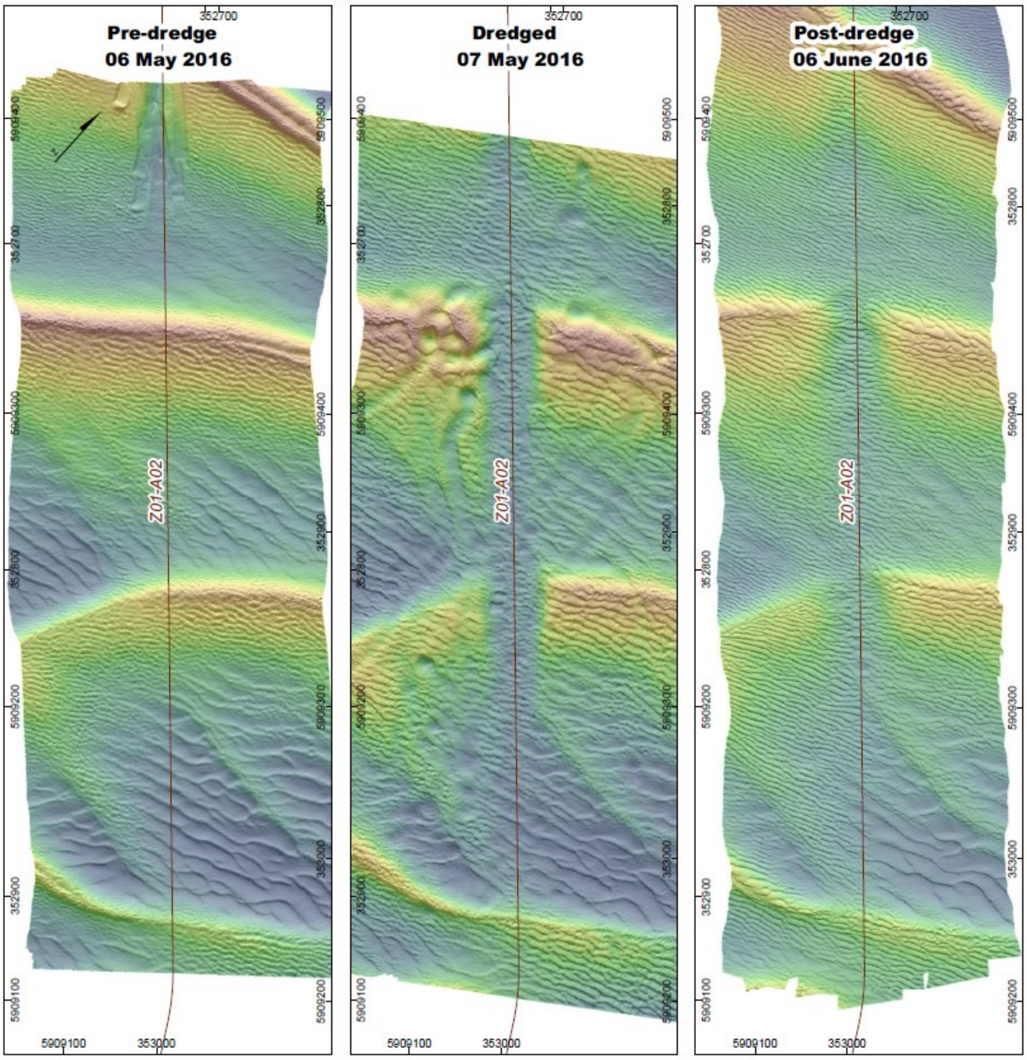


Cables are buried by either ploughing, jetting, trenching, rock wheel cutting or mechanical chain excavation or in difficult areas are laid straight onto the seabed and covered with protective mattresses. Target burial depths are indicated in consent applications for offshore wind farms and may be revised post consent (i.e. through the Cable Burial Risk Assessment process). Development Consent Order (DCO) or marine licence consents in the UK do not typically specify burial depths which need to be achieved, as this is an asset integrity issue and therefore the responsibility of the developer to ensure that the cable is adequately buried and protected for operational use (RPS 2019).

RPS (2019) reviewed offshore electrical cable installation techniques and seabed recovery for The Crown Estate (TCE) to inform the Plan Level HRA for Round 4 offshore wind leasing. The data reviewed was primarily drawn from geophysical monitoring reports available through the TCE Marine Data Exchange (MDE). One of the main limitations of this study was that the majority of the reports reviewed did not focus specifically on the recovery of seabed habitats or morphology following cable installation, with only a few exceptions (e.g. Humber Gateway and Race Bank). These geophysical datasets were scoped for a range of reasons, usually related to asset integrity, e.g. monitoring of scour effects around turbines and cable protection, cable integrity monitoring etc., and not for the specific purpose of assessing the recovery of the seabed or seabed sediments. Information was lacking on the sediment composition within cable trenches observed in geophysical datasets with only a small number of monitoring reports including geophysical interpretation of these and no ground truthing (e.g. via seabed imagery) of the sediments within the trenches. Similarly, there was little or no data on benthic communities within cable trenches, with most benthic ecology survey effort focussed on the wider cable corridor (RPS 2019).

The review concluded that predictions made in OWF EIAs largely aligned with the monitoring data available on seabed impacts and recovery and historic industry evidence reviews (e.g. BERR 2008, MMO 2014a, RGI 2015). It noted that impact assessments based on a maximum/worst case design scenario usually assessed a maximum disturbance corridor within which cable installation activities occur, typically 10-15m wide but wider corridors have been included in the project design envelope, where pre-clearance activities such as sandwave clearance and boulder clearance were required (e.g. between 20 and 30m wide). Sandwave clearance which involves the removal or reprofiling of sandwaves to maximise the potential for cable burial (e.g. by dredging or mass flow excavation) may also include disposal of cleared material. Recovery of the seabed following sandwave clearance operations was monitored at a number of sites within the Race Bank array area and the export cable route and occurred within one and two years following clearance operations. The monitoring undertaken within one-year post clearance showed some recovery, although complete recovery had not yet occurred (Figure 5.11). Monitoring undertaken two years after clearance showed a greater degree of recovery, with some large features (i.e. approximately 5m in height) recovering close to the pre-construction height (i.e. 3 to 4m height) within two years of the clearance activity (RPS 2019). Shallower levelling/dredging (relative to the sandwave height and irrespective of the water depth) was associated with faster rates of recovery. The locally dredged areas appeared to infill mainly *in situ*, with some contribution of sediment volume from the adjacent sandwave crest, and typically without significant migration. Deeper levelling/dredging (i.e. to the base of the sandwave) separated the sandwave into two discrete features that were then more likely to locally evolve or migrate with different rates and directions to that of the main sandwave body[126]. Natural England (2018) advise that any sediment extracted should be deposited up stream of cable trenches to encourage natural backfill.

Figure 5.11: Bathymetry data showing sandwave levelling at Race Bank



Pre-levelling period	Levelling period	Post-levelling period
Asymmetric sandwaves with the crest orientated approximately east-northeast to west-southwest. The sandwave wavelengths vary approximately between 40 and 70m and the cable is orientated perpendicular to their crests.	Three sandwaves are affected, with the bedforms levelled to the same depth as the surrounding seabed. The levelled section is approximately 30m wide across the full sandwave wavelength, resulting in two separate features for each sandwave.	For the most northerly affected sandwave (bottom of image), the effect of the levelling is not apparent, as the levelled area has completely filled in and the sandwave crest has reformed. For the remaining two sandwaves, the levelled area is infilling and merging across the levelled area, although not at the same degree as the northerly sandwave.

Source: Ørsted (2018a)

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126 https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-001133-DI_HOW03_Appendix%2011.pdf

RPS (2019) indicated that cabling resulted in disturbance to seabed sediments, with the level of initial disturbance dependent on the tool used (e.g. cable ploughs typically resulted in minimal displacement of sediments beyond the cable trench, while jetting resulted in greater sediment displacement). For most of the projects reviewed, monitoring data showed that cable installation resulted in trenches being recorded on the seabed in the geophysical datasets, although the proportions of the cable lengths where these remnant trenches were observed was variable across the projects. The review indicated that where these trenches were recorded, they infilled over time and that where these were present on the seabed after a number of years, the large majority of trenches were shallow depressions on the seabed (e.g. up to a few 10s of cm). In a small number of cases, more profound changes in seabed sediments/substrates were recorded (e.g. clay exposures in the Humber Gateway export cable), but for soft sediment habitats, there was clear evidence of recovery across a variety of sediment types and installation tools (RPS 2019).

Physical damage/change to biotopes

As described above, direct physical effects on habitats arise from various activities associated with the construction and placement of installations, cables and pipelines; with the operational presence of the installation and with vessel activities throughout construction, operations and decommissioning phases. These activities give rise to three mechanisms which produce habitat change: the introduction of hard substrates into a sedimentary environment, the movement of sedimentary particles over various time scales (scour, winnowing, suspended sediments and particle settlement) and direct damage to biota caused by physical abrasion (e.g. anchoring). Direct habitat removal results from dredging/ploughing for cable laying and site preparation. The effects of offshore disposal of dredging spoil are considered below. There are both short- and long-term implications for the local biological communities. The significance of any effects is likely to depend on the natural disturbance regime and the stability and resilience of the communities. Whilst there is a focus on OWF, the following impacts are also of relevance to other elements of the draft plan.

Introduction of hard substrates into a sedimentary environment

The main data gap identified in the monitoring review (RPS 2019) was on the effect of cable protection on benthic communities, e.g. colonisation of artificial substrate. Placement of cable protection resulted in a change in the substrate/sediment type, and the direct effects of this on benthic communities is poorly understood. The review noted that EIAs take a conservative approach and typically assume that this represents long term habitat loss, with a complete loss of ecological function in the areas affected. Although note Natural England's experience[127]. While the placement of cable protection (and scour protection) will clearly lead to a change in the substrate type, the effect of this change will depend on the sediment/substrate type of the receiving environment (e.g. in a sediment habitat this may result in a shift from a benthic community dominated by infaunal assemblages to one dominated by epifaunal assemblages). However, in certain circumstances (e.g. areas of rocky substrate or coarse sediments), the use of certain types of cable protection may limit the change of the substrate, therefore allowing some ecological function to continue in the areas affected (RPS 2019).

Considerable research on the influence of man-made structures in the marine environment, specifically that of the North Sea, has been carried out as part of the INSITE programme[128],

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[127] Of note is Natural England's experience of OWF gained post consent when projects move into construction. "*In many cases changes to cable installation techniques, remedial works and additional cable protection have resulted in habitat disturbance and loss/ modification within MPAs that had not been assessed as part of the application, requiring additional work by the developer, regulator and advisors.*" (Natural England 2018).

[128] https://insitenorthsea.org/

running since 2014. The artificial reef effect caused by introduced hard substrates is described in Section 5.6.

Habitat change from the deposition of hard substrates (including rock and concrete mattresses) in sedimentary habitats, particularly associated with offshore wind farm cable protection but also as a result of oil and gas pipeline installation and decommissioning, has become a recent cause of concern, particularly for southern North Sea sandbank MPAs. High level advice with respect to sandbank habitats in relation to potential cable routes associated with the Round 4 seabed leasing (Natural England & JNCC 2019) indicates that these habitats are often found in high – medium energy environments and have the potential to recover from cabling activities pressures relatively quickly. However, where features are dynamic, the introduction of hard substrate (such as cable protection) is often required causing the pressures physical change to another seabed or sediment type and therefore likely loss of extent of the existing habitat. It is particularly important in MPAs designated for sandbank features to consider these pressures in the context of other operations within the site, as many sandbank MPAs are already impacted by these pressures therefore reducing their capacity to withstand further impacts. The advice highlights those MPAs in each Round 4 leasing area that pose the highest risk of significant impact from cabling activities and these are shown on Figure 5.10 above.

As noted for a number of sandbank MPAs (e.g. Inner Dowsing, Race Bank and North Ridge SAC, Haisborough, Hammond and Winterton SAC and Margate and Long Sands SAC*),* *"Cabling activities in sandbank MPAs has been shown to be challenging due to impacts associated with cable installation such as sandwave clearance and use of hard substrate as cable protection. It may be possible to avoid an adverse effect from cabling through sandbank features of this SAC if sufficient evidence is provided that impacts are short-lived and the feature will recover. Consideration would need to be given as to how sufficient cable burial is achieved without the need for cable protection. Should sandwave clearance be necessary to achieve burial depth and avoid the use of cable protection then, as above, it would need to be demonstrated that impacts are short-lived, the feature can recover, and extracted material is retained in the system and can be deposited on material of the same grain size to avoid changes in habitat."*

Advice for the North Norfolk Sandbanks and Saturn Reef SAC and Dogger Bank SAC goes further, *"Cable laying, cable laying with associated protection and sandwave levelling are incompatible with the achievement of the conservation objectives advised for the SAC and would impede restoration of the sandbanks which are slightly covered by seawater all the time."* Similarly, The Wash and North Norfolk Coast SAC advice concludes that, "*As some of the features and subfeatures of this SAC are considered to be in unfavourable condition, adding further pressure to the SAC with cable laying and associated cable protection would be likely to have a significant impact on the conservation objectives of the SAC and may impede restoration of the features."*

The proposed cable corridor for the Hornsea Project Three OWF overlaps with parts of both the North Norfolk Sandbanks and Saturn Reef SAC and The Wash and North Norfolk Coast SAC. As part of the Development Consent Order (Schedule 14, Part Two)[129], Hornsea Three is required to implement a package of benthic compensation measures to compensate for potential impacts, resulting from the deployment of cable protection, to the Annex 1 benthic features 'sandbanks which are slightly covered by sea water all of the time' in both sites. The applicant has submitted Sandbanks Implementation Plans, describing proposed compensatory

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[129] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-003266-EN010080%20Hornsea%20Three%20-%20Development%20Consent%20Order.pdf

measures which are currently (as of January 2022) subject to consultation with MMO, JNCC and Natural England[130]. Similarly, a number of compensatory measures have been secured through the DCO for the Norfolk Vanguard project[131] in relation to the Haisborough, Hammond and Winterton SAC. This includes the establishment of a Benthic Steering Group ("BSG") to inform the preparation of a Benthic Implementation and Monitoring Plan ("BIMP") which must accord with the principles set out in the in-principal compensation strategy[132].

The SEA recommends that the development of appropriate benthic compensatory measures for sandbank and subtidal biogenic reef MPAs with respect to cable protection is reviewed at a strategic level (as supported by JNCC and Natural England[133]) to focus research in this area. Better definition of the nature and extent of existing introduced hard substrates within MPAs designated for sandbanks is required to improve understanding of the conservation status of these qualifying features, and characterise how the static hard substrates interact with the mobile features over time. Previous attempts have not catalysed the collection of specific industry information on hard deposits in relevant MPAs required to reduce uncertainty in this area, or have been limited by available data. As part of future permitting and licensing, data on the nature, scale and location of hard substrate deposition should be recorded and disseminated.

Suspended sediments

The dispersion and settling of sediment plumes from construction activities and cable or pipeline trenching activities have the potential to cause effects on pelagic and benthic biota through a number of pathways: the reduction of light for photosynthesis (Newell *et al.* 1998), temporarily altering the nature of the seabed sediments or near surface waters and the clogging of gills and feeding mechanisms. The extent of effects will vary according to the geographic location, frequency of occurrence and the tolerance of the species involved, itself a function of the average and extreme natural levels of sediment transportation/deposition experienced in an area (see also studies of thin-layer (<15cm) disposal of dredged material, Wilber & Clarke 2007). Newell *et al*. (1998) concluded that there was little evidence that deposition of sediments from outwash during aggregate dredging had a significant impact on the benthos outside the immediate dredged area. However, Desprez *et al*. (2010) suggests that the biological impact associated with aggregate dredging may extend outside the immediate vicinity of the dredged area (<2km) and corresponds to the "footprint" of sediment deposition and transport along the axis of tidal streams. Desprez *et al.* (2010) found a significant reduction in species diversity and abundance associated with sediments containing high levels of fine sand (from re-sorting along tidal gradients). Suspended particulate material (SPM) does not only affect species presence or absence; SPM concentrations of >50mg/l have been shown to affect reproduction in the scleractinian coral *Acropora digitifera* (Gilmour 1999) i.e. fertilisation, larval development and larval settlement. Similar effects may be possible in the cold water corals found in deeper water of the UKCS such as *Lophelia pertusa*.

Many construction phase activities are considered to have adverse effects due to the increase in the natural background levels of suspended particulate matter (SPM) in the water column (Degraer & Brabant 2013). However, as construction activities are relatively short and localised, the overall increase in SPM concentration is limited. Regardless of extent of impact,

[130] https://infrastructure.planninginspectorate.gov.uk/projects/eastern/hornsea-project-three-offshore-wind-farm/?ipcsection=docs&stage=7&filter1=Secretary+of+State+Consultation
[131] https://infrastructure.planninginspectorate.gov.uk/projects/eastern/norfolk-vanguard/
[132] https://infrastructure.planninginspectorate.gov.uk/projects/eastern/norfolk-vanguard/
[133] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-003633-EN010080_Hornse%20Three_SBIP_SNCB%20comments%20letter%20Final.pdf

where the near-bed SPM concentrations are naturally high, as in coastal and southern North Sea areas and the Irish Sea, the effects of such anthropogenic sediment plumes are unlikely to be significant on the existing seabed communities. The most recent review of post-consent monitoring of twenty two Round 1 and 2 wind farms indicated that increases in SSC were localised and temporary during construction and cable laying operations, with increases in SSC often within the limits of natural variation present at the site (MMO 2014).

Herring are demersal spawners and their spawning grounds are vulnerable to an increase in suspended sediments. Successful egg development is dependent on localised areas of suitable open substrate with good oxygenation in the sediment interstices. Although the prevailing hydrographic conditions make it unlikely that sediment particles finer that naturally present in the spawning habitat would settle out, it would be possible for particles of a similar size to settle and any herring eggs present would be smothered and unable to emerge from burial. For many years there has therefore been a requirement that potential herring spawning areas are identified by sidescan sonar and seabed sampling in advance of oil and gas drilling and development; and that appropriate mitigation such as timing and/or avoidance of specific areas is undertaken with the prior approval of regulatory agencies. Similar controls are applied through the EIA and marine licensing processes for OWF and are likely for other plan activities that could lead to increased levels of suspended sediments.

Offshore disposal of seabed dredged material

The effects of disposal of dredged material on the existing seabed and benthos are well informed by the extensive literature associated with civil engineering projects and the dredging industry e.g. Maurer *et al.* (1981, 1982), Harvey *et al*. (1998), Miller *et al.* (2002) and Wilber & Clarke (2007) e.g. studies of thin-layer (<15cm) disposal of dredged material (Wilber & Clarke 2007); and Last *et al*. (2011) who provide some useful experimental data on behavioural responses of species relevant to the UK aggregate industry operating locations in Regional Seas 2 and 3.

Benthic mortality and associated benthic community change is governed by individual species' ability to survive burial and eventually re-emerge to the sediment/water interface or at least re-establish a connection with it. The extent of effects therefore will vary according to the depth of overburden, frequency of burial occurrence and the tolerance of the species involved. The average and extreme natural levels of sediment transportation/deposition in an area are reflected in the benthic composition; in areas where large re-suspension and sedimentation events are the norm, the fauna is unlikely to be vulnerable to such effects arising from anthropogenic sources such as construction activities associated with marine developments.

Many species can emerge from considerable overburdens e.g. the bivalve *Mercenaria mercenaria* can migrate through ≤16cm of sand under summer temperatures and within a short period of time (Maurer *et al*. 1981); the polychaete *Nereis succinea* can survive a 90cm sediment overburden (Maurer *et al*. 1982). Survival and overburden escape ability also vary with life stages; the remarkable ability of *M. mercenaria* described above applies only to young animals, while adults can only tolerate a 1cm overburden. It seems likely that as deep burrowing organisms, they are habitually living close to their depth tolerance. Other species are considerably less tolerant and will die within hours or days from oxygen depletion in the sediment. The instantaneous deposition of large quantities of sediment, such as during the disposal of dredged material, can result in total mortality (Miller *et al*. 2002), while burial beneath thinner layers up to 25mm thick may have no discernible effect (Trannum *et al.* 2010). If the deposited material is not identical to the sediments on which it settles, or if it has been contaminated, the rate of mortality may increase (Trannum *et al*. 2010, Holdway 2002).

Recovery of disposal areas occurs through a mixture of vertical migration of buried fauna, together with sideways migration into the area from the edges, and settlement of new larvae from the plankton. The community recolonising a disturbed area is likely to differ from that which existed prior to construction. Opportunistic species will tend to dominate initially and on occasion, introduced and invasive species may then exploit the disturbed site (Bulleri & Chapman 2009). Harvey *et al*. (1998) suggest that it may take more than two years for a community to return to a closer resemblance of its original state (although if long lived species were present this could be much longer). Shallow water (<20m) habitats in wave or current exposed regimes, with unconsolidated fine grained sediments have a high rate of natural disturbance and the benthos represents an early successional stage community. Species tend to be short lived and rapid reproducers and it is generally accepted that they recover from disturbance within months. By contrast a deep stable sand and gravel habitat is believed to take years to recover. Recent studies in the Netherlands (de Jong *et al.* 2015a, b) describe how the presence of a distinct, highly productive and species-rich *Abra alba* assemblage occurred at both an 8m deepened shipping lane and near a disposal site for dredged fine sediment, suggesting that some of the fauna entrained in the dredge material survive disposal and migrate through the overburden.

Sabellaria spinulosa is described as being tolerant of smothering (MarLIN), this is supported by Last *et al*. (2011) who found it to be highly tolerant of short term (≤32 day) burial in fine sand whatever the burial depth. They observed ‘emergence tube’ construction under sediment burial conditions. This was found to be more extensive under the shallow and medium than deep burials and was most rapid during an 8-day burial (~1mm per day) rather than 16 or 32 days burial. They suggested that emergence tube formation was a mechanism by which *S. spinulosa* can avoid gradual burial and/or a possible method of adult dispersal. Other species assessed were *Psammechinus miliaris*, able to remerge from burial depths of 7cm, with better survival in coarse sediments than fine sand and was classed as moderately tolerant; while the brittle star *Ophiura ophiura* and the anemone *Sagartiogeton laceratus* were found to be highly tolerant of burial, surviving for long periods and in all sediment fractions tested. Of the two sessile, epilithic species tested, the sea squirt *Ciona intestinalis* was, unsurprisingly, found to be highly intolerant of burial, showing no ability to re-emerge, whereas *Mytilus edulis* tolerated a lengthy burial but was also unable to re-emerge.

Direct damage caused by physical abrasion (anchor scarring, anchor mounds, cable scrape and trenching)

Habitat recovery from physical abrasion (caused by anchor scarring, anchor mounds, cable scrape and trenching) will depend primarily on re-mobilisation of sediments by current shear. Subsequent benthic population recovery takes place through a combination of migration, re-distribution (particularly of microfaunal and meiofaunal size classes) and larval settlement. On the basis that seabed disturbance is qualitatively similar to the effects of wave action from severe storms, it is likely that in most of the shallower parts of the UKCS, sand and gravel habitat recovery from the processes of anchor scarring, anchor mounds and cable scrape is likely to be relatively rapid (1-5 years). For trenching, the estimate of 4-6 years given by de Jong *et al*. (2016) in relation to their investigation of ecosystem constraints for marine sand extraction is useful. They conclude that macrozoobenthos in a borrow pit with a tide-averaged bed shear stress of around $0.41Nm^{-2}$ (the figure at which coarse sand particles are mobilised) expected to return back to pre-extraction conditions within 4–6 years. When tide-averaged bed shear stress decreases below $0.17Nm^{-2}$ (the point at which fine sand mobilises), enhanced macrozoobenthic species richness and biomass can occur. Below a tide-averaged bed shear stress of $0.08Nm^{-2}$ (the upper threshold for medium silt), increasing abundance and biomass of brittle stars, white furrow shell (*Abra alba*) and plaice (*Platessa platessa*) can be expected.

Below $0.04Nm^{-2}$, an over-dominance and high biomass of brittle stars can be expected whereas demersal fish biomass and species composition may return to reference conditions.

Mud habitats, by contrast, are more sensitive to physical disturbance than the coarser sediments typical of high wave- and current-energy areas. Muddy sediments support benthic communities characterised by the presence of large burrowing crustaceans (*Nephrops norvegicus* and *Calocaris macandreae*) and pennatulid sea-pens (*Virgularia mirabilis* and *Pennatula phosphorea*). *Nephrops* and *Calocaris* are able to restore burrow entrances following limited physical disturbance of the sediment surface (a few centimetres), and video observations of burrow and pennatulid densities on the Fladen Ground sediments show little cumulative effect of fishing disturbance. Bioturbation rates, although poorly understood in deep water, are important indicators of ecosystem function and the process is important in the recovery of soft sediments after physical disturbance. Gates & Jones (2012) looked at the recovery of benthic megafauna at a deep well site (380m) in the Norwegian Sea over a three year period and reported large burrows on the disturbed seabed, indicating activity of the decapod *Geryon* sp. in this area. These crabs were observed entering and leaving the burrows - an activity thought to be important in the re-distribution of the sediment and gradual breakdown of the cuttings material. The nearest burrow was 5m from the well indicating activity in this area in the three years since disturbance. The holothurian *Parastichopus tremulus* is important in horizontal dispersal of sediment. Pennatulids are a key species of the EUNIS 'deep mud community' and were the most common organisms on the soft sediment in Gates & Jones (2012) study. However, in comparison to pre-drill data and reference sites, their density remained low for three years post-drilling in the visibly disturbed area i.e. the extent of the cuttings pile. Pennatulids are slow growing and may therefore take some time to recover from disturbance. Although the larval recruitment rates and settlement rates for these organisms are unknown, studies on the reproduction of *Pennatula phosphorea* and *Funiculina quadrangularis* suggest that these species have lecithotrophic larvae which have the ability to remain in the water column until suitable habitat is located, thus possibly avoiding settlement on sediment disturbed by drilling mud and cuttings.

Despite having a high potential for recovery from indirect effects of turbidity, biogenic reefs (blue mussel *Mytilus edulis*, horse mussel *Modiolus modiolus*, ross and honeycomb worms *Sabellaria* spp., the serpulid worm *Serpula vermicularis*, the bivalve *Limaria hians* and cold-water corals such as *Lophelia pertusa)* are susceptible to damage from direct impacts, e.g. towed fishing gear (Holt *et al.* 1997, Jackson & Hiscock 2008). Subtidal *Sabellaria spinulosa* reefs are reported to have been lost due to physical damage in at least five areas of the north-east Atlantic. In the Waddensee, Riesen & Reise (1982) reported the loss of extensive subtidal *S. spinulosa* reefs from the Lister Ley, Island of Sylt, between 1924 and 1982; they reported that local shrimp fishermen claimed to have deliberately destroyed them with "heavy gear" as they were in the way of the shrimp trawling. Similar reported losses from the Norderau area were attributed to similar causes (Reise & Schubert 1987). Shrimp trawling still occurs in these areas and the *S. spinulosa* reefs have not reappeared, their niche having been effectively replaced by mussel *Mytilus edulis* communities and assemblages of sand dwelling amphipods (Reise & Schubert 1987). In Morecambe Bay, the pink shrimp *Pandalus montagui* fishery has been implicated in the loss of subtidal *Sabellaria* reefs from the approach channels to the Bay (Mistakidis 1956, Taylor & Parker 1993). Aggregate extraction (licensed) is also as source of direct damage to *Sabellaria* reefs (Holt *et al*. 1997). Compared to fishing impacts, those from gravel extraction are likely to be more limited in extent, more controlled, and less likely to continue for very long time periods; hence although severe, recovery from direct damage in a short time scale is more likely as adjacent undamaged areas could provide a supply of larvae for new settlement. Reefs of *Lophelia pertusa* are known to occur in the deeper waters of Regional Seas 8 and 10. *L. pertusa* can tolerate short-term exposure to settling particles and the effects of partial low oxygen and anoxic conditions, but complete burial of the polyps for more than 24h has been shown to result in suffocation (Allers *et al.* 2013).

In relation to the likely locations of OWF development, *Sabellaria* reef is the Annex 1 biogenic habitat most likely to be affected by direct physical damage. Direct impact from OWF foundations will be of relatively limited spatial extent, and in view of the wide habitat tolerance of *Sabellaria* (Jackson & Hiscock 2008), it is likely that scour protection would be as likely to support aggregations as does the surrounding seabed (particularly when overlain by a sand veneer). Although note that the SNCB's consider the establishment of *S. spinulosa* reef on artificial substrate as not "counting" towards favourable condition of the feature and/or site as it is not a replacement for Annex I *S. spinulosa* reef on natural site sediment as set out at the time of designation and within the conservation advice package for the site[134]. Response to indirect impacts of turbidity and knowledge on *Sabellaria* resilience and vulnerability has been usefully informed by aggregate industry sponsored research e.g. Hendrick *et al*. (2011) and Pearce *et al*. (2011). This confirms Jackson & Hiscock (2008) supposition of the species' tolerance of turbidity from sediment mobilisation or scour; the suspension of fine material during dredging operations is not now considered likely to be detrimental (Last *et al.* 2011, Pearce *et al.* 2011).

Cable placement and trenching, both within the array and shore cables, may have a greater spatial extent of disturbance, but will be of short duration and habitats will recover rapidly over buried cables. There is also the potential to avoid impacts to reef through micro siting/routing of cables although the capacity to bend round relevant features will be limited by the physical nature of the cable. However, as indicated above, JNCC and Natural England advise against the use of cable protection within designated sites as the addition of hard substrata is often incompatible with the conservation objectives for Annex I sandbanks and reef features.

As described in Appendix A1b.2.5, there is considerable interest in the role that human activities play in the disturbance and resuspension of shelf sediments which can result in carbon remineralisation, some of which will result in net carbon losses to the atmosphere (e.g. see van de Velde *et al.* 2018). For example, the disturbance of the seabed by trawling may have several opposing mechanisms of impact on the benthic carbon budget (Legge *et al*. 2020). Resuspension of sediment by trawling decreases carbon storage (Oberle *et al.* 2016a), particularly in muddy sediments, causing an increase in benthic to pelagic carbon flux and water column remineralization (Jennings *et al*. 2001, Durrieu De Madron *et al*. 2005). However, resuspension and remineralization of sediment also releases nutrients back to the water column, which may stimulate primary production and increase deposition of new POC (e.g. Duplisea *et al.* 2001). Repeated trawling will prolong sediment resuspension and may disrupt existing carbon storage (Martín *et al.* 2014a,b, Oberle *et al*. 2016b), as well as increase the likelihood of long-lasting change (Mayer *et al.* 1991) in carbon concentration and spatial distribution (Legge *et al*. 2020). The net effect of these processes is highly uncertain, and likely depends on several local as well as broader scale conditions, such as sediment type, gear type, currents, and seasonal timing of the events. While it is certain trawling has a significant impact on the benthic system, its net effect on carbon stocks and fluxes at shelf scale is highly uncertain due to the complex interacting processes (Legge *et al*. 2020).

The effects that the activities covered by the draft plan assessed in OESEA4 may have on sedimentary blue carbon storage, and their significance relative to natural physical and biological processes remain important evidence gaps. However, given the global and regional

[134] Statutory Nature Conservation Bodies (SNCB's) generic advice in relation to colonisation of Sabellaria spinulosa reef on artificial substrate being considered as Annex I reef and contributing to the favourable condition status as reef. https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010079/EN010079-002637-DL4%20-%20Natural%20England%20-%20Deadline%20Submission.pdf

scale of some of the climatic and hydrographic factors influencing the flux of carbon within the marine environment (e.g. increasing atmospheric CO_2 and ocean acidification, storms, increasing water temperature, as reviewed by Legge *et al.* 2020), the generally localised and temporary physical disturbance to sediments caused by activities covered by the draft plan are unlikely to lead to a significant depletion of carbon stocks.

Other renewables

Tidal stream

In general, the devices currently in use or production have one of 4 support structure types (Rourke *et al.* 2010, see also[135]):

- Gravity structure
- Single monopile
- Tethered floating structure
- Tripod structure – using 3 steel monopiles

The physical effects associated with the installation, decommissioning and physical presence of a structure within the water column are all discussed within the sections above, with cabling again being a potentially important issue as the number and extent of tidal stream deployments increase.

One of the first tidal stream projects to deploy was the Meygen tidal stream project in the Inner Sound (Pentland Firth) consented in 2013 for the first phase for the installation in stages of up to 61 turbines (the original application was for up to 86 turbines – see Table 5.11) with a permitted capacity of up to 86 megawatts. Stage one of the consented development was limited to a maximum of 6 turbines[136]. With respect to potential physical disturbance effects, the Environmental Statement (Meygen 2012) assessed the parameters described in Table 5.11.

Table 5.11: Worst case parameters for the Meygen project with respect to physical disturbance effects

Project parameters	Details
86 monopile turbine support structures (TSSs)	The maximum amount of drill cuttings that would be generated from turbine support installations is 17,200m^3.
86 gravity base TSSs	Each GBS TSS (consisting of a steel tripod with large steel weights on each of the three legs) has a maximum footprint of 40m x 30m. The total footprint for 86 turbines is 0.103km^2.
86, 120mm unbundled cables each 1,300m in length with split pipe armouring	The maximum physical area of the seabed occupied by the cables is 0.027km^2. Based on a maximum 1.3km of cable from Horizontal Directional Drill (HDD) bore exit to turbine, and a cable diameter of 120mm (x2 to account for split pipe armouring) for 86 turbines.

Source: Meygen (2012).

[135] https://www.emec.org.uk/marine-energy/mooring-methodologies/
[136] The approved Construction Method Statement for Stage one indicates that 4 gravity base turbine support structures made up of a tripod substructure and 6 ballast blocks will be deployed.

Like many of the areas where tidal stream devices are likely to be deployed, the Inner Sound seabed is current-scoured bedrock, so indirect effects through sediment re-suspension from piling activities or cable installation were not expected. The ES considered any impact to be of short-term duration and that any changes would be imperceptible in comparison to the baseline conditions (Meygen 2012). The Meygen project is the first small tidal stream array to be constructed and the staged nature of its consent will allow further development to be informed by the results of site environmental monitoring.

The first 6MW sub-phase of the project, Phase 1A, was constructed in 2016-2017. Phase 1A consists of 4 turbines which entered operation in March 2018. Each turbine is mounted on a gravity-based foundation and connected to the shore by a dedicated subsea cable. In April 2017, Meygen submitted an application to proceed with Phase 1(b), which consists of a further four turbines, in addition to the four turbines already installed at the development. Project Stroma will connect two of these additional turbines via a new subsea hub to a single power export cable which will then be connected via the MeyGen substation to the National Grid[137]. The subsea hub was granted a Marine Licence (06978/19/0) in July 2019 and was planned to be commissioned in Q2 2020[138]. It is not clear whether the hub and additional turbines have been installed.

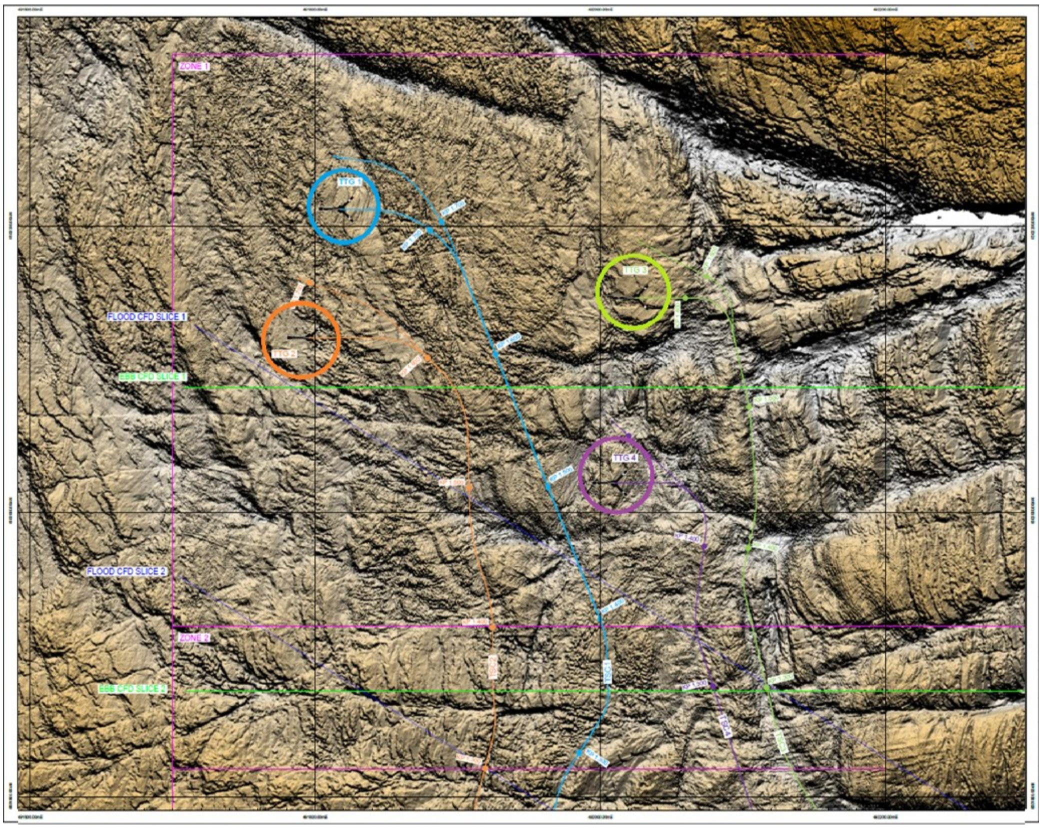
Dynamic effects on the physical environment associated with the movement of blades within the water column are discussed in Section 5.5.2.1.

Similar to OWF, the installation and operation of marine renewable energy devices may lead to alteration and/or loss of existing benthic habitats, for example during cable installation or due to turbulence and scouring around device and mooring foundations (as reviewed by Copping & Hemery 2020, Copping *et al*. 2020).

Tidal current devices and arrays are more likely to be installed on hard bottom seabeds (see Figure 5.12 showing hard seabed at Meygen development), or those with coarse sediments, both being the products of high-energy environments. Benthic infaunal communities of coarse sediments are adapted to living in mobile substrates, but the sessile epibiota of hard substrata are unable to recover from burial should it occur e.g. due to a reduction in current speeds. Where the seafloor is dominated by unconsolidated or consolidated hard substrate, cables are usually laid on top of the sediment, sometimes encased in protective iron pipes or covered with concrete mattresses or rock (Copping & Hemery 2020, and references therein). For example, up to 100 rock bags (up to 5m^3 and 0.7m height) were licensed for use as cable stability and turning points for the cable laying of the four turbine subsea cables for the MeyGen Tidal Energy Project Phase 1a[139]. Direct impacts of such methods of cable laying are the crushing, damaging, or displacement of organisms within the immediate footprint of the cable protection (Dunham *et al.* 2015, Taormina *et al.* 2018). Colonisation of the iron, concrete, or rocky cable protections by encrusting organisms may lead to full recovery of the disturbed seafloor to the pre-cable state within one to eight years (e.g. Kraus & Carter 2018, Sheehan *et al*. 2020, Taormina *et al.* 2018, as reviewed in Copping & Hemery 2020) (see also Section 5.6).

[137] https://simecatlantis.com/projects/meygen/
[138] https://simecatlantis.com/wp-content/uploads/2020/03/Subsea-Hub-Decom_Prog_v2.0.pdf
[139] https://marine.gov.scot/sites/default/files/cable_stability_marine_licence_-_january_2017_0.pdf

Figure 5.12: Seabed in proximity to Meygen Phase 1a turbine locations



Source: Construction method statement: construction works, Meygen tidal energy project phase 1[140]

Tidal range

There are several different designs for extracting energy from tidal range; the main ones being tidal barrages and tidal lagoons. Both barrage and lagoon designs may have large physical footprints and may have significant environmental impacts on both the physical environment and associated habitats. However, mitigation measures (e.g. two way operation, regular sluicing and fish diversion) may reduce the impact.

The building of a tidal barrage across a bay or estuary will permanently destroy the habitat under the physical footprint of the structure and modify others both within the wider development footprint and upstream and downstream of the facility. It may also alter tidal and residual flows and impact on the hydrography and physical characteristics of the wider region.

The previously proposed 16km long Severn Barrage from Cardiff to Western-Super-Mare was calculated to have a structural footprint of between 795,000 and 1,176,000m^2 (Sir Robert McAlpine Ltd 2002) although its impact would have extended to the full 480km^2 of the basin (DECC 2010e). This physical footprint and associated direct impact of removal of habitat are on a larger scale than any other renewable energy technology. Physical effects of piling, seabed preparation, dredging for construction material and the actual laying of the structure on the seabed are discussed in the OWF section but may apply on a larger scale in relation to tidal barrages.

Tidal lagoons are similar to barrages in construction impact although they do not span the whole channel width. To date, only one lagoon project has gone through the planning process with a

[140] https://marine.gov.scot/sites/default/files/construction_method_statement_redacted.pdf

development consent order granted for the Tidal Lagoon Swansea Bay project in June 2015 (a correction order was issued in October 2015). However, it is uncertain whether this, or other tidal range projects (e.g. including former proposals including Tidal Lagoon Cardiff, Tidal Lagoon Newport and the West Somerset Tidal Lagoon) will be developed. The Swansea Bay project would involve the construction of a seawall approximately 9.5km long impounding some 11.5km^2 of the seabed, foreshore and intertidal area of Swansea Bay. The Environmental Statement (Tidal Lagoon Swansea Bay 2014) described potential effects with respect to coastal processes and sediment transport, including:

- sediment dispersion arising from dredging activities creating a plume which will impact upon the water column and estuary bed – it was estimated that 8.1 million m^3 of sediment would be dredged for the project, of which 7.3Mm^3 would be used for the project.
- the direct removal (loss) or physical modification to the existing seabed within the project footprint – it was estimated that 0.21km^2 of intertidal and 0.68km^2 of subtidal habitats would be lost under the lagoon walls and turbine housing footprint in addition to significant removal of sediment within the lagoon as part of the dredging activities
- modification to both near and far-field hydrodynamics (e.g. water levels, flow speeds and waves) as a result of construction works and capital dredge disposal; and
- direct and indirect changes to the sediment (morphological) regime due to erosion/ accretion from the presence of the new infrastructure, driven by changes to sediment transport within Swansea Bay.

The assessment was informed by modelling work which indicated that during the construction phase, there was the potential for increased SSC, and subsequent deposition, within Swansea Bay resulting from the dredging and construction activity. The predicted increases tended to be of greatest magnitude closest to the location of the construction activity, although increased SSC values were shown to be relatively short-lived before returning to within peak natural background levels.

During the construction and operations phase of the project there is expected to be changes to the hydrodynamic and wave conditions across Swansea Bay, with associated effects on sediment transport. During the operational phase, there is a potential for changes in deposition of fine material within the lagoon. Directly in the lee of the turbines and sluice gates, the higher flows experienced over the flood tide act to maintain material in suspension, thus reducing the potential for deposition in these areas. Across the upper subtidal and lower intertidal regions of the lagoon, the reduced tidal flows and calmer wave conditions (compared to the baseline, as a result of sheltering by the lagoon walls) result in a predicted increase in deposition of fine material. Outside the lagoon, the reduced flows in the western part of the Bay result in a predicted increase in the deposition of fine material across parts of the shallow subtidal region.

With regard to coarser material, inside the lagoon a similar change is predicted to that described for the finer sediment. In the lee of the turbine array, the increased flows have the potential to reduce deposition, with lower flows towards the back of the lagoon resulting in the potential for increased deposition. Outside of the lagoon, the development is predicted to interrupt the transport of sand from the area around the Neath Delta, in a westward direction towards the western part of the Bay. This is predicted to result in a build-up of sand material along the outside of the eastern lagoon (Tidal Lagoon Swansea Bay 2014a).

The effects of the impoundment of water, associated reduction in current velocities and sediment characteristics is discussed in Section 5.5.2.2.

Predictions of environmental impact for the Severn barrage are summarised by Hooper & Austen (2013). As with the construction of other marine energy installations, construction of a tidal barrage will disturb seabed sediments giving rise to suspended sediment plumes, the particles of which will eventually settle onto the seabed at some distance from the construction site. Within these plumes the reduced water clarity and light penetration will impact plankton and fish in the water column; as settlement occurs, the benthic epifauna and infauna will be impacted on a spectrum ranging from no effect, through interference with feeding or digestion, to direct smothering and burial during rapid deposition of more than six or seven centimetres.

Habitat will be lost beneath the footprint of the tidal barrage, but the surface of the new structure will provide new areas for colonisation, albeit by different species. The presence of any hard substrate in areas of soft sediment (such as a muddy estuary) will act as a settlement surface, attracting species not otherwise able to extensively colonise the area. Evidence suggests, however, that the assemblages of species colonising artificial structures can differ from those on natural reefs (Moschella *et al*. 2005). The principal reasons for the differences are that artificial constructions have little physical similarity to natural habitats. Walls and pilings tend to be vertical, homogenous structures made of unnatural substances and lacking microhabitats and areas of refuge. They also create shelter and cause shading of the sea floor, extending the footprint of the impact (see Section 5.6).

Tidal lagoons are considered to be less environmentally damaging than barrages, since they do not obstruct the entire width of an estuary and also can be sited so as to minimise loss of intertidal areas. However, tidal lagoons would require considerably more construction materials than a barrage and damage to habitats during construction is likely to be greater and more prolonged.

Impacts during construction focus again on direct damage/obstruction to epibenthic species, and increases suspended sediment plumes followed by sediment deposition. Biological effects are likely in the subtidal benthos, the intertidal ecology and the plankton.

The area of direct loss of habitat beneath the lagoon wall will be dependent on the scale of project but is likely to be locally significant. The area lost is replaced by a greater area of new hard substrate habitat which will undergo colonisation to reach an ecological balanced community as seen at OWF turbine bases. As with the barrage though, constructed substrates of concrete are different from natural rock hard substrates and do not offer the heterogeneity and microhabitats for refuge and for predator-safe larval settlement.

Impacts from increased SPM will be as described above, but the estuarine location of tidal lagoons means that high SPM levels are a naturally frequent occurrence, hence benthic communities are adapted to survive them.

Wave

Most of the wave energy converting devices are either catenary or single point moored (Oxley 2006, Harris *et al.* 2004, Qiao *et al*. 2020), with associated physical impacts on the seabed for different foundation types discussed in the OWF section. Different anchoring types for wave devices are summarised below (Harris *et al.* 2004, see also[20]):

- Drag embedment anchor - holding capacity is generated in the main instalment direction by the embedment of the anchor in the ground

- Driven pile or suction anchor - holding capacity is generated by forcing a pile mechanically or from a pressure difference into the ground, providing friction along the pile and the ground.
- High drilled and grouted anchor - holding capacity is generated by grouting a pile in a rock with a pre-drilled hole.
- Gravity anchor - holding capacity is generated by dead weight providing friction between seabed and anchor

The anchors used for wave devices are smaller than those deployed for OWF, with concrete gravity foundations at the Lysekil research site in Sweden being >2m in diameter (Leijon *et al*. 2008) compared to 20-50m for individual OWF installations. However, the associated impacts remain the same, just on a smaller scale depending on how many devices and arrays are deployed. A study into the effects of moored wave energy devices on soft-bottomed communities at the Lysekil research site (Langhammer 2010) from 2004-2008 showed that there was only minor direct ecological impacts of the device foundations beyond the natural level of variation, which was highly variable in space and time due to strong natural disturbances of the seabed by powerful waves. The primary issue is scour, discussed in the OWF section above. It is however likely that only demonstrator scale wave projects will be developed within the lifetime of this report (apart from in the Pentland Firth and Orkney region) and therefore the scale of associated effects are expected to be minimal, with an overall spatial footprint of arrays of between 1 to 10km^2.

Some wave energy devices are shoreline based (e.g. LIMPET) and therefore have associated physical impacts on coastal processes and habitats. This is predominantly due to the physical footprint of the structure, which is semipermanent/permanent and therefore unlikely to be removed after use. Wave devices work by acting as wave breakers or by removing the wave energy from the sea and have associated impacts on current and water column characteristics and sediment deposition and accretion. These physical effects of the presence of the device in the water column are discussed further in Section 5.5.2.3.

Modelling and validation work by Krivtsov & Linfoot (2012) has shown that the area of benthic habitats adversely affected by the leading mooring line on a typical wave energy converter (height 19m, 16m diameter, mass 900 tonnes) monotonically increased with the increase in wave height. In regular waves of 6m height and 8s period, the area of benthic habitat adversely affected by the mooring lines may exceed 60m^2. Moorings can adversely affect the coverage of sea grass (Luff *et al.* 2019) and Moore *et al*. (1998) provide evidence that human activity has adversely influenced reef growth of the calcareous tubeworm *Serpula vermicularis* through the physical disturbance caused by mooring ground tackle.

Oil and gas

Similar to OWF, the impact of oil and gas installations on the seabed are considered minor on a regional scale in comparison to fishing activities. At present and for the foreseeable future, hydrocarbon developments are in regions dominated by faunal communities and therefore share most of the potential physical impacts with OWF, presented above. The primary issue is the placing of the infrastructure on the seabed and associated loss of habitat and installation issues described for OWF. The use of ROVs and precise navigational equipment to make it easier to avoid disturbance of vulnerable marine communities (OSPAR 2009).

As described in the OWF section, the placement of jack-up legs on the seabed may cause localised and temporary physical disturbance. With respect to oil and gas activities, jack-up drilling rigs are normally used in shallower water depths (usually <100m). In deeper waters, semi-submersible rigs may be used. These typically use between 8 and 12 anchors to hold position, the radius of which depends on the water depth, seabed conditions and anticipated metocean conditions. For example, a review of a number of relevant Environmental Statements indicated that the estimated area of seabed affected by the use of semi-submersible rigs varied between 0.009km^2 in 93m water depth (Marathon Oil UK Limited 2005) to 0.11km^2 in water depths of 435m (Total 2014). The depth of sediment over-turned by anchor-scarring would be of the order of a few metres and exposed sediments are likely to be qualitatively similar to existing surficial sediments.

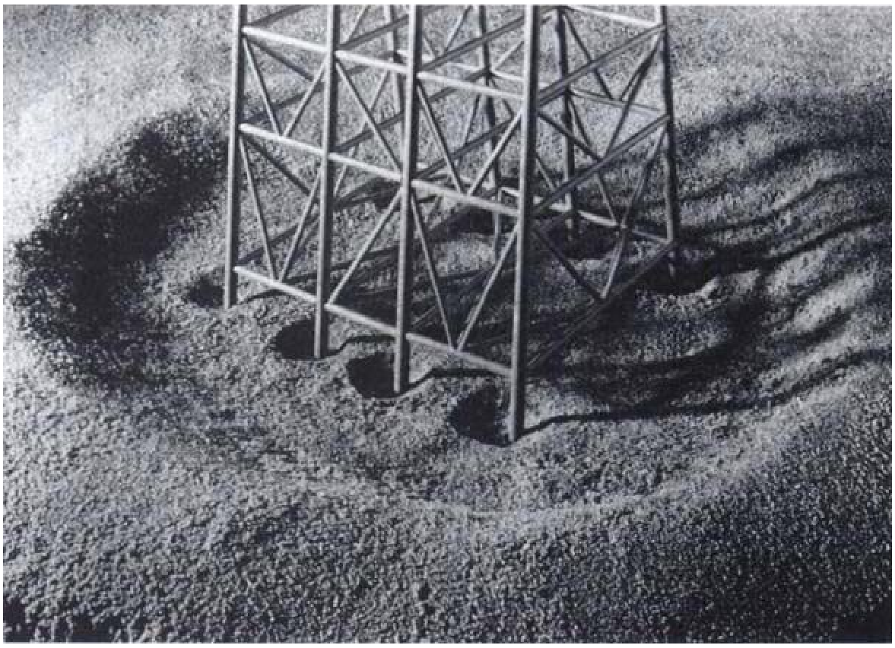
Another significant physical effect associated with oil and gas developments is the laying of pipelines, umbilicals and cables. The physical effects of pipelines, umbilicals and cables are the essentially the same as those for cabling presented in the OWF section above, with the footprint primarily being dependent on whether it is buried or not and the hydrology and sediment dynamics in the locality. Monitoring of the integrity of the pipelines is standard practice and therefore associated spatial environmental effects such as scour are well surveyed.

Although jacket structures piled to the seabed have been extensively used throughout the UKCS for oil and gas production, and in the southern North Sea have experienced substantial scour (and employed scour protection measures), this appears to have been regarded as less of an environmental concern than for OWF developments. For example, Watson (1973) reported rapid scour around gas platform jacket legs in the southern North Sea to a depth of 1.5-3.5m, with (in some cases) individual scour pits coalescing to form a depression ("dishpan" or "global scour") over a much bigger area, of the same order as the area of the structure supported by the piles (Figure 5.13). Scour protection in the form of gravel, rocks, sandbags, gabions, pre-formed concrete blocks or frond mats is routinely used for subsea structures and for pipelines to prevent free-spanning (with resulting structural and snagging risks).

Effects on habitats and communities (biotopes) from the construction of infrastructure (platform jackets, subsea wellheads and pipelines) for oil and gas developments are well documented in previous SEAs and there are many similarities with other types marine energy developments. Techniques for laying of pipelines and cables are similar as are methods of scour and impact protection using mattresses and rock placement. Direct displacement or loss of seabed habitat will occur during foundations preparation, jacket footings, subsea installations, pipelines and pipeline protection. Habitat change can also result from ploughing for pipeline and cable laying. Many of these seabed activities during construction and decommissioning create a temporary increase in suspended sediments, followed by deposition of particles at varying distances from the activity site dependent on the sediment particle size and seabed current speeds. In shelf depths additional habitat loss can result from the use of temporary anchors on the seabed from pipelay vessels or construction barges.

A recent review of rock and other protective material use in offshore oil and gas operations on the UKCS (BEIS 2021h), provided spatial analysis of Environmental and Emissions Monitoring System (EEMS) returns to estimate material placed on the UKCS between 2011 and 2016. The analysis indicated that the southern North Sea had the greatest percentage of the total area impacted by deposits, at just over 700,000 m^2 or 0.00102% of the total area, which was attributed to its smaller total geographical area and relatively high number of oil and gas installations; the mobile nature of the seabed sediments leading to the requirement for stabilisation/protection material around oil and gas infrastructure. Almost half of the total area impacted by seabed deposits (primarily rock) in the southern North Sea was located within existing designated areas including Haisborough, Hammond and Winterton SAC, North Norfolk Sandbanks and Saturn Reef SAC and Dogger Bank SAC. However, there were a large number of caveats associated with the quality of the deposit data, with the review suggesting that tools to help operators more accurately describe the location and extent of the deposit could be developed (e.g. locating on an interactive map or import of GIS Shapefiles), to determine the footprint of material within an area (e.g. a protected area).

Figure 5.13: Representation of global and local scour around jacket structure



Source: Angus & Moore (1982)

Hydrocarbon gas storage and unloading

Gas storage projects in UK waters currently use existing hydrocarbon reservoirs and existing infrastructure, and impacts are the same as those detailed for oil and gas installations. However, those that are located in non-hydrocarbon reservoirs (e.g. salt caverns), which require excavation, may potentially have slightly different physical impacts on the seabed and habitats.

The Environmental Statement (Gateway 2007) for a gas storage project (current status not clear[141]) in the Eastern Irish Sea identified the following activities which could result in physical disturbance to the seabed:

- Drilling operations during cavern creation resulting in the discharge of cuttings
- Installation of the monopods (monopile foundations)
- Installation of pipelines/cables (including dredging, ploughing and jetting)
- Temporary presence of rigs and vessels during construction, installation and maintenance activities

The presence of rigs and vessels, installation of foundations, pipelines/cables and the effects of structures in the water column during operation are all discussed in the OWF and Oil & Gas sections above. In terms of the discharge of drill cuttings, Gateway (2007) estimated that approximately 6,700 tonnes of cuttings from overlying rock strata would be produced and

141 https://www.stagenergy.com/gateway/

discharged just below the sea surface to allow access for the creation of 20 separate gas storage caverns within the underlying salt strata. Modelled deposition of the material on the seabed predicted that 95% (mostly particles >1mm diameter) would be deposited within 165m of the discharge point and the remaining finer particles would settle over a wider area at low small concentrations and be undetectable. The effect of additional suspended sediment from drilling within the water column was likely to be transitory.

Carbon dioxide transport and storage

The physical impacts of carbon dioxide storage projects are largely covered by the OWF, oil and gas and gas storage sections. For example, the offshore Environment Statement for the previous Yorkshire and Humber CCS offshore pipeline and storage project (National Grid 2015)[142] indicated that sources of physical disturbance associated with the project included:

- Disturbance of nearshore and offshore seabed from pipeline installation (trenching, pre sweeping, lay-barge anchoring, rock dump including pipeline and cable crossings)
- Disturbance from installation of the microseismic network (up to 31 seismometers of 6” diameter connected by up to 40km of 25mm cable, laid at a depth of between 0.6-1m below the seabed).
- Disturbance of seabed during rig placement (spud cans and if used, stabilisation materials)
- Disturbance of seabed from installation of the NUI (normally unmanned installation)
- Disturbance of seabed from surface hole cuttings discharge

The ES concluded that the installation of the pipeline, microseismic network, NUI and drilling rig placement will generate physical disturbance to the seabed over a limited spatial extent. Given the relatively limited scale of activities and inferred general resilience and recovery potential of the seabed, habitats and species, it was concluded that there would be a negligible to moderate level of effect at the seabed with an associated low level of significance.

Construction of gas storage caverns and CO_2 (and possibly hydrogen) storage facilities result is similar impact mechanisms as oil and gas construction and effects on biotopes will be comparable. The volumes of cuttings to be discharged during construction will create elevated concentrations of suspended sediments during the drilling period and the normal mitigation of effects through seasonal or spatial avoidance of vulnerable habitats such as herring spawning grounds would be standard practice.

[142] National Grid are now part of the Northern Endurance Partnership (NEP), the CO_2 transportation and storage company set up to deliver the onshore and offshore infrastructure needed to capture carbon from a range of emitters across Teesside and the Humber (the East Coast Cluster) and transport to offshore storage in the Endurance store. The consent application for the offshore works has not yet (as of January 2022) been submitted but the potential sources of physical disturbance are likely to be similar to the previous project.

5.4.3.2 Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc and impacts on the setting of coastal historic environmental assets and loss of access

Offshore wind farms, tidal stream and wave

OWF, tidal stream and wave projects have the potential to damage archaeological artefacts and sites, in particular through the trenching of cables into the seabed and through foundation installation, rig and other vessel anchoring. The recognition of the importance of prehistoric submarine archaeological remains has led to a number of initiatives.

A legal and policy framework for protection of maritime archaeology is in place. Guidance notes for the aggregates industry have been formally published (BMAPA & English Heritage 2003) covering legislation, statutory controls, possible effects of aggregate extraction, obtaining archaeological advice, application procedures, assessment, evaluation, archaeological investigation, mitigation, and monitoring. Recognising the need for interaction between seabed developments and the historic environment COWRIE published a guidance document entitled Historic Environment Guidance for the Offshore Renewable Energy Sector in 2007 (COWRIE 2007) which considered the survey, appraisal and monitoring of the historic environment during offshore renewable energy projects. A second COWRIE guidance document, Guidance for Assessment of the Cumulative Impacts on the Historic Environment from Offshore Renewable Energy, addressed the specific issues related to the cumulative impacts of offshore renewable energy projects on the historic environment (COWRIE 2008). A third COWRIE guidance document, Offshore Geotechnical Investigations and Historic Environment Analysis: Guidance for the Renewable Energy Sector (COWRIE 2011) provides best practice options in relation to the integration of archaeology with offshore development led geotechnical investigations, particularly with respect to the Round 3 developments. A protocol for archaeological discoveries with respect to offshore renewables projects was produced by The Crown Estate (2014), which addresses finds or anomalies of archaeological interest made on the seabed, onboard vessels, in the inter-tidal zone or on land. Most recently, Historic England (2021) have produced an advice note which provides, amongst other details, the main considerations to be made in relation to the historic environment for renewable development, including offshore renewables.

The archaeology and cultural heritage assessments carried out as part of the EIA process for the consented Round 3 developments provide valuable information with respect to the known and potential archaeological resource of each of the development areas and cable corridor routes. Geotechnical surveys of each area have highlighted known and previously unidentified wrecks as well as a large number of anomalies and these have been categorised according to their archaeological potential.

Direct impacts to archaeological receptors are likely to be permanent. Once archaeological deposits and material, and the relationships between deposits and material and their wider surroundings, have been damaged or disturbed it is not possible to reinstate or reverse those changes. As such, direct impacts to the fabric or setting represent a total loss of a receptor, or part of it, and the character, composition or attributes of the receptor would be fundamentally changed or lost from the site altogether.

As indicated by the Round 3 assessments, adherence to the revised (or the 2010 original) protocol for archaeological discoveries with respect to offshore renewable projects (The Crown Estate 2014) will provide for the reporting of archaeological discoveries made during the course of development. The response to reported finds will be implemented through the measures set out in the protocol, such as further survey or the establishment of Temporary Exclusion Zones (TEZs), which may be converted into new Archaeological Exclusion Zones (AEZs), if warranted.

With regard to local visual and character perceptions, the magnitude of the effect of construction activities upon local perceptions of the historic environment and local seascapes are expected to be negligible. Offshore construction activities at the landfall would be short term and comparatively small scale and the use of large construction vessels would be short term and transitory during the construction phase.

Oil and gas, gas storage and carbon dioxide storage

In terms of submerged archaeology, oil and gas, and gas storage installations have the same potential for damage as OWF, however, oil and gas and OWF activity is also recognised to present the opportunity to provide beneficial new archaeological data, for example through rig site or pipeline route mapping and sediment coring. Flemming (2004) therefore suggested that rather than seeking to prevent or limit oil and gas activities, "*it is therefore in the interests of long term preservation of the archaeological sites, and in the interests of acquisition of archaeological knowledge, that we use industrial and commercial activities as a means of identifying archaeological prehistoric sites in the offshore area".* This has in part been realised, for example in the reinterpretation of oil and gas seismic data in the southern North Sea (Gaffney *et al.* (2007, 2009, also see Appendix 1i).

Tidal range

Large scale changes to sediment regimes, erosion and deposition, mean water heights, tidal range and current velocities (discussed further in Section 5.5.2) may affect any historical or archaeological artefacts or structures either directly through physical damage from infrastructure or indirectly through sediment erosion and deposition or submergence or emergence due to changing water levels. For example, the proposed dredging activities to provide material for the seawalls of the Swansea Bay lagoon were identified as having the greatest magnitude of effect with respect to known archaeological sites and potential maritime archaeology (Tidal Lagoon Swansea Bay 2014a).

5.4.3.3 Post-decommissioning (legacy) effects – cuttings piles, footings, foundations, in situ cabling etc

Offshore wind farms, tidal stream, wave

The expected lifetime of OWF turbines is 20 to 25 years and 40 years for cables and other associated infrastructure. Similar physical impacts to those outlined for the installation of OWF, sediment and habitat disturbance, are also likely due to decommissioning activities.

BEIS (2019)[143] guidance indicates that it is expected that all installations and structures will be fully removed at the end of their operational life to minimise residual liabilities and that approval of decommissioning programmes will be based on this assumption. Exceptions from full removal will only be considered on presentation of compelling evidence that removal would create unacceptable risks to personnel or to the marine environment, be technically unfeasible or involve extreme costs. Exceptions will be considered on a case by case basis prior to decommissioning, taking on board environmental conditions, the balance of risk, and technological capabilities at that time.

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143 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/916912/decommissioning-offshore-renewable-energy-installations-energy-act-2004-guidance-industry__1_.pdf

Of relevance to this assessment section, developers/owners should take the following points into account if making arguments for exceptions to full decommissioning:

- arguments should be tailored to the individual site and should set out whether the risks of buried cables etc are equal across all parts of the site (for example, are some areas of the site more prone to sediment shift?).
- arguments should be relative to the effect of conducting the activity during construction.

The guidance notes that any redundant infrastructure permanently deposited or buried by exception as part of the decommissioning risks creating residual liabilities. For example, any remaining cables would need to be stay buried to a suitable depth so that they would be unlikely to become uncovered by sediment and current processes. This also applies to the cutting of piles and other below seabed style foundation types. Any foundations, scour protection or structures left on the seabed are likely to have similar impacts to those in operation, e.g. scour, and therefore some post-decommissioning monitoring would be expected in order to identify any new or increased risks to navigation or other users of the sea which may be posed by remaining materials (for example, where cables or foundations may have become exposed due to natural sediment dynamics), and removing any such exposed sections.

As part of DCO requirements, decommissioning programmes for OWF developments must be submitted before offshore works can commence. As a recent example, the Dogger Bank C decommissioning programme[144] was submitted to BEIS in November 2021, which states that the proposed approach for decommissioning is that:

- All structures above the seabed are removed i.e. wind turbines, offshore platforms and foundations above the seabed; and
- Cables and lower sections of foundations which are beneath the seabed are left *in situ*.

The programme indicates that this approach was chosen to minimise the disturbance of the seabed from decommissioning whilst ensuring that there was no risk to the safety of other users or that the materials will become exposed at any future time. The environmental impact of fully removing foundations was anticipated to be significant, considering the force required to remove foundations from the seabed, and any sediment and/or rocks that would be removed at the same time. The programme notes that based on current knowledge, there was not a vessel that would be able to exert the required force to essentially pull the foundations out from the seabed. As such, the complete removal of foundations was considered technically unfeasible. Based on this, removal of the foundations to approximately 1 m the seabed was considered by the programme to be the most suitable option for decommissioning the monopiles based on current understanding of the technology available.

Oil and gas

The decommissioning of offshore oil and gas installations and pipelines on the UKCS is controlled through the Petroleum Act 1998 (as amended). The UK's international obligations on decommissioning are governed principally by the OSPAR Convention and under the terms of OSPAR Decision 98/3, which entered into force on 9 February 1999, there is a prohibition on the dumping and leaving wholly or partly in place of offshore installations. Decision 98/3 requires that:

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144 https://doggerbank.com/wp-content/uploads/2021/11/LF700013-CST-DOG-PLN-0034-Dogger-Bank-C-Draft-Decommissioning-Programme.pdf

- The topsides of all installations must be returned to shore.
- All steel installations with a jacket weight less than 10,000 tonnes in air must be completely removed for re-use, recycling or final disposal on land.

The Decision recognises that there may be difficulty in removing the 'footings' of large steel jackets weighing more than 10,000 tonnes in air and in removing concrete installations. As a result there is a facility for derogation from the main prohibition for such installations. Potential derogation cases are considered individually to see whether it may be appropriate to leave the footings of large steel installations or concrete structures in place. Derogations are only granted if there are significant reasons why an alternative disposal option is preferable to re-use or recycling or final disposal on land, as assessed in accordance with the comparative assessment and consultation procedure, set out in the Decision 98/3. The derogation provision for the footings of large steel installations applies only to those installed before 9 February 1999. All steel installations placed in the maritime area after that date must be totally removed (BEIS 2018).

The OSPAR Recommendation 2006/5 on a management regime for offshore cuttings piles introduced a two stage management regime. Stage 1 provided for initial screening of all cuttings piles, to be completed by 2008 to identify any piles that require further investigation based on the thresholds set out in the Recommendation. A stage 1 screening of UK cuttings piles by the industry in line with the Recommendation concluded that they were all below the specified thresholds. However, at the time of decommissioning the associated installations the characteristics of the relevant cuttings piles should be assessed in detail and the need for further action in line with Stage 2 of the Recommendation reviewed. Stage 2 requires comparative assessment to determine the best option for handling the cuttings piles (BEIS 2018). It is considered unlikely that any oil & gas development resulting from the draft plan/programme will lead to the formation of a significant drill cuttings pile.

Decommissioning programmes will require EIA which must be documented in an Environmental Appraisal (EA) report[145]. The level of information in the EA should be proportionate to the scale of the activities described in the DP. Where the proposed activities could impact a sensitive area (e.g. a Marine Protected Area or coastal resources), this will also usually merit more detailed information and a more robust assessment of the potential impacts.

Where BEIS or the relevant SNCB considers that the decommissioning proposals may have a significant effect on the integrity of a SAC or SPA, it is likely that BEIS, as the competent authority, will undertake a Habitats Regulations Assessment (HRA). A number of strategic level HRAs have been completed by BEIS covering the decommissioning of multiple developments within the southern North Sea including:

- Viking and LOGGS Phase 1 decommissioning and Strategic Review of proposed further decommissioning at Viking and LOGGS (January 2019)[146]

[145] Note there is no statutory requirement to undertake an environmental impact assessment that satisfies the EIA Directive requirements for proposed decommissioning activities. Under the Petroleum Act 1998 there is a more straightforward requirement to undertake an assessment of the potential environmental impacts of the proposed decommissioning proposals, and the EA described here fulfils that requirement.

[146] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/778287/HRA_ConocoPhillips_10_Year_Decommissioning_Programme_Rev_11.0__002_.pdf

- Dogger Bank SAC Oil and Gas Decommissioning Strategic HRA (April 2019)[147]
- Spirit Energy A Fields (Ann A4, Ann, Alison, Audrey, Saturn (Annabel)) and Ensign Decommissioning HRA (July 2021)[148]

The HRAs were informed by information supplied by operators following a BEIS request (Dogger Bank), or from Environmental Statements submitted to support DPs. In general across the HRAs, proposed activities that could result in post-decommissioning effects included:

- The placement of rock over pipeline ends and to remediate any hazardous free spans.
- The leaving in situ of pipelines exposed on the seabed.

The HRAs described the extent of physical disturbances or loss associated with these activities, utilising information from relevant surveys of assets to describe for example, the extent to which pipelines were buried or exposed by sand waves. The HRAs estimated the total area of seabed loss from planned decommissioning activities. For example, with respect to the most recent Spirit Energy A Fields and Ensign HRA, the total area of physical loss of habitat within the North Norfolk Sandbanks and Saturn Reef SAC and the Southern North Sea SAC was estimated to be 0.0082 km^2. In general, the HRAs cited evidence including from surveys (noting that it would be useful if survey information was made publicly available as it may represent a valuable resource to better understand the impact of introducing hard substrates into dynamic environments) to show that permanent impacts would cause a loss of habitat but the impacts would be localised and not affect the hydrography such that it would affect the maintenance of the sandbank features.

Draft and approved decommissioning programmes are listed on the BEIS website[149].

Gas and carbon dioxide storage

The decommissioning provisions of Part IV of the *Petroleum Act 1998 Act* apply to offshore facilities established for the purposes of gas storage and CCS. The framework for decommissioning outlined by BEIS (2018) is also relevant to such projects. Potential post-decommissioning effects are likely to be similar to those described for oil and gas and OWF.

Tidal range

Given that there are no constructed projects, there are unlikely to be decommissioning activities in the lifetime of this plan.

5.4.4 Controls and mitigation

Site surveys are required to be undertaken before potentially damaging activities such as drilling rig placement (for safety and environmental reasons) and the results of such surveys allow for the identification of further mitigation including the relocation of the proposed activities (e.g. wellhead, rig leg or anchor positions) to ensure sensitive seabed surface or subsurface features are avoided. Such survey reports are used to underpin operator/developer environmental

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147 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/799510/Dogger_Bank_Decommissioning_Strategic_HRA_rev3.0.pdf

148 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005565/Spirit_Energy_-_A_Fields_and_Ensign_Decommissioning_HRA.pdf

149 https://www.gov.uk/guidance/oil-and-gas-decommissioning-of-offshore-installations-and-pipelines#table-of-approved-decommissioning-programmes

submissions (e.g. Environmental Statements) and survey information is made available to nature conservation bodies during the consultation phases of these assessments.

No measures are likely to be able to mitigate for the potential physical disturbance associated with tidal barrage and lagoon schemes.

5.4.5 Likelihood of significant effects

The consideration of evidence indicates that with the exception of tidal range, plan activities, particularly those associated with the construction phase are unlikely to cause significant effects at a Regional Sea level to seabed sediments, features and habitats given the localised and/or temporary nature of potential effects and the dynamic nature of many of the areas where development is likely to occur. Habitat change from the deposition of hard substrates (primarily rock) in sedimentary habitats, particularly associated with offshore wind farm cable protection but also as a result of oil and gas pipeline installation and decommissioning, has become a cause of concern, particularly for southern North Sea sandbank MPAs and the SEA makes a number of recommendations below. The requirement for site surveys before activities take place will ensure that impacts to more sensitive features (both geomorphological and archaeological) can be avoided or minimised.

Potential cumulative effects from plan activities are possible where the ‘footprints’ of physical disturbance overlap incrementally with those of other plan activities or cumulatively with other non-plan activities (e.g. fishing, aggregate extraction, dredge disposal). The aspect of the plan with the greatest potential for cumulative effects is the ongoing and future development of offshore wind given the large scale development proposed over the next decade and the relative localised nature of much of this in the central and southern North Sea, an area also used extensively by other industries. The assessment has shown that the strategic-level footprint of physical disturbance associated with the construction of the consented offshore wind development will be limited both spatially and temporally. The potential for significant incremental and cumulative physical damage/change effects is further reduced by the naturally dynamic environment of the southern North Sea which is adapted to re-suspension and sedimentation events. In a UKCS context, the contribution of all other sources of disturbance are minor in comparison to the direct physical effects of fishing – for example, ICES calculated that the fishery using mobile bottom-contacting gears impacted 490,185km^2 of the Greater North Sea in 2018, corresponding to over 70% of the region’s spatial extent (ICES 2021a).

The dispersion and settling of sediment plumes from construction activities (primarily associated with OWF) has the potential to be detectable across median lines. However, within the plume, the levels of suspended sediments, which may have a significant impact on sensitive receptors, is limited both spatially and temporally. Regardless of extent of impact, where the near-bed SPM concentrations are naturally high, as in coastal and southern North Sea areas and the Irish Sea, the effects of anthropogenic sediment plumes are unlikely to be significant on the existing seabed communities.

5.4.6 Summary of findings and recommendations

Physical disturbance associated with activities resulting from future oil and gas licensing and OWF, wave and tidal stream leasing will be negligible in scale relative to natural disturbance and the effects of demersal fishing. The potential for significant effects, in terms of regional distribution of features and habitats, or population viability and conservation status of benthic species, is considered to be low.

The potential impacts of tidal range schemes however, could be very significant with the potential loss of large areas of inter-tidal habitats and salt marshes as a result of a change in water levels and sediment transport within an estuary or river channel.

In areas with vulnerable habitats and species such as biogenic reefs and deep mud communities, mitigation may be required for physically damaging activities such as rig/vessel anchoring, discharges of drilling wastes and cable, pipeline or umbilical installation (from hydrocarbon, gas storage or renewable energy related activities). Prior to decisions on activity consenting in such areas, developers should provide a detailed assessment and seabed information so that appropriate site specific mitigation can be defined.

The SEA notes post-consent changes made to cable installation techniques, remedial works and additional cable protection which have resulted in habitat disturbance and loss/ modification within MPAs that has not been assessed as part of the consent application process[150]. The SEA recommends that while some flexibility may remain for effects to be considered at the marine licensing stage, which may include changes to the national site network between the date of consent and construction, developers must ensure that realistic levels of impacts and where possible impact location, particularly those associated with cable installation and protection in sensitive MPAs, are assessed as part of their submissions at the consenting stage.

The SEA recommends that the development of appropriate benthic compensatory measures for sandbank and subtidal biogenic reef MPAs with respect to cable protection is reviewed at a strategic level (as supported by JNCC and Natural England[151]) to focus research in this area. Better definition of the nature and extent of existing introduced hard substrates within MPAs designated for sandbanks is required to improve understanding of the conservation status of these qualifying features, and characterise how the static hard substrates interact with the mobile features over time. Previous attempts have not catalysed the collection of specific industry information on hard deposits in relevant MPAs required to reduce uncertainty in this area, or have been limited by available data. As part of future permitting and licensing, data on the nature, scale and location of hard substrate deposition should be recorded and disseminated.

Connected with the above, the volumes of rock used, for example, in cable armouring, foundation scour protection and pipeline protection and upheaval buckling prevention, must be the minimum required to provide the necessary protection in order to minimise permanent habitat change and to ensure areas developed as a result of the current draft plan/programme are left fit for other uses after decommissioning. Alternative methods of protection/control (e.g. those that are more easily removed on decommissioning) should be considered to minimise the potential for permanent habitat change.

A further comprehensive strategic review of post-consent wind farm monitoring is required to inform the environmental assessment and consenting of future developments.

[150] e.g. https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-001240-Natural%20England%20-%20Offshore%20Cabling%20paper%20July%202018.pdf
[151] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-003633-EN010080_Hornse%20Three_SBIP_SNCB%20comments%20letter%20Final.pdf

5.5 Consequences of energy removal

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Energy removal from wet renewable devices, and offshore wind farms				X	X	X	X	
Changes/loss of habitats from major alteration of hydrography or sedimentation (indirect effects on the physical environment)				X	X	X	X	
Changes to sedimentation regime and associated physical effects				X	X	X	X	
Changes to thermal stratification, current strength and wave climate				X	X	X	X	

5.5.1 Introduction

Energy removal by turbines, or the turbulent wakes resulting from the introduction of structures through the water column, may cause changes in the tidal regime or water column mixing; the existing regime and environment are, in large part, a function of energy inputs, for example from density driven currents and wind, and removals from friction and turbulence. The magnitude and extent of any change is very site specific and also depends on where the energy is extracted from within a system. It has been shown that removing the same amount of average power from two different sites within the same body of water may lead to very different effects on the far-field physical environment. In addition, specific aspects of a device (e.g. foundation type, support structure, shape and size, orientation) can also alter the fraction of energy removed, e.g. by variously altering a change in bed roughness and in the nature of the turbulence generated. Additionally, wind turbines reduce wind energy as it passes through the farm, and though environmental effects of this are not well documented, effects on the limits to wind power extraction and effects on downstream wind turbines or wind farms has been a consideration of a number of authors (e.g. Lundquist *et al.* 2018).

Sites that are high in dynamic energy are targeted as suitable for deployment of wave and tidal devices. Understanding the impact of these devices on the hydrography and morphodynamics of an area requires a baseline understanding of the movement of water and sediment through these natural systems. Despite decades of measurements of circulation, tidal dynamics and waves in oceanographic settings, very few deployments or studies have been undertaken in areas of extremely high energy. This means that baseline information on the natural dynamics of these areas are often not well understood, with studies focused on impacts from wet renewable devices reliant on modelling simulations, and generally having few or no validation points. The emergent nature of these technologies also means that few measurement campaigns have been undertaken in areas of device deployment. Similarly, hydrodynamic changes can result from the interaction of tidal flows with device foundations, including for wind farms, which may not be in high energy environments. While local effects, for example turbulent wakes on sediment movement, have been noted and studied at a project level, the scale of future deployment of wind farms in European seas is such that far-field and basin scale effects on hydrodynamics may be envisaged. Modelling has similarly informed studies to date but these also lack validation and accurate input parameters for future wind farms.

As the effects of energy removal are so site specific there is a high level of uncertainty in relation to the significance of effects, the ability to connect changes to the hydrodynamic regime to other aspects of the physical environment and ultimately biogeochemical processes, and also to applying impacts from one scenario more widely. The parts of the physical system most likely to be affected by energy removal are: tidal range, transport both of water and sediment, turbulent dissipation and boundary layer structure, and wave regime (dependent on wave-current interactions). These have the potential to affect water quality, sediment transport, habitats and marine ecosystem functions such as stratification and primary productivity.

Despite the above uncertainties there are a number of international and national projects and initiatives aimed at increasing the understanding of the impacts of energy removal on natural systems, e.g. EBAO (optimising array form for energy extraction and environmental benefit), TerraWatt, EMIR International Conference (environmental interactions of marine renewable energy technologies), SMARTtide (simulated marine array resource testing), Tethys, the scoping and synthesis reports of the *Wind Op Zee Ecologisch Programma* (Wozep) in relation to the potential effects of offshore wind (e.g. Boon *et al.* 2018, van Duren *et al.* 2021), as well as an increasing number of academic studies, a selection of which are referred to below.

5.5.2 Consideration of the evidence

5.5.2.1 Tidal Stream

The placement of tidal stream devices in the water column has two linked but separate forcing effects: the change in natural flow of water associated with the physical presence of the device, with resulting effects such as scour around anchors and foundations (discussed in Section 5.4); and, the removal of energy from the water column, which primarily reduces current velocity, alters bed shear stress and sediment transport.

A number of idealised and site specific modelling studies have been undertaken to investigate the impacts of tidal devices on hydrography and sediment dynamics (e.g. Bryden & Couch 2006, Neill *et al.* 2009, Wolf *et al.* 2009, Martin-Short *et al.* 2015), with a few monitoring studies based on recent deployments in the real environment. These include the grid connected SeaGen device in Strangford Lough, deployed in 2008, and a number of demonstrator scale devices at EMEC sites in Orkney. Whilst far field impacts from single tidal stream devices or small arrays are generally shown to be insignificant (Ahmadian *et al.* 2012), 1D, 2D and 3D modelling work has started to focus on the impacts of array scales of devices, e.g. de Dominicis *et al.* (2018), O'Hara Murray & Gallego (2017), van der Molen *et al.* (2016).

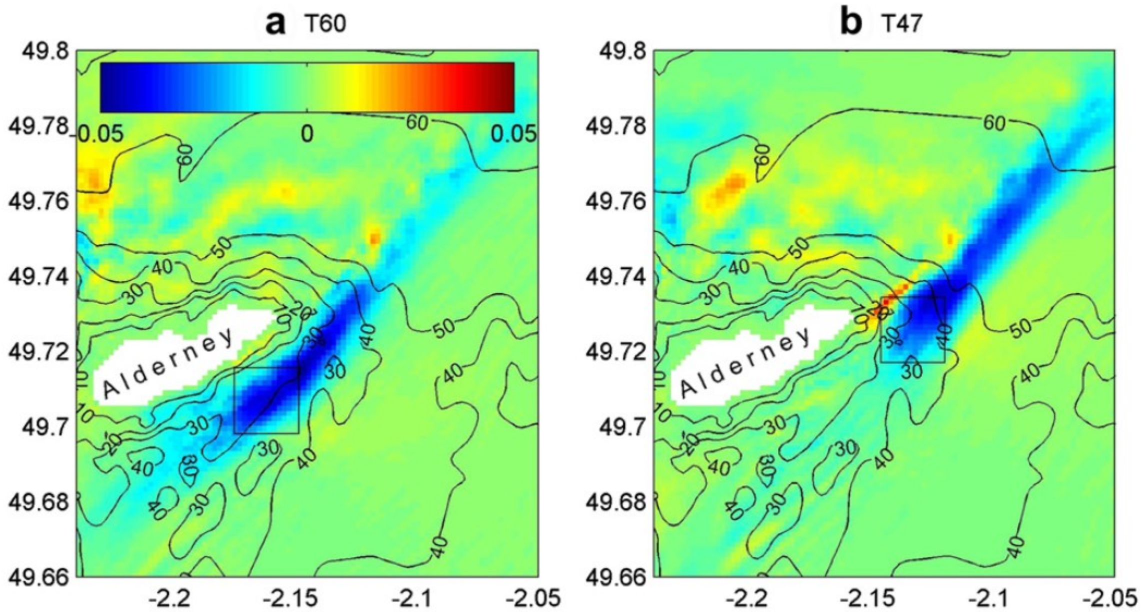
Velocity changes

Tidal energy extraction from tidal stream devices has been shown to reduce the volume of water exchanged through an area over a tidal cycle, reduce the tidal range landward of an array and reduce the power density in the tidal channel itself (Bryden & Couch 2006, Polagye *et al.* 2008, Walkington & Burrows 2009, O'Hara Murray & Gallego 2017). Tidal stream devices intercept the kinetic energy in strong tidal currents resulting in a change to the velocity structure of a channel and changes to current speed over the wider area (Figure 5.14). However, there appears to be a non-linear relationship between the rate of energy extraction and the velocity reduction (Bryden & Couch 2006, O'Hara Murray & Gallego 2017), due to the fact that energy extraction decreases the available energy flux and therefore diminishes the overall flow speed. Simulation of an array of 400 turbines in the Pentland Firth shows that residual tidal currents are affected within a 10km area, with the weakening not uniformly distributed over the area (Martin-Short *et al.* 2015). A scenario of 5,636 tidal turbines occupying the bottom 25m of the water column in the Pentland Firth suggested 1.4GW installed capacity could be achieved with a 7% reduction in the volume of transport, with a phase difference either side of the array in the order of 0.1m, and a change in tidal speeds in the order of 0.5ms^{-1} (O'Hara Murray & Gallego 2017).

Additionally, it was found that the use of a speed dependent turbine thrust coefficient could enhance energy production and reduce changes to tidal flow. O'Hara Murray & Gallego (2017) also simulated a number of other scenarios to understand the maximum potential extractable energy from the Pentland Firth (peaking at 10.8GW, with a mean of 4.9GW), however, changes to volume transport of 38% and changes to tidal flows of up to $2ms^{-1}$ are significant for these scenarios. These were not considered to be realistic but are useful to understand the limits to potential extraction. Van der Molen *et al.* (2016) similarly undertook modelling of a realistic 800MW scenario and unrealistic 8GW scenario for the Pentland Firth, with the former estimated to have minor and likely undetectable effects on tides and biogeochemistry. Effects from the 8GW scenario were estimated to be observable hundreds of kilometres away and along the east coast of the UK, with an area around the Wash apparently most sensitive to such large-scale deployment.

Modelling evidence also points to a blockage effect from flow diverting around arrays of devices, further reducing the fraction of incident energy which is extractable (Walkington & Burrows 2009), something that was not properly accounted for in early assessments of tidal stream resources. Modelling of an array in open water in the Celtic Sea suggests that this blocking effect reduces the available extractable energy by up to 14 times compared to currents undisturbed by an array (Shapiro 2011).

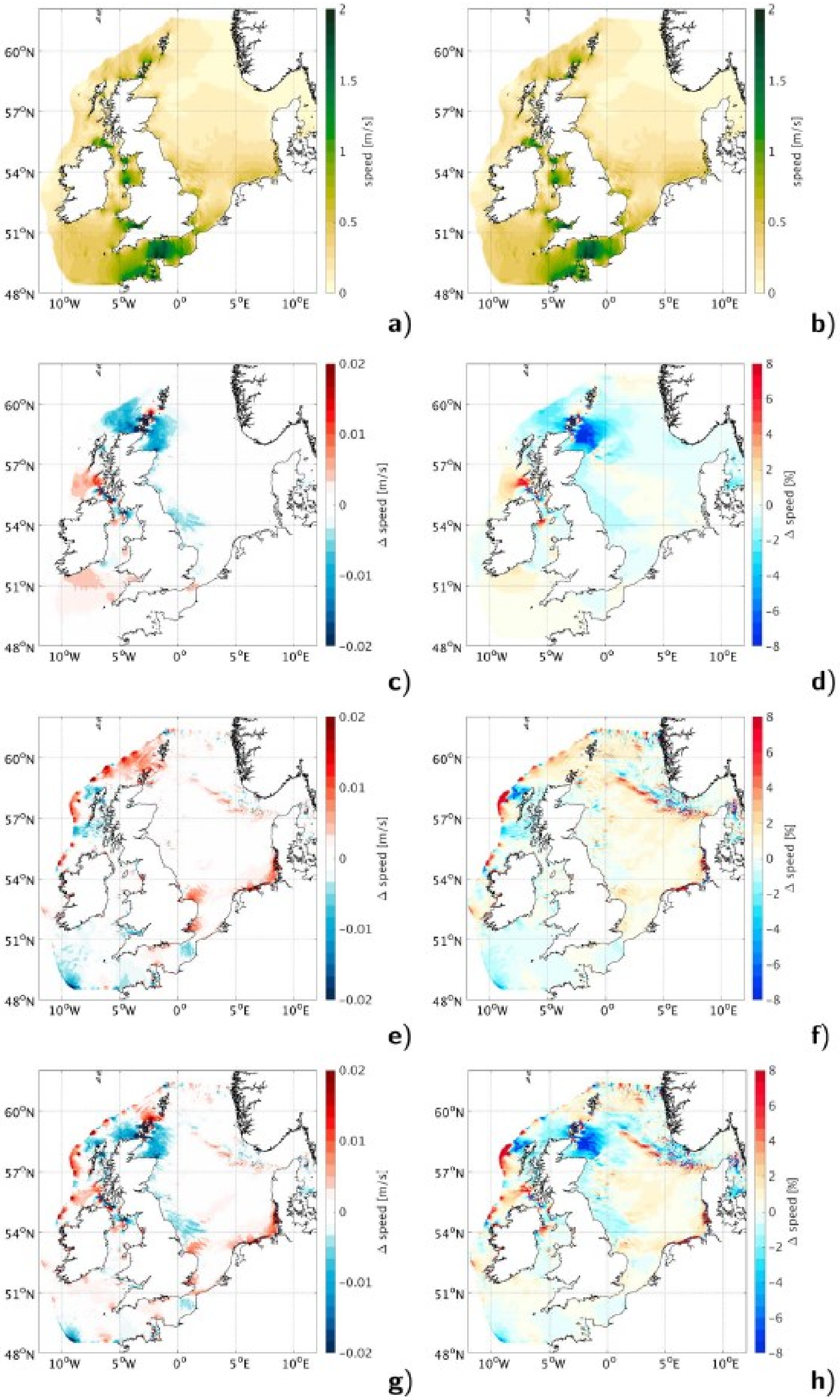
Figure 5.14: Modelled change in magnitude of velocity (m/s) compared to baseline due to energy extraction averaged over a spring-neap cycle for a tidal array in two locations in the Alderney Race



Notes: Black box is the location of the tidal array in two scenarios. Array contains 200 x 1.5MW devices.

Source: Neill *et al.* (2012). Also see Blunden *et al.* (2020) and Thiébot *et al.* (2020) which provide new modelling and a review of work for the Alderney Race respectively.

Figure 5.15: Current and future spring peak tidal current speed



Notes: Spring peak tidal currents during present (a) and future (b) climate conditions; change due to tidal stream energy extraction during present conditions, absolute (c) and percentage (d) difference; change due to future climate conditions, absolute (e) and percentage (f) difference; change due to tidal stream energy extraction and future climate conditions, absolute (g) and percentage (h) difference. Source: de Dominicis *et al.* (2018).

For single devices or small arrays these effects are expected to be very small (Polagye *et al.* 2011) with studies suggesting that in a tidal channel the impact of energy extraction on current speed only becomes significant at extraction values of 10-50% of available kinetic energy (see below). Even for larger arrays, isolating the signal of marine energy devices from natural variability can be difficult. However, whilst this suggests minimal environmental impacts from small arrays of tidal devices, bed shear stress is also a function of current speed, with small changes in velocity leading to large changes in bed shear stress and resultant sediment transport pathways (Neill *et al.* 2012). Thus, large changes in sediment erosion and deposition can occur from small changes in velocity. A study of the impact of maximum energy extraction by tidal turbines in the Minas Passage, Canada (Hasegawa *et al*. 2011), showed that significant far field effects on the residual circulation of the Bay of Fundy and Gulf of Maine can be expected, similar in impact to that of a barrage. They also concluded that tidal energy extraction from the lower water column produces less far-field impacts than turbines situated throughout the water column, an additional variable when considering potential impacts.

Published simulation values of reductions in flow range from 56% (Vancouver Island, Canada, Sutherland *et al*. 2007), 19% for Ramsey Sound (Haverson *et al.* 2014), 15% in the Alderney Race (Thiébot *et al*. 2015), to just a few percent for 10-50MW array scenarios offshore Anglesey (Robins *et al*. 2014). The wide range of figures reflects the different physical settings of devices, with the system response to energy extraction dependent on the geometry of the area (e.g. narrow channel, estuary, wider channel), tidal regime and non-linear turbine dynamics (Polagye *et al.* 2008). The location of devices within the same area can also result in significant variation in the change to flow velocities, for example Blunden (2020) note that the location of turbines (using a 300MW example) in within the Alderney Race affects whether changes to flows around the South Banks were or were not significantly affected, and therefore, the significance of any potential effect on sediment dynamics. Bryden & Couch (2006) suggested that in an idealised simulation case 10% of the raw tidal energy flux could be extracted without undue modifications to flow characteristics. Estimations of the limit of percentage energy extraction before any significant alteration to flow speeds and environmental effects occur (the *Significant Impact Factor (SIF))* for several potential tidal stream sites around the UK were detailed by a Carbon Trust study (2005) (see Table 5.12).

Table 5.12: Modelled acceptable limit of percentage energy extraction from specific UK tidal resource areas before environmental effects become significant (SIF) and associated reductions in velocity as a result of extracting this much energy.

Site	Regional Sea	Velocity change (%)	SIF(%)
Pentland Skerries	8	15	20
Stroma, Pentland Firth	8	15	20
Duncansby Head, Pentland Firth	8	15	20
Casquets, Channel Islands	-	10	8
S. Ronaldsay, Pentland Firth	8	15	20
Hoy, Pentland Firth	8	15	20
Race of Alderney, Channel Islands	-	10	12
S. Ronaldsay, Pentland Skerries	8	15	20
Rathlin Island	7	10	8
Mull of Galloway	6	10	12

Source: Carbon Trust (2005)

Values for the limit of SIF are shown to vary with physical location, with inter island channels, open sea sites and headlands having a value of 10-20%, sea lochs a value of 50% and resonant estuaries values of <10% (Carbon Trust 2005). These values are based on theoretical modelling and still have to be validated against physical measurements. SIF values have been built into power estimates for several tidal stream sites around the UK, with a SIF of 20% used to estimate resource extraction capacity for 4 sites in Pembrokeshire totalling a 1,265GWh annually (Fairley *et al.* 2011). There have, however, been assertions that the theoretical resource and therefore environmental effects of extracting kinetic power are unrelated to cross-sectional kinetic power (Garrett & Cummins 2008) and therefore these SIF values should be treated with caution.

De Dominicis *et al.* (2018) modelled the far field effects of ten tidal arrays in Scottish waters around Orkney, the west coast of Scotland and Shetland along with “worst case” climate change effects on hydrodynamics to 2050, using the Scottish Shelf Model (SSM, Wolf *et al.* 2016). Climatologically averaged conditions from 1990 to 2014 were used to represent the present, validated with observed water level and current data from the NW European Shelf and just over the shelf edge. The HadGEM2-ES, a coupled Earth System Model was forced using the RCP8.5[152] “business as usual” scenario and used with the SSM to represent the future climate. Changes in mean spring currents were found to be in the order of a few cm/s. A dipole velocity change was evident upstream and downstream of the Pentland Firth, with the change in velocity downstream being greatest at up to 8%. This was also seen for west coast arrays, though with a more localised effect, and an increase in speed in northern Orkney waters due to blockage effects of flow in the Pentland Firth (Figure 5.15). A decrease in tidal range leads to a small reduction in current along the east coast, and conversely, an increase in currents were identified at the northern and southern entrance to the Irish Sea as a result of enhanced tidal range. These patterns of change were not identified to be substantially different under the future climate change scenario, with the effects of both found not to substantially overlap or interact (Figure 5.15).

Wake effect

Despite the significant reduction in current velocities associated with energy extraction, several studies have shown that this is restricted to the area within the tidal array and in the near-field (Ahmadian *et al.* 2012, Robins *et al.* 2014, Thiébot *et al*. 2015, Tidal Ventures 2015). The extent of the wake effect from a single device or array associated with physical diversion or deflection of flow around a device has been modelled to extend significantly further than the area impacted by energy removal. For single devices it has been modelled to extend ~500m downstream of the 16m rotor diameter device in Strangford Lough (larger on flood over ebb tide), 30 times the width of the turbine blades. This effect is far smaller for the open water 11m rotor diameter Seaflow device off Lynmouth; 167m long wake effect, 15 times the blade diameter (RPS 2005, Faber Maunsell & Metoc 2007). For the 10MW Ramsey Sound array (27 turbines) this extends to 4km downstream (Haverson *et al*. 2014) which was similarly found for a 5% reduction in the S2 amplitude, but extended up to 12km at a 2% reduction, up to 10km for a 300MW array in Alderney Race (Neill *et al*. 2012) and 10-20km from a large array in the open Celtic Sea (Shapiro 2011). This highlights the variability in physical effects with number of devices and geographical setting, with the most noticeable influences expected in estuarine and

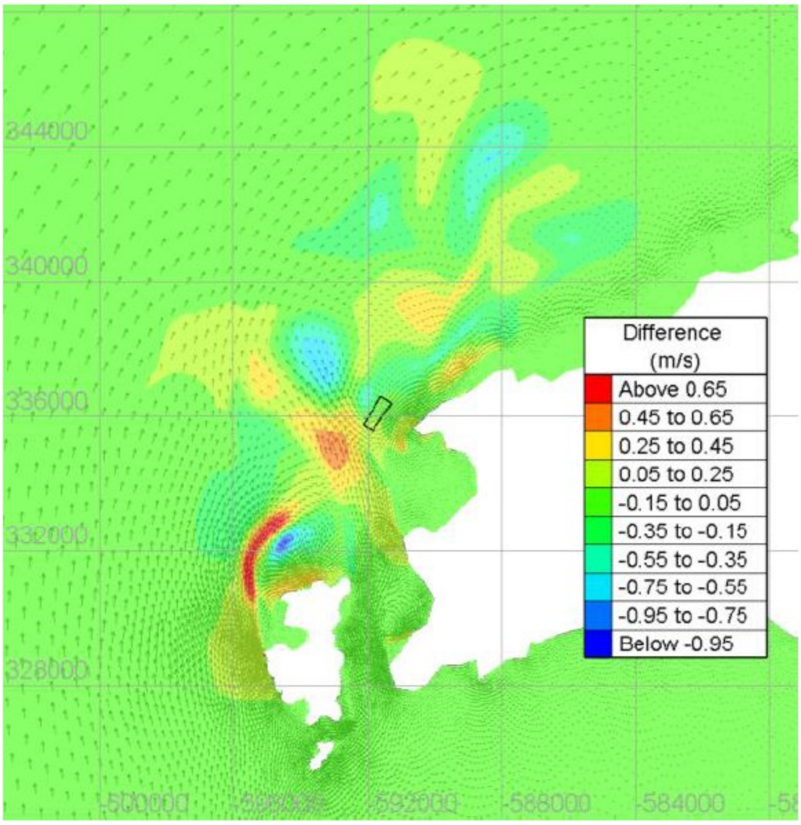
[152] See Section 5.12 and Appendix 1f for an explanation of Representative Concentration Pathway (RCP) and other scenarios used by the IPCC and others in projecting climate change.

narrow channel conditions rather than open water or energetic channels already strongly influenced by waves and currents.

Turbulence

The reduction in current velocities in the wake of a device will increase eddy formation and associated turbulence and affect both sediment deposition and erosion, and water column turbidity. Whilst this is clearly seen in modelling studies (e.g. Churchfield *et al.* 2013, Masters *et al*. 2013) real energetic tidal channels are turbulent even without tidal devices and the nature of that flow will be far more complex than those represented in modelling studies. Understanding short term variations in velocities resulting from turbulence and wave-current interactions are essential for proper evaluation of impacts from devices (Shields *et al.* 2011), with *in situ* measurements at the EMEC tidal stream test site in Orkney showing complex turbulent flow, with enhanced turbulent kinetic energy near the seabed (Osalusi *et al.* 2009). Modelling of a 10MW array of 27 turbines in the Ramsay Sound, Pembrokeshire (Haverson *et al*. 2014), shows how although the wake effect only extended 4km downstream of the array, it directly influenced an area of eddy formation on the northern tip of Ramsey Island. This produced a shift in hydrodynamics and a change in propagation of the eddies, which in turn affected propagation of eddies forming off the Bishops and Clerks to the west of Ramsay Island (Figure 5.16). As a result there were simulated large scale variations in hydrodynamics in the area extending over 10 times further than the direct wake of the array. A later study on a Ramsey Sound array was undertaken by Haverson *et al.* (2018) using the Telemac 2D model. It modelled a similar 10MW array of 9 devices with 27 rotors based on the TEL DeltaStream device at the same location as Haverson *et al.* (2014), with an assumed layout of three rows of three devices. The range of far field effects from the turbines was represented by the normalised range of difference, calculated by subtracting the magnitude of velocity at each node of the model mesh including the tidal array from that representing the base case at each time step. The “zone of influence” delineated by a 5% change extends between 19km and 24km in the east and south respectively.

Figure 5.16: Changes to current speed and eddy propagation from a tidal array in Ramsey Sound



Notes: Black box denotes extent of the 10MW tidal array, consisting of 27 turbines with 18m rotor blades. Scale relates to velocity difference between model runs with and without the tidal array. Source: Haverson *et al.* (2014)

Turbulence and tidal currents also play a key role in determining the location of seasonal shelf fronts, through tidal stirring and mixing of the water column (Woolf *et al.* 2014). Any changes to hydrodynamics may cause mixing in areas of strongly defined salinity or temperature gradients and promote both potential deposition of sediments in areas of reduced velocity and possible re-suspension in areas of turbulence within the wake. A reduction in thermal or salinity based stratification will have an additional effect on nutrient distribution within the water column within the immediate area. This will potentially have a knock-on effect on the food chain, with reduced stratification and increased mixing potentially affecting primary production and larval settlement, although probably on a localised scale and in relation to larger arrays of devices. Enhanced turbulence and vertical mixing may also lead to higher bottom dissolved oxygen which in some circumstances could reduce hypoxia where this is present (Neill *et al.* 2021). In the far field, de Dominicis *et al.* (2018) modelled potential changes in shelf stratification from the deployment of ten tidal arrays in Scottish waters and indicated that the extraction of energy by tidal turbines increased the strength of stratification mostly along the UK’s east coast and off north east Scotland towards Norway and did not result in a significant change in the locations of fronts. It was also found that when taken in combination with climate change related effects, those alterations by tidal turbines were an order of magnitude smaller than those projected under the climate change scenario.

Alterations in turbulence may also affect the feeding behaviour of some seabirds, particularly terns (ICES 2010). Predictions of turbulence from tidal range arrays is challenging to model, as it requires an understanding of the interaction of turbulence from multiple devices on antecedent turbulent conditions, which are spatially variable and linked to local topography and influenced by wind and wave conditions (Neill *et al.* 2021).

Sediment dynamics

Neill & Hashemi (2018) (cited in Coles *et al.* 2021) note that the transport of sediment is approximately related to the cube of the current speed such that a modest change in velocity can result in a significant change in sediment dynamics. It is suggested that even in areas without a local source of sediment supply, tidal devices impact sediment transport and morphodynamics. Neill *et al.* (2009) demonstrated that energy extraction in a relatively long channel with tidal asymmetry produces up to 20% more bed level change associated with sediment movement than in a site with tidal symmetry. They also suggested that the presence of a tidal stream array in a different location may actually reduce the magnitude of bed level change relative to a natural system due to the general reduction in tidal velocity and hence sediment transport. Monitoring of the ambient velocity field beyond the near-field wake and flow direction for the SeaGen Turbine in Strangford Lough showed no evidence of significant deviation from pre-deployment values, suggesting limited impact on flow dynamics, scour patterns or turbulence characteristics (Royal Haskoning 2011). This highlights the site specific nature of impacts.

Modelling of the impact of a large (300MW) array in the western side of the Alderney Race on headland sandbanks for several scenarios showed that energy extraction of this magnitude could have significant impact on the morphology of local sandbanks (a 10% difference in bed level change over a spring-neap cycle relative to the baseline) (Neill *et al*. 2012). However, careful siting of the array could mitigate some of this impact. Additional modelling on the eastern edge of the Race (290MW array) showed a change in mass balance between the sediment deposited in the eastern and western parts of the English Channel, peaking at 20% for the particles with the greatest erosion threshold (Thiébot *et al*. 2015).

In comparison, only small differences in sediment transport were seen in modelling of an 86 tidal turbine array in the Inner Sound, Pentland Firth (MeyGen 2012) with no evidence of net bedload transport away from existing bedforms. This is supported by Robins *et al.* (2014) who found that for smaller arrays (<50MW) off the northwest coast of Anglesey the impact of energy extraction on bed shear stress and sediment transport was less than the natural variability. However, for larger arrays (>50MW) significant impacts were observed, although they did not extend to affecting sand banks 10km away. This difference in impact related to array size is also seen in simulations for the Pentland Firth (arrays composed of 0-400 turbines), where arrays larger than 85 turbines affect bed shear stress distributions and the movement of sediment accumulation from the edges of the Inner Sound of Stroma towards the centre (Martin-Short *et al.* 2015). Relatively minor changes in sediment accumulation occur at arrays with <85 turbines, whilst deposits of fine gravel and sand within the array develop at arrays >240 turbines. The reduction in flow velocities within the Inner Sound appeared to have implications for sediment transport elsewhere within the Pentland Firth, although an exact pattern was hard to distinguish.

The modelling of Haverson *et al.* (2018) indicated that changes to sediment transport from a 10MW array in Ramsey Sound would be subtle, with a greater accumulation of medium gravel within the array and in 1km of its wake on the flood, and fine gravel within and 3km downstream of the array on the ebb with coarse sand accumulating north of Ramsey Island, but current speeds in the sound are unlikely to result in deposition of material finer than coarse gravel. The absence of fine sediment in and around the array would likely mean that local changes are not likely, but far-field effects in less energetic areas may be more pronounced. The authors note that the largest impact of the array may be on net sediment transport, but caution is urged in the interpretation of the modelled outputs. For example, the study used a depth-averaged model which will not reflect changes in vertical profile brought about by the turbines, and does not include other factors such as atmospheric forcing or wave driven currents. The authors note that while the results may not allow for a quantitative interpretation, 2D modelling can be useful for a pragmatic and cost-effective initial appraisal of the potential effects of a tidal array before more complex 3D models are used.

Such potential far field effects are also seen in an array of 2,000 turbines in a 7.2km^2 area of the Bristol Channel. Ahmadian *et al*. (2012) showed decreases to suspended sediment concentrations both upstream and downstream of the array and an increase to the sides, up to 15km away. However, a study in the open Celtic Sea north of Cornwall suggests potential impacts up to 100km from an array (Shapiro 2011) This highlights both the site specific nature of impacts due to the range of hydrodynamic, bathymetric and sedimentary properties of the sites and the size of the array.

Flow diversion

The presence of a tidal stream device within the water column will also accelerate velocities around the structure, although in open water cases the impact on far-field areas is suggested by modelling evidence to be negligible (Walkington & Burrows 2009). Modelling of the SeaGen device in Strangford Lough showed flow acceleration around the device extending 250m on either side as far as the shore (RPS 2005). In this case the substrate, composed of rock and coarse sand, is unlikely to be affected but softer sediment types in other locations will experience scour and where the increased flow impacts the shore, potential erosion effects are expected (Walkington & Burrows 2009). Modelling of an array of 400 turbines in the Pentland Firth shows that on flood tides significant velocity shear zones form to the sides of the array as peak flow velocities are diverted towards the edge of the Inner Sound of Stroma, with implications for sediment dynamics (Martin-Short *et al.* 2015). This is also shown at the MeyGen turbine site (Inner Sound, Pentland Firth) which shows an 0-1m/s velocity increase in the middle of the channel as a result of 86 turbines, with an increase of 0.1-0.8m/s to the north and south around the edges of the array (MeyGen 2012). Further wave refraction around devices also has the potential to affect coastal wave erosion especially in narrow and enclosed sites. Whilst increased velocities around single devices are localised, the blocking effect of arrays of devices within a channel or area does have the potential for impact, primarily associated with deflection. Modelling of the 100MW Torr Head tidal array site off Northern Ireland (Tidal Ventures 2015), shows that by removing energy from the water column the array deflects the region of high flow slightly further out into the North Channel, although the overall current flow does not change significantly.

Water levels

The extraction of energy, especially in enclosed sites, will also modify the water levels both upstream and downstream of the device, which would potentially have the effect of moving erosion up or down the coastal height profile. This is seen to be largely minimal at open water sites, e.g. 0.03% at Alderney Race for a 300MW array (Neill *et al.* 2012). Modelling work in the Solway Firth suggests that whilst the effects on maximum water levels of a tidal array are not significant, low tide levels would potentially be affected with the intertidal area covered for a greater period of time (Garcia-Oliva *et al.* 2014). A review by Neill *et al.* (2021) noted that most studies on water levels indicated only a small effect, for example a 3D model of a 115 turbine array in the Zhoushan Archipelago, China, found water levels changed ±3cm relative to the reference scenario of (Zhang *et al.* 2020), and similarly, Yang *et al.* (2015) noted a change of less than 1cm for a 100 turbine array in Tacoma Narrows, USA. It was also noted that some studies did suggest noticeable changes in levels and in particular where tidal flats were present in the system or when tidal phase was affected. This would have ecological implications for benthic habitats and species using the intertidal area.

5.5.2.2 Tidal Range

Tidal range devices, both barrages and lagoons, may have a large impact on the energy balance of the local environment and wider region. Barrages not only remove energy from the water column at a single point but also affect velocities across the whole channel and upstream and downstream of the installation. Due to the nature of a barrage it is difficult to separate out changes in hydrography due to energy extraction and those caused by physical constriction and restriction of flow by the barrage itself. The impacts and effects of both the changes in down and across-stream current velocities and sediment transport patterns are considered below. With only a few operating tidal barrages in the world (e.g. La Rance, France), the majority of assessments of impacts are based on modelled simulations, whilst tidal lagoons are still in their infancy and have not been widely studied.

Velocity changes

The presence of a barrage or lagoon will restrict the flow of water affecting both the mean water level within a basin and causing a decrease in tidal current speed. Dual mode of operation of turbines is thought to have less severe impacts than the single flood or ebb generation modes (Ward *et al.* 2012). Several studies have modelled the impacts of different barrage options within the Severn Estuary on velocity and water characteristics (e.g. Falconer *et al.* 2009*,* Xia *et al.* 2010, Kadiri *et al.* 2012). Figure 5.17a,b shows the predicted changes in maximum tidal current velocities with and without a Cardiff to Weston-super-Mare Severn barrage (Falconer *et al*. 2009), and illustrates the large impact of a barrage on the flow of water through the estuary. The figure clearly shows that upstream of the barrage there is a significant reduction in current velocities, predominantly in the main channel, with similar reductions seaward of the barrage in the main channel and across large areas of the estuary as a whole. Subsequent 2D and 3D modelling (Zhou *et al*. 2014a) shows a very similar pattern with a reduction in velocity due to the barrage of up to 50% in some areas. Whilst the centre of the Bristol Channel has a reduction in maximum velocity from 2.4m/s without a barrage to 1.2m/s with a barrage, the area around the sluice gates and turbines shows much greater velocities due to barrage operation. Investigation into the impacts of different operating modes of a Cardiff to Weston-super-Mare barrage (Ahmadian *et al.* 2014a) show that the reduction in maximum velocity downstream of the barrage would be greater for a two-way generation scheme (>0.75m/s) than for an ebb only generation scheme (0.5m/s). Conversely the ebb only generation scheme produced a greater reduction in upstream velocity (0.5m/s) than the two-way generation scheme (0.25m/s). The operation of a barrage also causes a shift and a time lag in the ebb and flow velocities due to the holding phase.

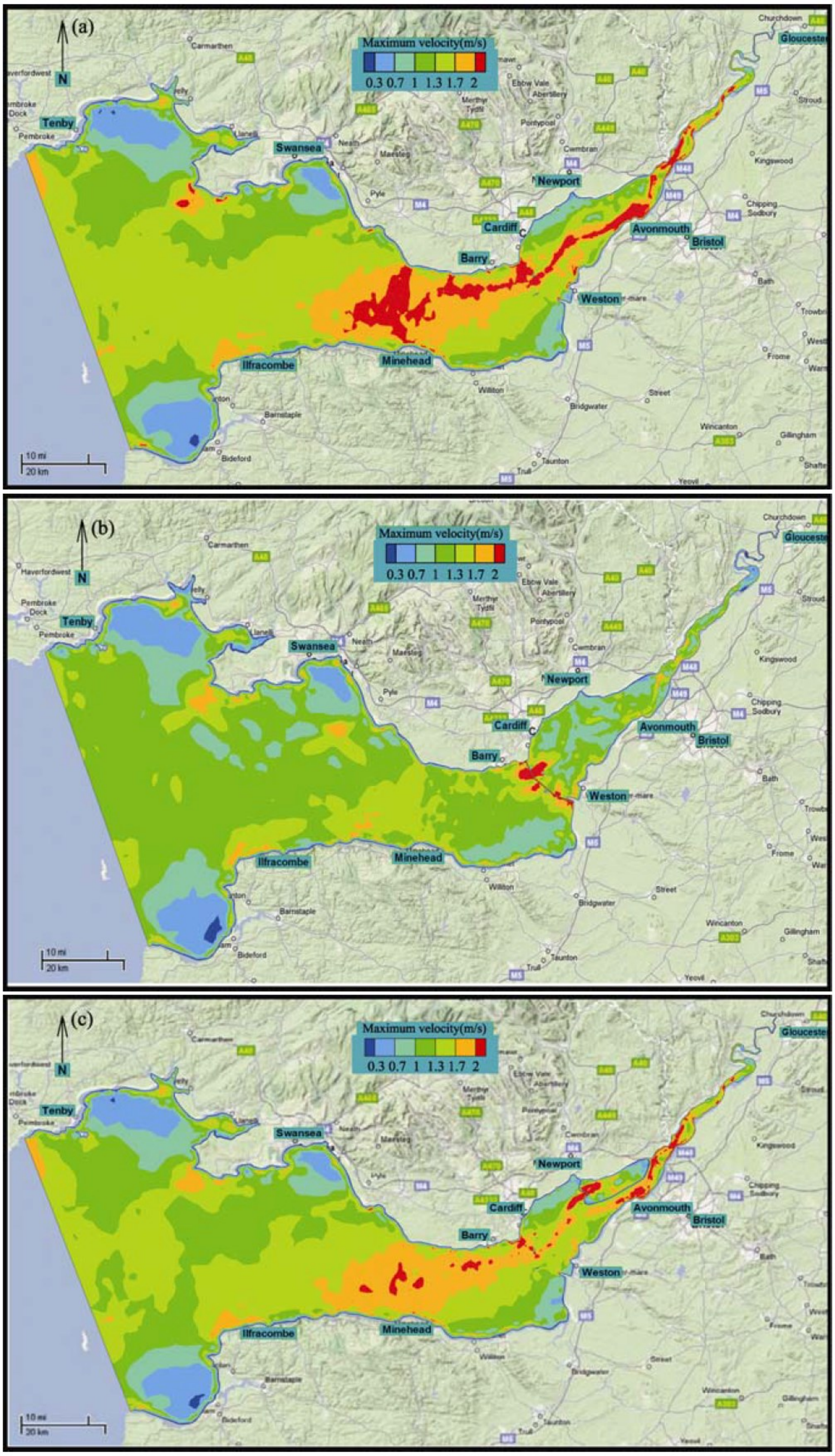
Additional studies corroborate the pattern and scale of likely impacts from a Cardiff to Weston-super-Mare barrage with: a 20% reduction in upstream velocity and an 18% and 30% reduction in tidal amplitude for the M_2 and S_2 components respectively and a 17% decrease in tidal velocity downstream of the barrage (Ward *et al*. 2012); a 1.4m decrease in upstream water levels and a 0.5m/s decrease in velocity (Ahmadian *et al.* 2014b); a decrease in current speed downstream of the barrage from 2.0m/s to 1.4m/s and a decrease in water levels downstream of a barrage of 0.5m and upstream of 0.5-2m (Kadiri *et al.* 2012). A 40% reduction in tidal velocity over tidal shoals and salt marshes and a 20-40% decrease of velocity in tidal channels has also been measured at the Oosterschelde storm surge barrier, Netherlands (Louters *et al.* 1998) with similar reductions measured at La Rance in France (Kirby & Retière 2009).

In addition, the duration of slack water at La Rance has increased from 15 minutes to 2 hours since the barrage has been in operation, with the volume of water exchanged with the sea reduced by 30%. Strong local currents in potentially complex patterns form around a barrage itself, with an obvious increase in the region of the turbines and sluices (Figure Figure 5.17b; Xia *et al.* 2010, Retière 1994).

Whilst the impacts from the Cardiff to Weston-super-Mare barrage have been relatively extensively considered, less work has been undertaken on identifying impacts from other tidal range options within the wider Severn Estuary. Figure 5.17c shows the impact on maximum spring tidal currents of the Fleming lagoon, between Newport and the Severn road crossing. It shows that velocity changes are not as extreme as for the full barrage option, with a decrease upstream of the lagoon and a minor decrease downstream. In the case of water levels a decrease of only 0.2-0.5m upstream of the lagoon would be expected, compared to 0.5-2m for a barrage, with no significant impact downstream (Falconer *et al*. 2009). The construction of the lagoon would therefore only slightly reduce the flood risk upstream but would have far less impact on the loss of intertidal mudflats.

Numerical modelling of the impact of the Swansea Bay tidal lagoon project on mean spring tidal flows shows smaller spatial scale impacts, with changes largely restricted to Swansea Bay. The greatest changes are in the vicinity of the sluice gates/turbines (over 100% increase from baseline within 225m), decreasing with distance to around 5-20% at 2.3km from the turbines, with the variation related to 'jetting' from the turbines. This jetting is caused by a rapid increase in flow speeds approximately 3hrs after high water when the turbine gates are opened, with flow speeds of 1.7-1.9m/s compared to 0.45m/s for the baseline conditions. Just after low water, ebb flows are further accelerated when the sluice gates are opened to further drain the lagoon, with peak flow speeds of up to 3m/s for a short duration (15 minutes). Although these changes in flow speeds are relatively short in duration and spatial extent they are significant in magnitude and can be expected to have an impact on the sediment patterns of the area. Reductions in flow of typically <40% are seen within the Swansea Bay lagoon, peaking at 80% at the far eastern side, with additional decreases in flow seen to the west of the Bay probably as a result of the physical presence of the lagoon rather than energy removal. A modelling study (Ma & Adcock 2020) found that the Swansea Bay lagoon would have almost no effect on hydrodynamics of the wider region of the Severn and Bristol Channel, though noted there would likely be significant local changes (e.g. as described above), similarly concluded by Angeloudis & Falconer (2017).

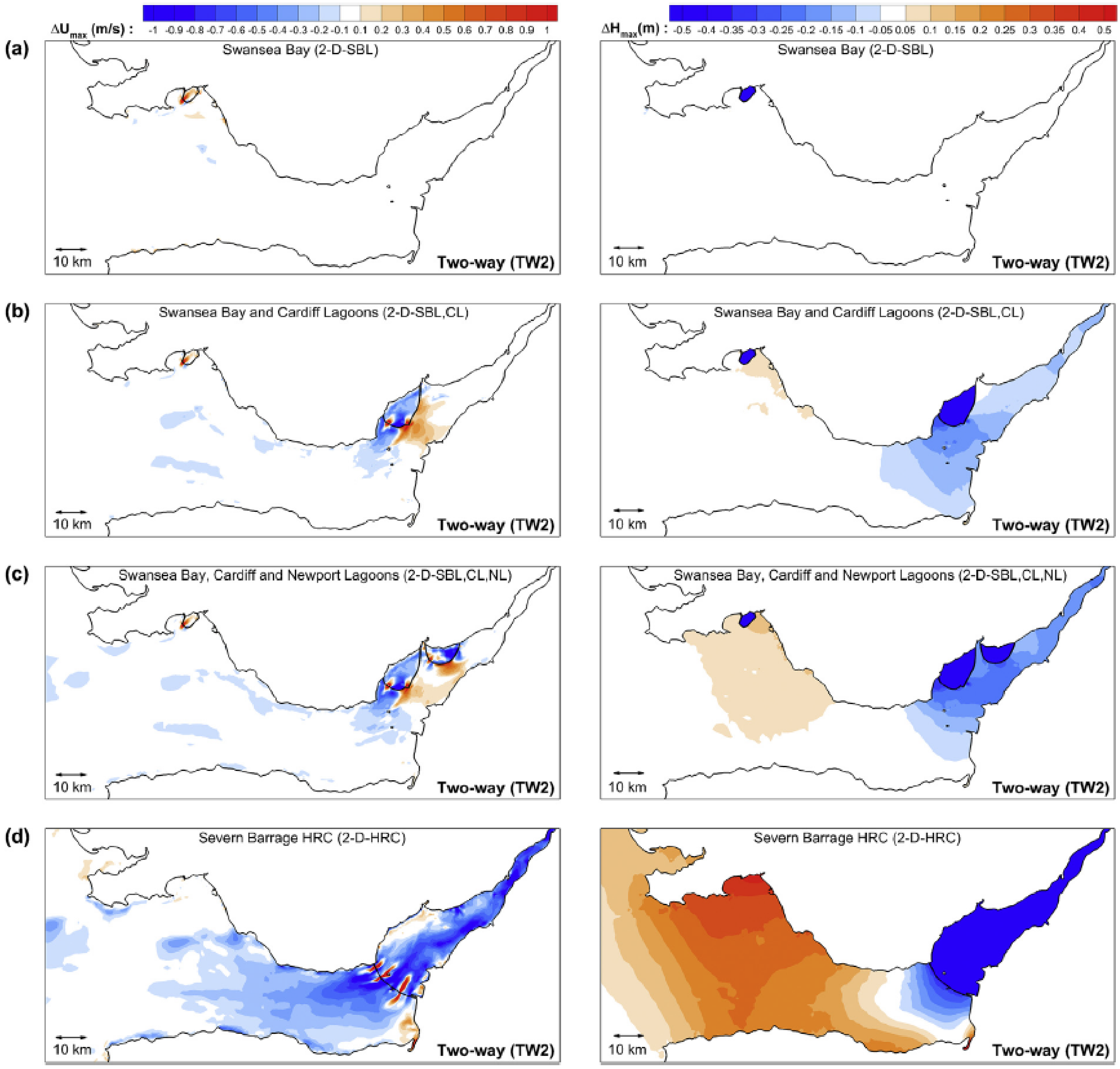
Figure 5.17: Modelling comparison of maximum spring tidal currents (a) no scheme, (b) Cardiff to Weston-super-Mare barrage, (c) Flemming lagoon



Source: Falconer *et al.* (2009)

Angeloudis & Falconer (2017) also modelled a range of lagoons (Swansea Bay, Cardiff, Newport), and two versions of the Cardiff to Weston-super-Mare barrage which included a consideration of the combined effects of lagoon deployment on the Severn (Figure 5.18). As noted above, while Swansea Bay showed limited hydrodynamic changes other than locally around the sluice, the larger impoundments of Cardiff and Newport generated more significant changes, with current accelerations in the central channel of the Severn and significant flow reductions within the lagoons, along with marked changes in water levels of 0.25m during spring tides from the operation of all three lagoons, however, the changes are significantly less than a tidal barrage (an increase of 0.3-0.4m in the Severn and a reduction of up to 4m upstream of the barrage close to Avonmouth. The operational mode (e.g. ebb only, conservative vs. optimised two-way) of the lagoons was noted to influence the hydrodynamic changes and also intertidal area loss, with ebb-only generation estimated to result in significantly more intertidal area being lost than two-way generation.

Figure 5.18: Cumulative impact of tidal lagoons and barrage on maximum velocities (left) and maximum water levels (right) under a conservative two-way operation

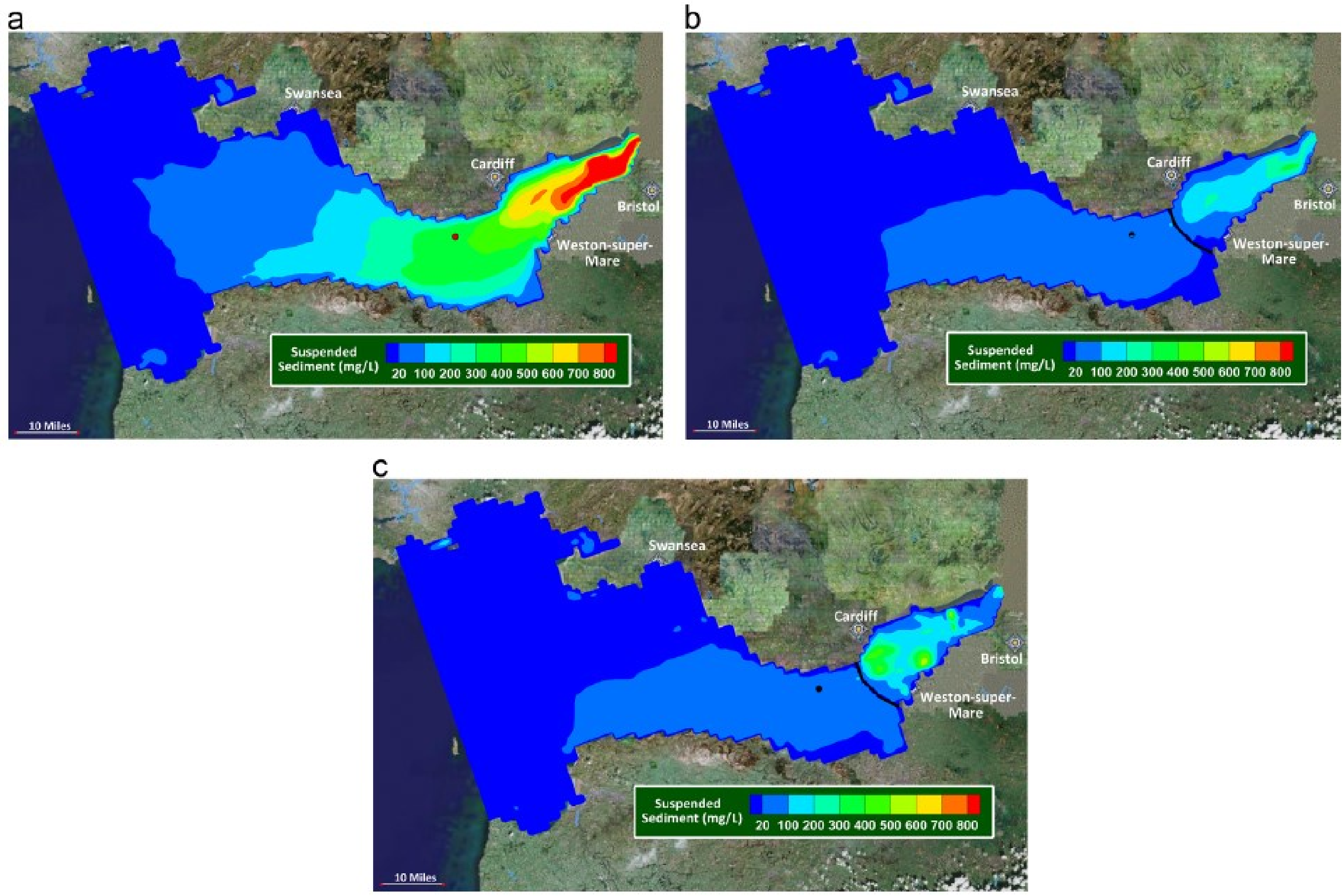


Source: Angeloudis & Falconer (2017)

Turbulence and sediment dynamics

Areas of large tidal range tend to be areas with high current velocities and as such generally have high suspended sediment loads, low levels of light penetration into the water column and therefore low primary productivity and dissolved oxygen concentrations. Even small changes in current speeds may have large implications, as the energy within a tidal flow is proportional to the cube of the velocity. Modelling of the Severn barrage shows a decrease in upstream suspended sediment concentrations from 1200 mg/l without a barrage to 200 mg/l after construction (Kadiri *et al*. 2012), although two-way generation slightly reduced the level of this decrease compared to ebb only generation (Figure 5.19; Ahmadian *et al*. 2014a). This significant reduction in suspended sediment concentration may increase primary productivity in the water column (through increased light penetration, and assuming equivalent nutrient fluxes), with associated effects on the ecosystem function as a whole. Simulated reductions in bottom shear stress due to reduced downstream velocities throughout the Bristol Channel, also means that the water column would become less turbid, also allowing more light penetration and increased productivity (Wolf *et al.* 2009). Greater benthic biodiversity was suggested as a result of decreased velocities at the sea bed (Kirby & Retière 2007).

Figure 5.19: Predicted suspended sediment levels at high water spring tide at Barry (a) without barrage, (b) with ebb only generation barrage, (c) with two-way generation barrage



Notes: Barry is represented by black dot. Source: Ahmadian *et al.* (2014a)

A large build up of sediment is expected upstream of any barrage, calculated for a Cardiff to Weston-super-Mare barrage to be around 8.2M tonnes compared with 1.2M tonnes downstream (DECC 2010e). Calculations suggest a reduced variability in deposited sediment mass from spring to neap tide of 3M tonnes after construction of a Cardiff to Weston-super-Mare barrage compared with 5.4M tonnes under existing conditions (DECC 2010e), with rapid accumulations of up to 2m in deep channel regions. The calculated reduction in the mobile sediment load was by a factor of between 2 and 3 (DECC 2010e), illustrating the large amount of sediment deposition and significant changes in bed profile, geomorphology and habitat types that would result from the construction of a barrage. Decreased velocities and increased sediment deposition upstream of a barrage would increase water clarity and increase phytoplankton derived primary production (Underwood 2010) It is likely however, that basin wide erosion will vastly exceed accretion (as in the Eastern Schelde (Pethick *et al.* 2009)) with accretion occurring in sheltered locations, areas local to regions of erosion or tributary mouths (DECC 2010e), the barrage itself and main channels, with mudflats and sandbars experiencing high levels of flattening and erosion. The simulated large changes to tidal dynamics especially upstream of a barrage could also increase stratification and reduce flushing rates, increasing the eutrophication risk (Burrows *et al.* 2009, Wolf *et al.* 2009, Frid *et al.* 2012).

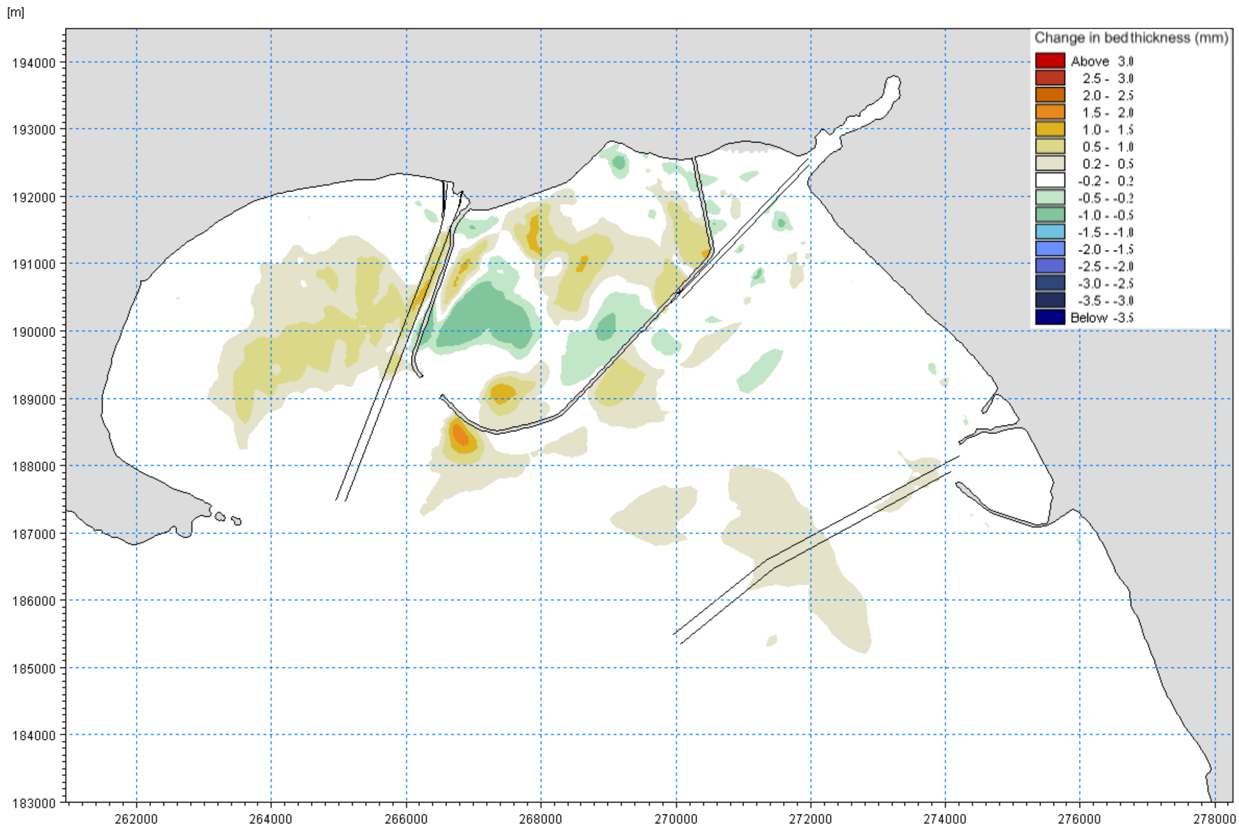
The transport of fluid mud in the Severn Estuary upstream of a barrage, which has important biological and chemical implications, would largely stop due to the reduction in current velocities. It is calculated that up to 2.5m of fluid mud could therefore be deposited in channels, which will compact to a mud bed layer about 0.3m thick (Kirby 2010). As a result of fine sediment deposition upstream of a barrage, sediment starvation may occur downstream affecting salt marsh development, allowing a further increase in erosion through greater wave propagation to the upper shore (Pethick *et al.* 2009). Presently the upper estuary has extensive sand distribution due to the high tidal flows (Underwood 2010), which would become increasingly silty with the deposition of finer sediments, changing the biotope and therefore the communities inhabiting the area. The low species richness and biomass of the present Severn Estuary, characterised by boring bivalves and species such as *Hydrobia ulvae*, *Macoma balthica* and *Nephtys hombergii* in the muds, and *Bathyporeia spp*. in the sands (Warwick & Somerfield 2010), could potentially change to one with increasing populations of deposit feeding or filter feeding invertebrates (Underwood 2010).

In addition, the constraint of flow through a barrage will lead to turbulent flows and increased mixing immediately downstream during outflow and immediately upstream during inflow. This would lead to highly turbid conditions and low primary productivity in the near-field, increasing the spatial complexity of response of the area to a barrage.

In the long term an estuary would adapt geomorphologically to a new regime leading to modified flow conditions. Calculations of a timescale for this readjustment for the Severn Estuary are in the order of 1,500 years (Pethick *et al.* 2009), a similar value was given for the Oosterschelde tidal barrier (Louters *et al.* 1998), which suggests 1 or 2 magnitudes larger than the two decades it took for the system to adapt to the closure of two small dams. The huge scale of these effects and their potential complexity combined with natural variations in the physical conditions of locations means that individual estuaries/river basins will respond differently to the construction of a barrage. The effects of climate change for example on sea level and increased storminess will add further complexity. As a result, detailed site specific data gathering and assessment should be undertaken before any decisions on suitability of the area for construction are taken.

In terms of tidal lagoons, the effects of water impoundment are largely the same but on a more localised scale than those of tidal barrages. The presence of a tidal lagoon within Swansea Bay is seen to significantly alter the residual tidal flows within the bay (Tidal Lagoon Swansea Bay 2013a), with resulting impact on sediment dynamics. Figure 5.20 shows predicted changes to mud deposition over a spring tidal cycle within Swansea Bay compared to the baseline, with changes largely restricted to within the lagoon and wider bay. Changes in sediment dynamics are largely driven by reductions in flow speeds resulting from the physical presence of the lagoon and from increased mobilisation of sediments in areas due to jetting. Modelling identified a reduction in cross bay sand transport during storm events and a possible increase in sand deposition at the entrance to Neath due to a reduction in wave height.

Figure 5.20: Predicted changes to mud deposition during a 10 in 1 year storm event in Swansea Bay due to a tidal lagoon



Source: Tidal Lagoon Swansea Bay (2013a)

Salinity and temperature

Due to the presence of a barrage there would be reduced penetration of saline water into a basin leading to freshening, i.e. more brackish water (Wolf *et al*. 2009). Initial modelling on the Cardiff to Weston-super-Mare barrage (Zhou *et al.* 2014a) shows that the salinity concentration at high water for the area seaward of the middle of the Bristol Channel is unaffected. However, the salinity concentration would decrease by 1-2psu immediately upstream and downstream of the barrage, with a dominance of freshwater inputs as the river narrows upstream of the barrage (up to 5psu decrease between Beachley and Sharpness). The salinity concentrations are seen as relatively stable upstream and downstream of the barrage with only a small variation, suggesting that a barrage can reduce salt intrusion upstream. These changes in salinity would have implications for the extent to which marine species are able to penetrate the estuary, with implication for their local abundance. Reedbeds may also replace saltmarshes if the influence of freshwater extends further down an estuary (Hooper & Austin 2013). There may be minor changes to upstream temperatures associated with a barrage, although these are expected to be within the range of natural variability (>1ºC) and are therefore considered not significant (DECC 2010e).

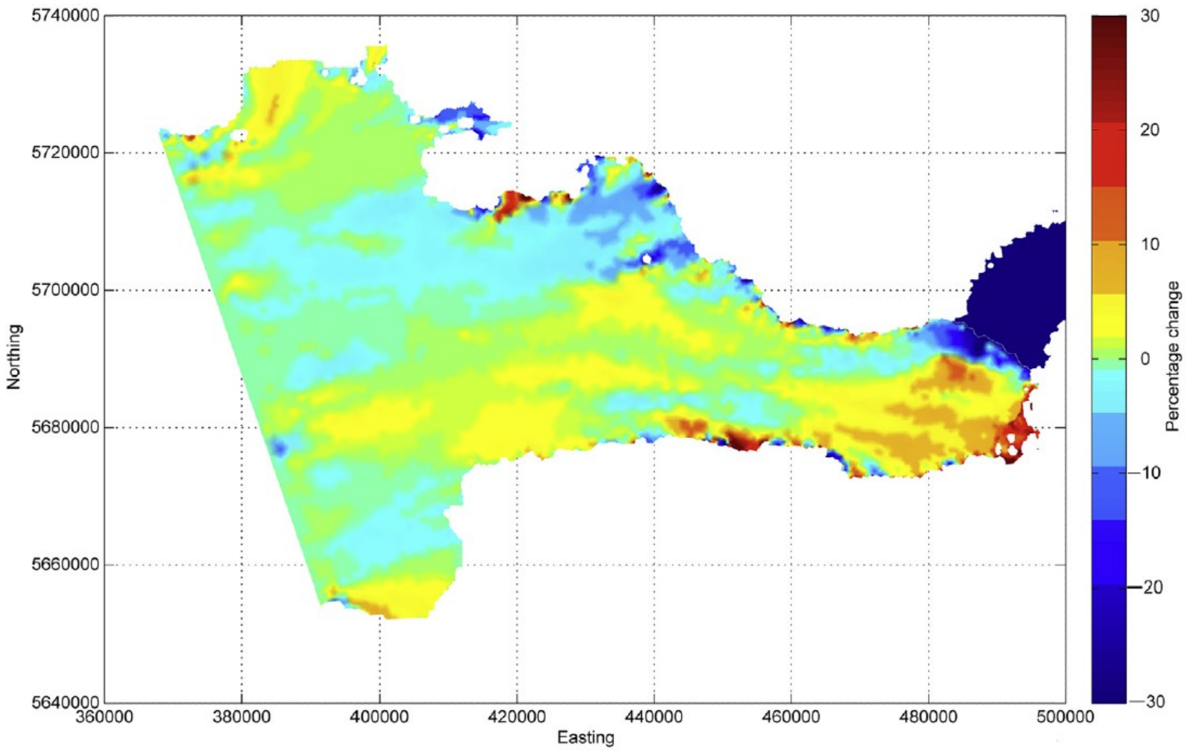
A reduction or change in circulation associated with tidal lagoons may be expected to affect temperature and salinity. The Swansea Bay Tidal Lagoon project (Tidal Lagoon Swansea Bay 2013b) shows that summer temperatures are largely unaffected by the lagoon, with a marginal increase in winter temperatures within the bay (0.1-0.75ºC) and the lagoon (0.5-1ºC). As with the barrage, these are within expected annual variability and are therefore not seen as significant. In terms of salinity, the lagoon would cause a change in salinity of 1-5psu within the bay with the greatest change in the shallower areas. This is due to displacement of the river plumes and increase in entrainment of offshore water into the western bay. Within the lagoon the salinity remains relatively stable at 25-30psu, compared to 15-30psu for the baseline. Again these changes fall within the range of natural variability of the bay area and are therefore also not seen as significant.

Wave Conditions

As has been shown, barrages affect tidal currents and water elevations in the wider area. In the Severn Estuary there is strong tidal modulation of the wave climate and therefore the presence of a barrage may affect the local wave climate, with impact on erosion and flooding. A study on the impact of the Cardiff to Weston-super-Mare barrage on wave climate of the area (Fairley *et al*. 2014) showed that over one spring tidal cycle (Figure 5.21) in general the changes to the wave climate were within ±5% of the pre-barrage values. There were however, localised areas of greater increase (by >10%) around the north Somerset coast between Minehead and Weston-super-Mare, Tenby, west of Bideford and the south Gower coast. The latter is due to a reduction in the tidal race around the headland which produces wave dissipation and blocking. The main area of decrease (apart from upstream of the barrage) is in the wider Swansea Bay area. Whilst the sum of wave height over the tidal cycle is higher in some areas, the maximum significant wave height in these areas does not increase post barrage. Simulations for the neap tide show similar patterns, with a visibly larger increase in wave heights on the ebb rather than on the flood tide.

Modelling work on the Swansea Bay tidal lagoon shows that whilst impacts on the local wave climate also results from the lagoon development, they are very localised and do not extend outside the bay area.

Figure 5.21: Percentage change to wave height over one spring tidal cycle from a Cardiff to Weston-super-Mare barrage



Source: Fairley et al. (2014)

Far-field effects

Most of the impacts of a tidal barrage have been identified and investigated through modelling, using the same open boundary conditions for pre and post barrage simulations. In the Severn Estuary the disturbance to the tidal regime from the barrage is likely to propagate far from the barrage and affect the boundary conditions of a model if the computational domain is not large enough. Zhou *et al*. (2014b) used two models to investigate far-field effects of a Severn barrage (Cardiff to Weston-super-Mare) with the open boundaries extending to cover the continental shelf in one and Celtic and Irish Seas in the other. The presence of a barrage increases tidal velocities within the wider Bristol Channel, with increases of 0.52m/s for a site in the centre of the Channel and 0.19m/s at the boundary of the channel. However, in regions of comparatively deeper water in the Celtic Sea the impact of a barrage on tidal velocities is seen to be negligible. There is however, a discernible far-field increase in maximum water depth over most of the Irish Sea, associated with a barrage. Cardigan Bay especially sees an increase of 4-7cm, peaking at 9cm in the north of the bay. Due to the obstruction of the barrage, the volume of water flowing into the Bristol Channel is reduced, forcing more water to flow into the Irish Sea, changing the resonance frequency of the Bristol Channel and Severn Estuary basin. In addition, Wolf *et al.* (2009) investigated the near and far-field impacts of barrages within 5 estuaries in the west of the Irish Sea. They showed a 10% increase in tidal amplitude along the east coast of Ireland which could have implications for flooding, although the increase was less than that of a 1 in 50 year storm surge event. This highlights a major issue of evaluating far-field impacts even for large installations such as a barrage. Measurements of tidal range, for example, are confounded by long-term natural changes such as isostatic rebound and climate variability, and isolating the far-field impact of a barrage from natural variability may not be statistically possible. Some other parameters, such as turbulent dissipation, would be even harder to measure in the real environment and therefore very difficult to assess at far-field scales. Noting these changes to resonant response are a potential cause of significant hydrodynamic change, Ma & Adcock (2020) indicate that for a Severn barrage approximately between Cardiff and Weston-super-Mare, appears to make little difference to the resonant response for frequencies close to the dominant semi-diurnal frequencies but the authors note that their study does not interpret the effect of this on hydrodynamics, sediment dynamics, and other changes of environmental concern.

These studies suggest that impacts on hydrodynamics may be seen at significant distances from barrages, with the need for large computational domains in modelling studies to better identify far-field effects. One of the regions evaluated for the siting of tidal stream devices and tidal lagoons is within a projected far-field area of velocity decrease due to the construction of a Cardiff to Weston-super-Mare barrage. This highlights the need to consider cumulative impacts of multiple energy devices on resource availability.

The fine sediment component of the Severn Estuary is predominantly from fluvial sources (Allen 1991) upstream of any barrage location. The alterations to sediment transport pathways associated with the building of a barrage may therefore have implications for the sediment balance of the wider area, with a reduction in inputs of finer, fluvial sediments which contribute to mud flats to the downstream region. The extent of the implications of this are currently unknown, but have the potential to extend to the far-field. In addition, the reduction in flushing rate of water upstream of a barrage and increased resident time would likely mean a reduction in nutrient dispersion throughout the estuary. This may also have implications for far-field nutrient concentrations if the estuary is a source for the wider area.

Climate change impacts

There is evidence that a rise in sea level, associated with climate change, may have significant impacts on the tides on the European shelf, changing the tidal amplitude by potentially tens of centimetres (Pickering *et al.* 2012, 2017). This would have implications for tidal range projects, especially barrages which have a long life span, although the same study suggested that response to climate change was very variable both spatially and in magnitude. Ward *et al.* (2012) modelled the impact of sea level rise and a tidal barrage in the Severn Estuary, and sea level rise and tidal devices in the Solway Firth and Morecambe Bay. They discovered that whilst the presence of a barrage in the Severn Estuary would reduce current velocities compared to present day, sea level rise of 2m combined with a barrage would actually increase velocities due to more water entering the Estuary. Sea levels also affected the spatial extent of impacts of energy extraction when there were multiple tidal plants in the Irish Sea.

Additional modelling work on the Severn Estuary (Ahmadian *et al.* 2014b) applying a lower sea level rise estimate of 0.48m showed that the presence of a barrage would reduce the water level rise upstream of the barrage by 0.18m so it would only experience a 0.3m rise compared to the 0.48m rise for the downstream part of the Estuary. This would reduce the flood risk associated with increased sea levels upstream of a barrage. The study also suggested that whilst building a barrage could reduce the intertidal mudflats in the estuary by 127km^2, a sea level rise of 0.48m by 2100 would reduce the mudflats by a further 41km^2 if a barrage was present. This would have significant ecological and environmental implications.

5.5.2.3 Wave

Wave devices remove energy from the wave train, potentially affecting water mixing properties in the near field, sediment transport in the near and far field, wave-current interaction and current power generation capacity of neighbouring areas. The interaction between waves diffracted by devices and the waves radiated by the motions of a device can also strongly affect both the power production and impact of an array (Borgarino *et al.* 2012). As with tidal stream and range technologies, the majority of studies on environmental impacts are based on modelling evidence (e.g. Folley *et al*. 2012) with few deployments of individual devices in the real environment. Modelling has tended to focus primarily on the impact of devices to wave fields, local wave climate and accurately representing wave devices in numerical models. Less work has been undertaken on the changes to sediment transport and morphological changes, although the use of wave devices for coastal defence has been focused on by some studies.

Wave height and wake effect

Reductions in simulated wave height immediately downstream of wave devices are modelled to be significant (e.g. around 45% for a device 10m wide and 160m long (Venugopal & Smith 2007)). However, this is not a reflection of the large absorption of energy by the device, it is predominantly due to the high level of diffraction of wave energy around the structure (calculated as 70% of the wave power for long-crested waves for the Wave Dragon device type (Beels *et al.* 2010)). This diffraction is seen as a small increase in wave height at the edge of the wake (Troch *et al.* 2010).

Variations in the maximum reduction in wave heights within the wake (with values ranging from 13–69% reduction (Venugopal & Smith 2007)) are also modelled to occur for different porosities of devices (how much energy they absorb) and different array sizes and shapes: 18% for an array of 25 devices (Troch *et al*. 2014) in the DHI Shallow Water Wave Basin as part of the WECwakes project; 30% for 11 devices arranged in 2 rows offshore Perranporth Beach, Cornwall at the WaveHub site (Abanandes *et al.* 2014).

Modelling of a row of 30 devices parallel to the shore off the Isle of Lewis (Figure 5.22) showed a 15% wave power reduction behind the devices, although the largest impact can be seen behind the southern end of the array due to incident wave direction (Greenwood *et al.* 2013). Figure 5.22b also shows that wave power reaches pre-device levels some 320m downstream of the array. Maximum wave power reduction values of 36-38% have been modelled for the immediate lee of the first row of 10 devices offshore NE Spain (Iglesias & Carballo 2014). By the second row of 10 devices (270m behind first array) the wave field had partially recovered through energy diffraction, with the second reduction in incident wave power lower at 17-18% at 500m. A slightly different pattern was shown by Abernandes *et al.* (2015) whereby the reduction in wave height actually peaked with the second row of devices in an array (50% reduction) with a secondary peak occurring 1.5km from the second row due to the merging of shadows caused by the first and second rows of devices. This highlights the importance of array spacing and shape on wake effects.

The size of the wake effect of a device will also be dependent on device shape and wave type, with wider but far shorter wakes observed for short-crested compared to long-crested waves. The wake effect of the device is reduced with distance due to wave diffraction and energy redistribution so that for short-crested waves modelling has shown that after 3km downstream from the device the wave height is the same as that in front of the device (Beels *et al.* 2010). However, for long-crested waves at 3km downstream only 70% of the initial wave height is recorded. Measurements in the Shallow Water Wave Basin (Stratigaki *et al*. 2014) shows that for an array of 25 turbines arranged in 5 rows of 5 devices a wave height decrease is seen after the first row of 5 devices in a sea state dominated by short-crested waves. A decrease in wave height is only seen after the 3rd row of devices for a sea state dominated by long-crested waves. Troch *et al.* (2010) confirmed that regeneration behind a wave device depends on the wave length, peak period and directional spreading of the incident wave climate, with the higher the peak period and directional spreading the faster the waves regenerate downstream of the device. Greenwood *et al.* (2013) suggest that there is a greater change in wave power outside of and within the wake of an array in winter due to more energetic wave conditions. Palha *et al*. (2010) also suggest that the percentage of wave energy extracted by a wave device exhibits seasonal variability, with the proportion of energy removed greatest in summer.

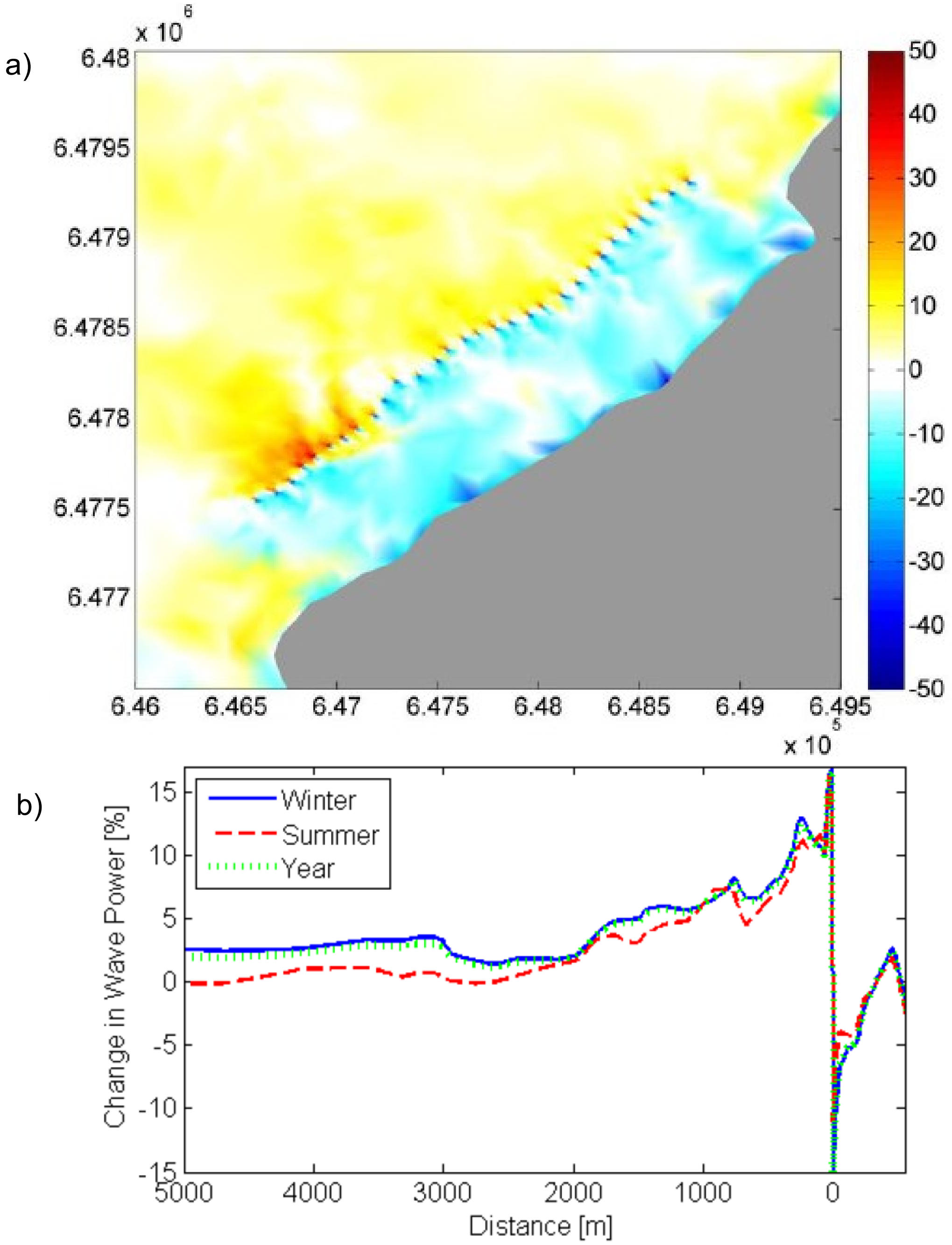
A local increase in wave height is also seen in front of devices (Beels *et al.* 2010), due to reflection, with calculations suggesting increases of up to 31% (Venugopal & Smith 2007, Troch *et al*. 2014). The modelling study of Greenwood *et al*. (2013) suggests a significant upstream increase in peak wave power (15% close to devices) due to an array (Figure 5.22) which may propagate over 3km from the array affecting the surrounding wave climate.

The wake effect is also dependent on the distance of the array from shore. A study of an array at different distances from shore at the WaveHub site (Abanandes *et al*. 2015) showed that an array close to shore (2km) caused a greater reduction in wave height than the same array at 6km offshore, but the resource in the shallower area was seen to be lower and therefore caution should be taken when comparing impacts and resource generation capacity from different arrays.

The effect on wave height has a potentially greater impact for those devices which are shore-based or situated close to land. Modelling work on the Siadar breakwater project, Isle of Lewis (Amoudry *et al.* 2009), showed that most of the wave energy will be diffracted around the structure with very little energy remaining in the lee, with a large potential for changes in shoreline and surf-zone processes and sediment accumulation. This has the potential to be a positive effect in areas with significant coastal defence issues and could possibly be used as part of a system to manage coastal erosion and coastline retreat. However, any changes to surface productivity linked to reduced turbulence or mixing of the water column will potentially modify the food supply to benthic populations (Pelc & Fujita 2002). This is likely to be very localised and the area affected is likely to vary with changing wave direction.

All of these factors emphasise the need for careful planning of spatial array designs to maximise power and minimise wake effects, including device type, array shape and size, and location in relation to the local wave climate.

Figure 5.22: Simulated a) percentage change (yearly average) in wave power behind multiple wave devices offshore west coast of Lewis, Scotland, b) change in wave power along a perpendicular transect through the central device



Source: Greenwood *et al.* (2013)

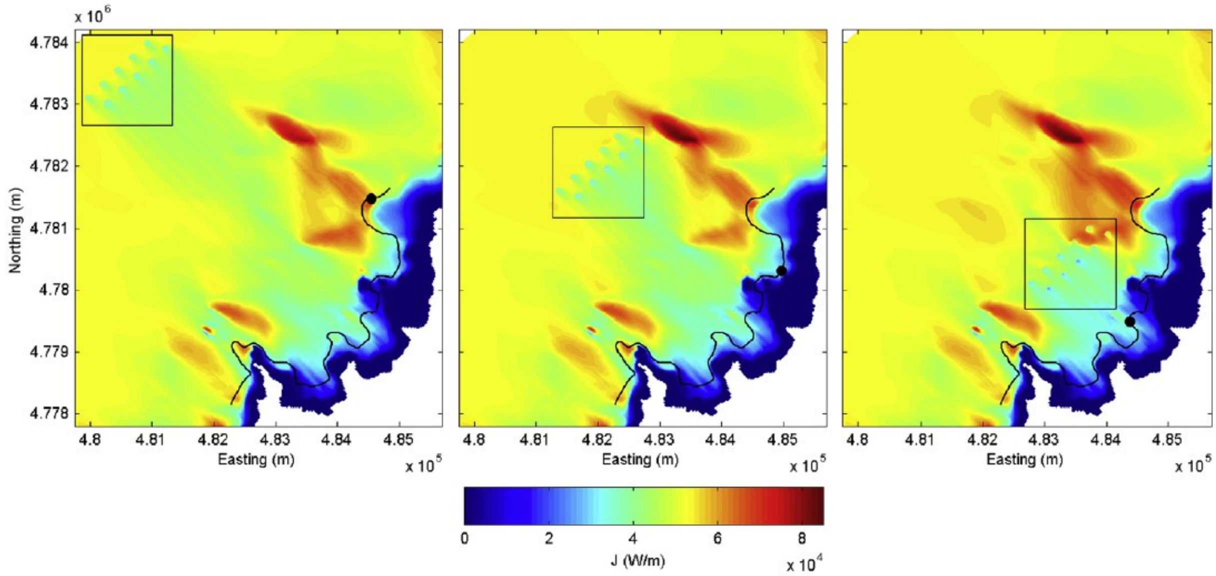
Far field impacts

In terms of a reduction in wave height, both the Pelamis and Wave Hub modelling work suggests that a ~30km (20-26km for Pelamis depending on the configuration of array) section of coastline is likely to be affected by a wave array 3km in length (taking a 60˚ variation in wind direction into consideration), with between 1-2cm (Millar *et al.* 2007) and <5cm decreases in wave height at the coast predicted (Palha *et al.* 2010). A slightly greater change in wave height of 5-10cm in the nearshore line in the wake of an array at the WaveHub site has subsequently been simulated, with the potential impact of the array stretching 26km northwards (González-Santamaría *et al.* 2012). This suggests potential far reaching impacts from an array, even if wave height changes at the coast are relatively minor. Despite the high level of refraction of wave energy around devices modelling has also suggested that in the far field the wave direction is not modified significantly, with differences of less than 0.5° (Palha *et al.* 2010). This small diffraction does also have the potential to increase the impact from an array by altering sediment dynamics especially along coastlines.

Even small changes in wave height at shorelines may have a significant effect on intertidal habitats. Intertidal habitats have well defined zones of organisms which are all ecologically adapted to different levels of exposure. A significant change in mean wave height at the shore will therefore alter the ecology of these areas. Similarly, any change in hydrodynamics may increase the drag acting on an organism or affect marine organisms that are specially adapted to cope with extreme hydrodynamic forces like breaking waves or strong currents (Shields *et al.* 2011), although this is likely to be a localised effect. Sediment re-suspension, outside the boundaries of normal natural variations, may also cause health effects in fish, with prey detection abilities of species that rely on visual cues also potentially hindered by increased turbulence (DFO 2009).

A modelling study of the effect of distance of a wave array from the coast on impact of nearshore wave conditions on the NW coast of Spain (Iglesias & Carballo 2014). Figure 5.23 shows that the point of maximum nearshore impact (black circle) can be within the direct array shadow when the distance from the array to shore is small but when that distance increases the point of maximum impact can move outwith the array shadow area a significant distance along the coastline. This is due to the waves experiencing greater refraction in their propagation from array to coast when the array is further offshore. This is also seen in modelling of an array at the WaveHub site at varying distances off Perranporth Beach, Cornwall (Abanandes *et al*. 2015). Here the length of coastline affected by a reduction in wave height was 7km for the array furthest from the coast (6km) compared to just 4km for an array situated 2km offshore. However, this smaller area of impact had a greater reduction in wave height (>10%) compared to <5% for the 6km scenario, so a more concentrated wave energy impact over a smaller area.

Figure 5.23: Winter wave power pattern for an array of wave devices at differing distances from the coast of NW Spain



Notes: Distance of array from coast is from left to right: 6km, 4km, 2km. The maximum nearshore impact point is shows as a black circle on the 10m contour line. Source: Iglesias & Carballo (2014)

Sediment dynamics & coastal protection

Most devices are tuned to extract power from swell or low frequency wind-waves which generally represent a much greater source of power than higher frequency waves (PMSS 2007, Shields *et al*. 2011). A reduction in wave height will reduce the associated stress on the seabed and sediment resuspension and also reduce wave breaking and turbulence. Often wave energy is expended at the shore or nearshore and therefore the extraction of energy may be expected to have an effect on shoreline environments rather than in the immediate vicinity of the devices themselves (Boehlert *et al.* 2008). In addition, some wave devices have an operating limit and will not operate during storm conditions. Large waves during storm events are therefore not modulated or reduced by arrays, with resulting onshore erosion and offshore transport of sediment. However, smaller waves which are generally responsible for offshore erosion and onshore transport of sediment, would be affected by tidal devices. This means that potentially a reduction in energy of smaller waves combined with no reduction to larger waves could result in long term migration of sediment offshore (Shields *et al.* 2011). It should be noted that this process already occurs naturally in some areas, modulated by inter-annual variation in wave energy and direction and climate change (Woolf *et al*. 2006, Wolf *et al.* 2020). This impact of an array on sediment dynamics is therefore dependent on device type, setting, local wave climate and morphodynamics.

Initial modelling at the WaveHub site suggested near-shoreline bathymetry changes of -0.2 to +0.2 metres from an array, which would likely be indiscernible against background sediment transport and beach level changes (Halcrow 2006). However, subsequent modelling at the site (González-Santamaría *et al*. 2012) has shown that the wave contribution to bottom stress is significantly larger than the tidal contribution and therefore is driving sediment transport especially during storms. Reductions in wave energy in the lee of an array are shown to affect bottom stress in the shallow water and nearshore region with a maximum change in sediment concentration with and without the wave array of -0.1 to 0.1 kg/m^3 at low tide. Sediment concentrations are higher within the lee of the array, as longshore transport has been diverted around the array, with impacts greatest to the north of St Ives Bay. There is also evidence of a northwards shift of erosion and deposition patterns due to wave diffraction caused by the array. Further modelling at the site found a 1.5m reduction in erosion of bed levels after a storm at the beach face with an array, compared to baseline (Abanandes *et al*. 2015). This study also suggested that an array closer to shore (2km) caused a greater reduction in erosion (5% more) than the same array further offshore (at either 4 or 6km). However, the sediment erosion and deposition patterns were complex, suggesting that careful siting would be needed if a wave array was to be used for coastal protection, as has been suggested by multiple studies (e.g. Ruol *et al.* 2011, Nørgaard *et al.* 2011, Zanuttigh & Angelelli 2013). This is corroborated by additional modelling at the same site, which found that the effect of a wave farm varied in different parts of the beach with a reduction of the eroded area of up to 35% in the north of study area and 20% in centre of the beach (Abanandes *et al*. 2014). There was also a significant reduction in erosion in a nearshore bar which formed part of the natural defence of the beach face, increasing the defence of sand levels on the beach.

In addition to the distance offshore, the type of device and the natural setting also need to be taken into consideration for coastal protection purposes. A study of 4 different wave devices at 2 sites, a semi-enclosed water body (Bay of Santander, Spain) and an open beach (Las Glorias, Mexico), shows that the impacts can vary greatly from site to site (Mendoza *et al.* 2014). At the Santander site, the selection of the most effective device for shoreline impact protection was complex, although it did conform to the previously described notion that to cover a larger length of coastline the devices should be placed in deeper waters (although the level of protection will be reduced compared to a nearshore siting). Whereas the Las Glorias site suggests that for an open beach having an array occupying a larger marine area does not necessarily mean a higher wake effect or wave energy reduction, or greater beach protection. It was then concluded that devices with smaller longshore gaps should be used to protect longer stretched of coastline, whilst arrays with more lines of devices should be used where high wave reduction is needed in a short length. This added complexity is also highlighted by Iglesias & Carballo (2014) who concluded that by increasing the distance of the array from the coast does not necessarily result in a reduction in maximum absolute impact, it may just result in a change in the location of impact. So moving an array further offshore is not necessarily the answer to reducing impacts, with a recommendation for including array to coast distances as part of impact assessments for specific sites.

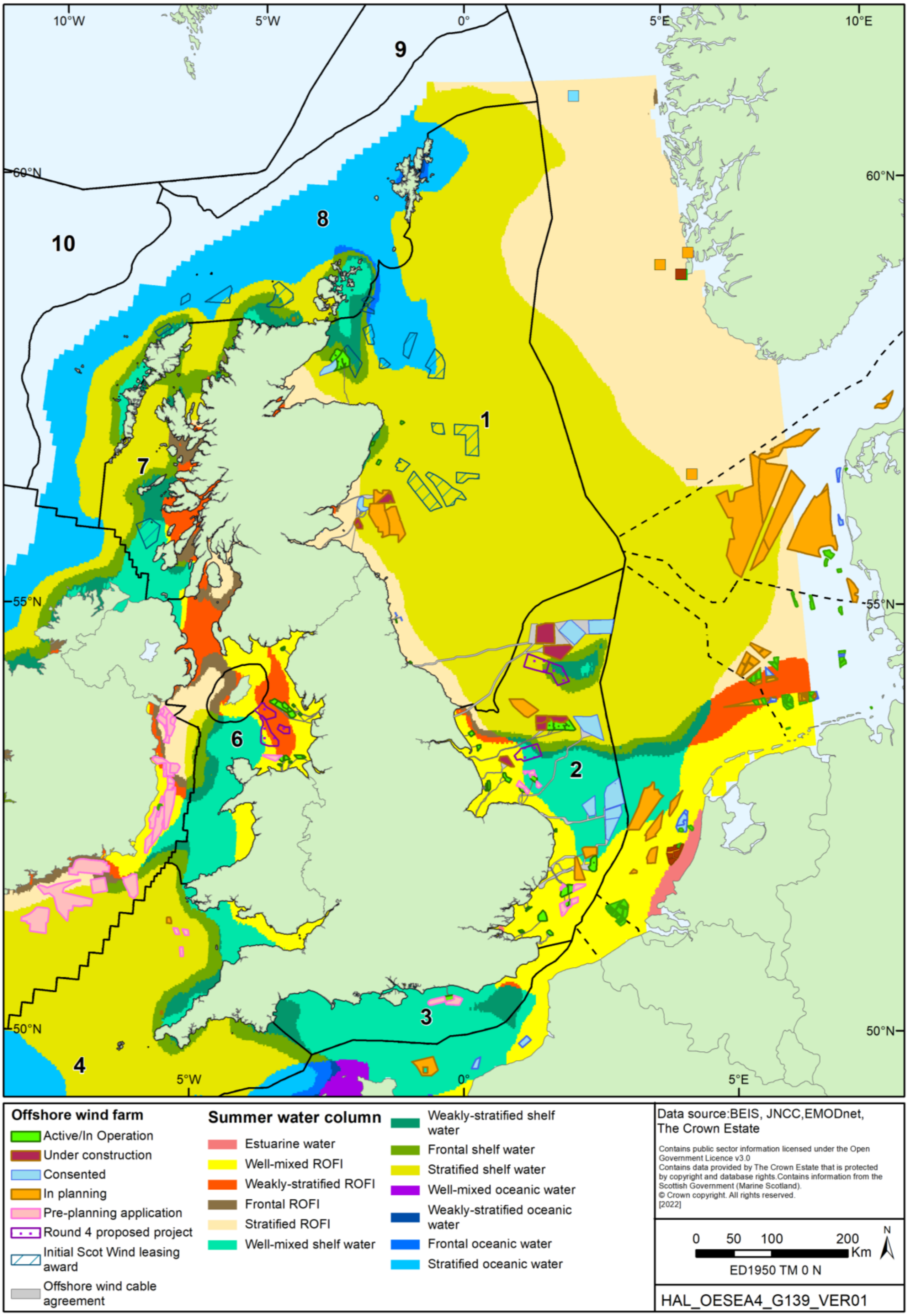
A significant issue associated with the modelling of sediment transport and wave and tidal devices is the highly spatially variable nature of the natural sediment in the study areas. For example a model for a tidal array in the Pentland Firth covers a wide range of seabed types including: swept bedrock areas, sand veneers on bedrock, large cobbles with interstitial sand and gravel, large sandbanks and sand wave fields (Fairley & Karunarathna 2014). Varying quality and availability of data makes it difficult to build such variability into models with most studies showing areas of uniform and abundant sediment (e.g. Abanandes *et al.* 2014, Mendoza *et al.* 2014).

5.5.2.4 Wind

Offshore wind farm foundations interact with part of all of the water column depending on their design, e.g. floating and fixed. Turbulent wakes are generated as waters pass through offshore wind farms under tidal action which has the potential to contribute to a range of effects on hydrodynamics, including enhanced vertical and horizontal mixing and effects on stratification (Carpenter *et al.* 2016, Cazenave *et al.* 2016, Floeter *et al.* 2017), changes to primary productivity and potentially related effects at higher trophic levels (Floeter *et al.* 2017). Additionally, wind wake effects may generate significant reductions in wind speed and related changes to surface wave energy (Christiansen & Hagar 2005, Rodriguez and Harris 2012, Christiansen *et al.* 2013, Bärfuss *et al.* 2021).

To date, most wind farms have been deployed in well-mixed shelf seas (much of the southern North Sea) or areas of weak summer stratification (East Irish Sea); see Appendix 1d. Recent exceptions in the southern North Sea have been the Hornsea One and Two projects, with other consented (Dogger Bank A, B, C and Sofia, Hornsea Three) and proposed (Hornsea Four, Round 4 Dogger Bank South) wind farms located within the summer/autumn stratified area, and to the north of the Flamborough Front (Figure 5.24). Outside of the waters covered by this SEA, fixed foundation wind farms have also been constructed in the Moray Firth in seasonally stratified seas, including Beatrice and Moray East, with Moray West wind farm proposed, and further proposals made in the ScotWind leasing round (Figure 5.24). In a transboundary context, wind farms in adjacent areas including the German Bight have deployed fixed foundation wind farms mainly in stratified shelf waters, or weakly stratified shelf waters (Figure 5.24). There has been a recent tendency to site new offshore wind capacity further from shore for technical, economic (e.g. improved capacity factors and a recent reduction in capital cost) and environmental reasons, including those related to landscape/seascape issues (see Section 5.8) and other user interactions (e.g. shipping). As space becomes more constrained in shallow and well-mixed UK shelf waters, further offshore wind capacity in relevant waters of the UK covered by this SEA (and likely future leasing in Scotland), is likely to be in areas of stratified shelf seas (see Section 5.15). While numerous oil and gas structures have been placed in the UKCS since the 1960s, including in areas of weakly or strongly stratified seas, they have been relatively few and dispersed compared to the projected expansion of offshore wind in the coming decades.

Figure 5.24: Location of operating, proposed and potential offshore wind farms in relation to summer seasonal water column structure



Modelling work undertaken to simulate the potential effects of wind farms at the scale of a single array (Carpenter *et al.* 2016, Cazenave *et al.* 2016, Floeter *et al.* 2017) and for potential future scenarios of large-scale deployment (van Duren *et al.* 2021), though few field studies area available to corroborate the potential scale and effect of changes in hydrodynamics from offshore wind farm deployments (see Floeter *et al.* 2017, but note the uncertainty in attribution concluded, and also Forster *et al.* 2018).

Carpenter *et al.* (2016) used idealised modelling and *in situ* measurements to make order of magnitude estimates of the impact of wind farm structure mixing on large-scale stratification by calculating the residence time for stratification at a mixing rate characteristic to wind farm foundations (mixing timescale), and the residence time of a parcel of water within a wind farm given mean residual currents (advective timescale). The results suggested that wind farms could impact stratification if they occupied large areas of the shelf but were unlikely to present significant effects at present. Carpenter *et al.* (2016) noted some limitations to their modelling and current uncertainties that limit their conclusions, for example, including an accurate representation of natural mixing of the upper mixed layer and bottom boundary layer, and pycnocline evolution. They also note that the drag coefficient of foundations, and foundation type, are important factors, and while the former may be estimated for an idealised monopile, surface roughness including as a result of marine growth will alter this coefficient over time. While mainly observed in shallower and well-mixed waters, sediment plumes extending from monopiles such as those associated with the London Array, demonstrate the hydrodynamic changes occurring as a result of the interaction of tidal flows with wind turbine structures, study of which (Forster *et al.* 2018) has found evidence to support that they are formed by the redistribution of sediment already suspended in the water column from lower in the water column towards the surface, and that they do not represent sediment from scour.

Floeter *et al.* (2017) made observations at the Global Tech and BARD Offshore 1 wind farms in the German EEZ and while there was an observed doming effect on the thermocline and enhanced nutrient transport to the surface mixed layer, baseline measurements indicated that at least some of the observations may be attributable to antecedent conditions.

The impact of a single structure or wind farm may be low (Carpenter *et al.* 2016, Schultze *et al.* 2020) and relatively well accounted for at a local level using the approaches taken in some studies to date, albeit with the requirement to both improve the range of parameters the model accounts for, and also with greater validation needed. However, the potential for large-scale, cumulative, and far-field effects remains uncertain, and would require a large 3D model which incorporated the North Sea. This would also need validation and realistic foundation parameters and scenarios for future wind farm deployment, as recommended by Boon *et al.* (2018). Following on from this recommendation, van Duren *et al.* (2021) used the 3D Dutch Continental Shelf Model – Flexible Mesh (3D DCSM-FM) across three scenarios: reference, “2020” and hypothetical upscaling scenario based on offshore wind targets to 2050 (also see Zijl *et al.* 2021). Note that the wind farms used to represent the hypothetical scenario for the UK’s seas only include those currently consented or most of those for which consent applications have been submitted. It does not include the 2017 extensions, Round 4 proposals, or other recent additions such as the floating demonstration farms in the Celtic Sea, nor would it be able to realistically account for turbine parameters which are not readily available even for some consented wind farms. Significantly expanded wind farm deployment was modelled to result in destratification in areas of the southern North Sea and German Bight that occurred both within wind farm areas and at distances of more than 100km. Similarly, changes in residual flow velocities were significant (several cm/s) within and just outside wind farms, but effects on sediment and nutrient transport were found to be limited (Zijl *et al.* 2021). A delay in the onset of stratification was also observed, particularly in the German Bight.

Model parameters for the reference scenario were verified where possible using a comparison between modelled and observed values, but more validation is required to reduce uncertainty. While the relative values were often similar between modelled and observed data, absolute values differed, but sufficient correspondence was regarded to be available for the modelling exercises to be undertaken. For example, modelled SPM concentrations were found to not be suitable for use in ecological models, and the full coupling of SPM and ecological models was not possible. The modelling indicated that surface SPM increased by 10-20% at most wind farms with a near-bed reduction of 5-15% which did not extend far from wind farm boundaries. Such a change could have effects on light levels that may locally affect primary production (see Forster *et al.* 2018), however, mixing by turbulent flows would also be predicted to result in increased primary production through more nutrients being available in the surface waters. When these factors were taken together, a reduction in primary productivity was observed in the wind farms, but an increase was observed further away, but overall the effect was regarded to be minor. In the upscaling scenario, primary productivity was estimated to increase substantially in the southern North Sea, even when changes to fine sediment were included, but this was not the case in the German Bight where enhanced sediment caused a reduction.

Floating wind farms may provide limited mitigation to changes in mixing, as the required draughts for these structures are likely to be large enough to penetrate the thermocline; spar buoy-type devices may act in a similar way to monopiles as they may reach the well-mixed bottom layer. Shallower draught alternatives including semi-submersibles will generate mixing via shed lee waves, internal waves, blockage effects and wake-wake interactions as well as directly interacting with the thermocline (Dorrell *et al.* 2021).

Stratification is important as part of the annual phytoplankton bloom, such that effects on the timing of its onset and intensity need to be better understood. There may be some balance of nutrient and light effects as to whether the mixing enhances phytoplankton growth from greater nutrient availability from vertical upwelling, but also enhances turbidity from sediment redistribution in turbine wakes (e.g. see Forster *et al.* 2018), along with other potential effects including elevated deposition of organic material, changes in CO_2 uptake and increased oxygen supply from the surface (Dorell *et al.* 2021) and related effects on higher trophic levels (van Duren *et al.* 2021). The alteration of the timing of thermocline onset and breakdown, with an overall shorter season, may also have implications for species which annual cycles rely on the timing of its formation, such as breeding seabirds. Effects on large scale circulation patterns, should they occur, may not be observed for months to years (Boon *et al.* 2018). These potential changes in circulation and stratification must also be considered in the context of the projected changes in these factors resulting from climate change (e.g. see Appendix 1d and Section 5.12).

Based on modelling to date, effects on stratification and primary production may be expected with large scale deployment of offshore wind but there remain sufficient uncertainties that they cannot be taken to represent definitive outcomes or be used to inform planning at this stage (e.g. van Duren *et al.* 2021). Studies note limitations including a lack of model integration (e.g. hydrodynamics and sediment dynamics), a need to include more parameters (for example, some models do not include wind wake effects on waves and any related effect on surface mixing, or the longer-term effects on drag coefficients from marine growth) and to be able to validate findings with *in situ* measurements. This is further compounded by a need to understand the various potential geometries of floating and fixed wind farms and their drag coefficients, which are not yet accurately quantified. Despite this, there is the expectation that local impacts will likely take place around wind farms, particularly in weakly-stratified seas, with delayed onset and early breakdown of the thermocline.

5.5.3 Controls and mitigation

Evidence, primarily from modelling work, on the placement of different devices/schemes in different settings highlights the complexity of impacts arising from all types of renewables devices. Scales and spatial extent of impact are heavily dependent on physical, hydrodynamic, bathymetric and sedimentary properties and regimes of an area. Variability in device type, array size and pattern/orientation also contributes to the unique response of an area to a specific scheme. It is therefore suggested that detailed site specific investigations be undertaken including impacts from different device types, array size and shapes, distance from shore and position within a channel or area.

To date, offshore wind deployment in UK waters has largely taken place in well-mixed waters that do not stratify in summer, such that any hydrodynamic effect of deployment has not affected the timing or intensity of the thermocline (exceptions include Walney extension, Beatrice and Moray East). This is a function of the nature of the foundation types largely used to date (i.e. fixed, and mostly monopile) and their limitation to shallower waters. The advancement in floating wind farm technologies and related cost reduction is such that deeper waters which do stratify in the summer are now accessible to development. The potential effect of large-scale deployment of such structures is uncertain, and as above, will be a function of design and location (e.g. the nature and scale of mixing potential from a semi-sub compared to a spar-type structure may not be the same depending on thermocline depth and individual device characteristics). As with wave and tidal devices, detailed site and device-specific investigations should be undertaken to understand the potential effect of an array on the thermocline, such that the related implications for marine ecology can be considered. The potential for wider basin-scale impacts are subject to ongoing research which will help to inform the nature and scale of in-combination impacts, however, these require more work to appropriately model realistic scenarios of future wind farm deployment in the North Sea, Irish Sea and Celtic Seas.

5.5.4 Likelihood of significant effects

Whilst there has been a significant increase in the number of studies conducted on arrays of wave and tidal devices and tidal range projects, the scale and dynamics of impacts from energy removal are still primarily based on evidence from modelling. It is likely that barrages and large arrays of tidal and wave devices may produce significant, far-field effects (extending over hundreds of km), with permanent impacts on the energy balance, physical hydrography and associated ecology of the estuary/river basin, though this is unlikely for individual devices or small-scale developments. This is reasonably well understood for barrages but further work is needed to investigate array sizes, shapes and siting and understand at which point and under which physical and hydrodynamic conditions impacts both become significant, and extend from near- to far field. Some evidence suggests that careful siting of wave and tidal devices can mitigate impacts to some degree and can even be used for positive coastal defence purposes, although this is very site and device specific.

Since wave and tidal energy have yet to be deployed at a large commercial scale in the UK, there is neither evidence for cumulative effects nor the opportunity to validate modelling predictions which do suggest cumulative effect from the upscaling of arrays. Wave and tidal devices tend to occupy different geographic zones i.e. the typically estuarine requirement for tidal range and land-constrained narrows for tidal stream versus an along-shore siting of wave devices in open water; these scenarios have very different dependent habitats downstream (and upstream) of the devices. Some models predict far-field effects of up to hundreds of kilometres, therefore it seems inevitable that multiple energy extraction devices within the same hydrographic basin, will have impacts. These impacts are predicted to range through reduction in current speed and particle size of sedimentary habitats, with subsequent changes to infaunal elements. At a strategic level however, the anticipated scale and geographical location of wave and tidal development associated with this plan is unlikely to create significant cumulative effects.

In addition to wave and tidal devices, large-scale deployment of wind farms could have effects on hydrodynamics including mixing of the water column which has implications for sediment movement, stratification and biogeochemical cycles. Like tidal stream or wave energy, broad-scale and far-field significant effects at current levels of wind farm operation are not predicted or have not been observed, however, models of hypothetical future scenarios suggest the potential for significant effects on thermocline onset, strength and persistence. Analogous to models used to estimate the effects of wave and tidal devices, these need improved input parameters, validation, and also realistic scenarios for future deployment to understand the scale of potential effect. To understand the potential for wider cumulative effects, future models would ideally consider the potential scale of wave and tidal energy extraction and their influence on water bodies affected by wind farms and climate change forcing factors on the same time scale.

5.5.5 Summary of findings and recommendations

Numerous studies on the hydrodynamic effects of energy removal have now been undertaken to provide an indication of the nature of scale of energy removal effects. Results are typically site-specific and connecting those changes to other aspects of the physical environment (e.g. sediment dynamics) requires additional work. It may generally be concluded that there are limited and localised impacts from single or pilot scale deployments of tidal stream and wave devices, and current levels of offshore wind deployment, but scaling those impacts up to commercial wave and tidal arrays and the number of wind turbines that could be required to meet net zero target in the UK sector and adjacent north west European states, potentially has some significant issues. There is a clear need to continue to improve modelling capability and to improve model validation.

Tidal barrages have far reaching, large scale impacts that potentially change the energy balance, physical hydrography and associated ecology of the estuary/river basin permanently. For this reason and because individual estuary/embayments are so different it is recommended that detailed site specific data gathering and assessment is required before decisions can be taken on the acceptability or otherwise of a development. The infancy of tidal lagoon technology means that further work is needed to understand the nature and extent of impacts, especially in relation to far-field and cumulative effects, though the modelling studies to date specifically for the Swansea Bay lagoon have indicated that it would be unlikely to generate far-field hydrodynamic effects. This may not be more widely applicable to other areas of the Severn or other estuaries, however, it suggests that pilot-scale projects on their own may not generate significant hydrodynamic effects.

There is evidence that the type of wave energy device, size and shape of array, distance from land, morphology of the site and local wave climate all influence impacts. As with the spacing of turbines in offshore wind farms, careful consideration therefore needs to be given to the spatial arrangement of devices within arrays in order that shadow effects do not impact on downstream devices, and large cumulative impacts and far-field effects from multiple devices does not occur. The potential dual use of wave arrays for coastal protection should be investigated further, but would need site-specific studies to be undertaken to evaluate site suitability.

It is clear that any change in the biogeochemical cycles of UK waters from renewables expansion would require an understanding of the potential range of effects from wind farms, tidal stream and wave arrays and tidal range, both locally and in the far-field (and cumulatively), together with the likely range of potential impacts from climate change along realistic timescales and scenarios of deployment for such technologies. Further modelling will be required to provide estimates for the potential magnitude of change. The largest barrier to effective and accurate modelling is collecting data from the natural environment to validate models. This needs to be improved so as to better understand the natural dynamics of the baseline environment. The number of different renewables device designs also make it difficult to judge the applicability of generalised results from studies to specific devices deployed in specific waterbodies. As a result, interactions between device design and the marine environment are needed to simulate many types of devices to assess varying levels of impacts for specific sites.

5.6 Physical presence - ecological implications

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H production/ transport
The introduction and spread of non-native species	X	X	X	X	X	X	X	X
Behavioural disturbance to fish, birds and marine mammals etc from physical presence of infrastructure and support activities	X	X	X	X	X	X	X	X
Collision risks to birds				X	X	X	X	
Collision risks to bats				X				
Collision risks to water column megafauna (e.g. fish, marine mammals), includes entanglement in moorings and from vessels	X	X	X	X	X	X	X	
Barriers to movement of birds				X	X	X		
Barriers to movement of fish and marine mammals				X	X	X	X	
EMF effects on electrosensitive species	X	X	X	X	X	X	X	X

5.6.1 Introduction

Before the relatively recent development of offshore renewables, energy developments in the UKCS have primarily been oil and gas installations, with the physical presence of offshore energy infrastructure and its effects relatively well documented and where required, mitigated for. The locations of these installations are constrained geologically to fields within hydrocarbon basins, and their export infrastructure to oil and gas terminals onshore. The deployment of offshore renewables has increased substantially in the last decade and is projected to continue to do so to 2030 and beyond as part of UK Government policy to reduce greenhouse gas emissions during the transition to net zero by 2050. Offshore renewable developments of the projected scale raises questions about the potential ecological impacts.

Potential effects include the risk of introduction and invasive spread of non-native/non-indigenous species, as well as several potential interactions between mobile species and primarily renewable infrastructure and support activities, including collision, avoidance, barrier effects, ‘reef effects’ and electromagnetic field (EMF) effects.

To date, the majority of wind developments in the waters around the UK have had fixed foundations (e.g. monopile, jacket or gravity based structures), largely due to the available technologies and the developments being in shallower water depths. However, cost reduction in turbines and advances in floating foundations (e.g. tension-leg platform, semi-submersible, spar-buoy) are making deeper waters further offshore more accessible, and there are a number of demonstration and commercial proposals in the Celtic Sea, and the recent ScotWind leasing round has attracted a large number of floating wind farm proposals.

This Section discusses the potentially significant ecological effects that may arise from the physical presence of structures associated with the draft plan/programme, concentrating on potential effects from renewable energy, and primarily effects from offshore wind deployment. Other renewables (wave and tidal) and other energy (oil and gas) are also considered.

5.6.2 Sources of potentially significant effect

5.6.2.1 Introduction and spread of non-native/non-indigenous species

Non-native/non-indigenous (used here interchangeably) species are those species which have arrived in the UK by accidental transport, deliberate introduction, or natural dispersal from adjacent non-native populations; these are species which have established breeding population(s) outside their native range. Whilst some such species will be benign, those non-native species that go on to have a negative impact on native species, e.g. through altering local ecology and disrupting normal ecological function, spreading disease, predation or competition for resources, are termed non-native invasive species.

The impacts of many non-native species known to colonize offshore structures are still unknown and the establishment of some species may be beneficial, such as providing additional food sources for fish species.

Shipping is the major pathway for introducing non-native marine species to new environments from, for example, hull fouling and ballast water discharge/exchange; *Didemnum vexillum* (carpet sea-squirt), has become established in UK waters, where, in a suitable environment, can become invasive (see below) with the main pathways of spread being shipping (fouling), recreational boating and movement of aquaculture stocks[153]. Mitigation is through the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments[154], which includes the requirement for all ships to implement a ballast water management plan, have a ballast water record book, an international ballast water management certificate and to conduct any ballast water exchange, wherever possible, at least 200 nautical miles from the coast and in at least 200m water depth. Where ships are unable to conduct ballast exchange under these circumstances, this should be done as far from the nearest land as possible and in all cases, at least 50 nautical miles from the nearest land, and in water at least 200m in depth. UK regulations to give effect to the Convention have been drafted[155] and expected to come into force in 2022.

The areas with a high volume of shipping traffic are hotspots for non-native species in UK waters (Pearce *et al.* 2012). Additional potential pathways for introducing non-native species is the wet storage and wet transport (towing) of renewable energy infrastructure from ports to final location; to date, wet storage has not been extensively used in the UK.

The establishment of non-native species requires successful settlement, growth and reproduction and can be aided by marine structures. Many intertidal and subtidal invasive species (e.g. species of barnacle, mussel and limpets) have mobile planktonic larvae and require hard substrate to recruit. Windfarm foundations can introduce new hard substrate into offshore waters that otherwise would have limited or no existing hard substrates, thereby

[153] e.g. Wales Invasive Non Native Species portal, https://gov.wales/sites/default/files/publications/2018-02/invasive-aquatic-species-priority-marine-species.pdf, Marine Scotland Non-Native Invasive Species, (https://www.gov.scot/policies/marine-environment/invasive-non-native-species/

[154] https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships%27-Ballast-Water-and-Sediments-(BWM).aspx

[155] The Merchant Shipping (Control and Management of Ships' Ballast Water and Sediments) Order 2022 https://www.legislation.gov.uk/ukdsi/2022/9780348228748/data.pdf

providing new hard-bottom habitat that the mobile larvae of invasive species can populate, to the potential detriment of native species (Kerckhof *et al.* 2011, Glarou *et al.* 2020).

All energy installations (and structures including navigational buoys) in the marine environment provide additional hard substrate available for colonisation by algae and benthic invertebrates from planktonic larval settlement; the use of protective material associated with the energy industry e.g. concrete mattresses and rock also provide additional hard substrate available for colonisation.

The deliberate and accidental placement of hard substrates in the marine environment where the seabed is predominantly sand and mud will create reef effects, allowing the development of "island" hard substrate communities and there is a possibility that a substantial expansion of the number of hard surfaces (e.g. see De Mesel *et al.* 2015, Coolen *et al.* 2020) could provide "stepping stones" allowing species with short lived larvae to spread to areas where previously they were effectively excluded (i.e. secondary dispersal). Such "islands" are naturally widespread and numerous in continental shelf areas, for example on glacial dropstones, moraines and iceberg ploughmarks, but less so in the shallower waters of the southern North Sea and eastern Irish Sea.

5.6.2.2 Interactions between infrastructure and mobile species

The three main groups of interaction associated with renewable infrastructure and birds are: displacement (and attraction); barrier effect and collision (mortality). In principle all aerial structures can induce an avoidance response by individual birds but currently only wind farms are at a scale large enough to potentially cause a displacement that may result in biologically significant impacts (e.g. loss of high quality habitat, large increase in travel time between roosting and feeding areas). The activity of support vessels may also contribute to the overall effect. The main factors are the size and configuration of wind farms as well as their position with respect to bird flight behaviour (e.g. foraging areas, migratory routes). The presence of structures may also present a physical or sensory barrier to the movement of marine species, particularly migratory species, with impacts associated with additional energy expenditure. Barriers to movement can relate to regional/global migrations as well as local movements (within and between breeding and feeding areas) in open waters and in coastal environments, including up-river movements.

Structures with a large vertical component are a potential source of collision for birds and bats, and of greatest concern are the rotating blades of wind turbines. Collision risk depends on a range of species specific, site specific and wind turbine/farm specific factors (many of which are interrelated) as summarised in Table 5.13.

Table 5.13: Factors influencing collision risk with offshore wind farms

Species specific	Site specific	Wind turbine/farm specific
Morphology (e.g. body mass, wing loading, wing span – factors affecting flight strategy and manoeuvrability and hence collision vulnerability).	**Flight paths** (although the abundance of a species *per se* may not contribute to higher collision rate, areas with higher concentrations of birds seem to present a higher risk of collision).	**Turbine features/design** (e.g. turbine size, rotor diameter, rotor speed, sound and lighting, faster moving objects are harder to avoid than slow moving ones (caution is needed when analysing rotor speed alone, as it is usually correlated with other features that may influence collision risk such as turbine size, tower height and rotor diameter).

Species specific	Site specific	Wind turbine/farm specific
Sensorial perception (e.g. species with relatively small frontal binocular fields, limited visual fields of perception, motion smear, birds looking down rather than ahead during flight).	**Weather** (strongly influences flight behaviour and can influence ability to perceive and avoid risk. E.g. strong winds affecting ability to control flight manoeuvrability, poor visibility, low altitude clouds can lower flight altitudes and daily temperatures and thermal convection can affect migrating birds flight altitudes).	**Blade visibility** (e.g. if blades are spinning at high speeds, a motion smear effect can occur – something moving too fast for the brain to process the image and as a consequence the moving object appears blurred or even transparent).
Avoidance ability (e.g. some birds can take last minute action to avoid turbine blades – closely linked to morphology and perception).	**Food and other resource availability** (e.g. the "reef effect" of structures, attracting fish aggregations and in turn attracting birds, increasing potential for collision, provide resting/roosting platforms.	**Wind farm configuration** (layout may have an impact, e.g. turbines arranged perpendicular to a main flight path).
Age (e.g. age and experience may influence flight capacity and recognition of danger).		**Lights** (lit structures can attract birds, increasing the potential for collision, especially in conditions of poor visibility, and nights of heavy migration movements).
Behaviour (e.g. flight type appears to be influential such as hovering, foraging (breeding) birds commuting repeatedly through a wind farm area, (this can also show sex-bias in fatality rate, with higher proportion of adult male deaths), song-flights, frequency of trips, night flying, including migrating birds, social behaviour, e.g. flocking birds.		

Source: adapted from Marques *et al.* (2014)

Other aerial elements which may attract birds and bats are the lights and flares on offshore oil and gas platforms and rigs. All require navigation lights, including those installations that are generally unmanned (most of these are located in the gas fields of the southern North Sea). Operational flaring of gas is another source of light on some platforms but note that there is a target to eliminate routine flaring by 2030. Wind farms also carry navigational lights which may be an attractant to birds although there is little published literature on this.

The range in design of marine energy devices includes infrastructure that is submerged, floating or surface-piercing (static or dynamic), harness wave, or tidal energy resources and have different spatial scales of installations (i.e. single device or array). The impacts from such devices include: physical obstruction/displacement; collision/entanglement, noise and EMF effects. Changes in benthic and pelagic habitats and oceanographic processes as a result of constructing and operating the devices, are also considered a pathway for potential impact (see Sections 5.4 and 5.5).

Tidal range schemes (e.g. tidal barrages) represent physical obstructions and any wave or tidal stream device may constitute an obstacle to normal movements or provoke a behavioural disturbance. Displacement may result from acoustic disturbance during installation or operation (see Section 5.3) but may also be the result of a response to the general physical presence of devices and/or vessels and increased human activity (Sparling *et al.* 2015); displacement may result in a barrier effect for example when animals are impeded from using an area previously used for transit. To assess these effects, the key factors for consideration are the location and the size of the development relative to the width of the movement 'corridor' utilised by species.

Rotating submerged turbines and other moving infrastructure associated with wave and tidal power are perceived to carry a risk of collision (Long 2017, Copping *et al.* 2020) particularly for marine mammals, fish and marine birds (Wilson *et al.* 2007); many tidal stream and wave devices have extensive submerged components, often involving complex moving parts and internal chambers, and may present a risk of collision, entanglement or entrapment to diving seabirds (Grecian *et al.* 2010, Langton *et al.* 2011, Witt *et al.* 2012). The risk of injury from rotating underwater turbine blades could be greater if they cause increased water turbidity and reduced visibility (Grecian *et al.* 2010). Submerged infrastructure in the water column is also associated with floating wind turbines (e.g. anchors, mooring lines and foundations), and these are likely to become more prevalent as deeper waters are exploited.

Collision risk depends on the type and size of device and its physical and mechanical features (including rotating speed), the depth of which they are operating, as well as behavioural assumptions of the receptors (i.e. such as avoidance or fine-scale evasive responses) (Copping *et al.* 2020).

Tidal barrages and lagoons operate on the same basic principle, and include rows of turbines in a high tidal range area which generate electricity from water flows. The turbines used in barrages and lagoons rotate in sluices or constricted ducts and present a collision risk to a range of marine fauna. Collision with wave devices may also be possible but much less probable; instead wave devices are more readily associated with a risk of entanglement in mooring lines (Sparling *et al.* 2013).

Cables associated with wind, tidal stream and wave devices present the risk of electromagnetic fields to electrosensitive animals. Electromagnetic fields (EMFs) are generated when electricity is transported through a cable. An industry standard AC offshore cable produces a magnetic (B) field component and an induced electric (iE) field component in the marine environment. Although submarine power cables are fully electrically insulated, it is the fluctuating magnetic field which induces the electric field in the environment (CMACS 2003). An electric field is also generated by the movement of water or objects (e.g. an animal) through the magnetic field in the same way that movements through the natural (geomagnetic) field of the earth induce an electric field. A number of marine taxa are potentially capable of responding to anthropogenic sources of electric and magnetic fields and the response of an animal to EMF will depend on the electro-and magneto-sensitivity of the animal. The probability of an encounter will depend on the animal's movement and spatiotemporal use of the environment where the EMF occurs (Copping *et al.* 2020).

The current status of UK offshore wind, tidal and wave developments (pre-planning, in planning, consented, under construction and operational) is provided in Appendix 1h, with a summary shown below in Table 5.14.

Table 5.14: Summary of wind, wave and tidal developments in Regional Sea areas

Wind (status and total number of turbines, where known)[1]	Wave[1,2]	Tidal[1,2]
Regional Sea 1		
Pre-planning (3 developments, total number of turbines 243) Consented (4, 325) Under construction (1, 100) In operation (8, 153)	-	-
Regional Sea 2		
Pre-planning (4, -) In-planning (5, 142) Consented (8, 335) Under construction (2, 255) In operation (19, 1,299) Consent refused (1, 34)	-	-
Regional Sea 3		
Pre-planning (1, -) In operation (1, 116) Consent refused (1, 121)	-	Consented (managed test facility) (1)
Regional Sea 4		
Pre-planning (3, -) In-planning (2, 4)	In development (1) Operational (2)	In planning (1) Pre-construction (1) In development (1)
Regional Sea 5		
-	-	-
Regional Sea 6		
Pre-planning (1, -) Consented (1, 90) Under construction (1, 32) In operation (11, 570)	-	Pre-planning (1) In planning (2) Consented (3) Decommissioned (1)
Regional Sea 7		
-	-	Consented (4)
Regional Sea 8		
Consented (1, 2)	Operational (2)	Consented (1) In development (1) Under construction (1) Operational (3)
Regional Sea 9, 10, 11		
-	-	-

Notes: [1] – denotes number of turbines not known and no development (wave and tidal) [2] The wave and tidal listed here are a mixture of managed test facilities, and demonstrations (i.e. zones, engineering and commercial demonstration), with only a small number commercial. Source: The Crown Estate December 2021, updated using the Planning Inspectorate Website and the BEIS renewable energy database (February 2022)

5.6.3 Consideration of the evidence

5.6.3.1 Non-native/non-indigenous species introductions

Despite the UK's 60 year history of oil and gas development, there has been little focus on its role in benthic species introductions and spread, however, the available evidence on fouling growth development and composition suggests a limited role. Wind turbines, including their foundations have been found to act as stepping-stones for the dispersal of hard bottom organisms facilitating the spread of both exotic and indigenous species (Connell 2001, Bulleri & Airoldi 2005, Glasby *et al.* 2007, Bulleri & Chapman 2010, Zintzen & Massin 2010, Kerckhof *et al.* 2012). The introduction of new hard substrate into the marine environment sees a rapid colonisation (biofouling) with vertical zonation observed by different species (i.e. splash, intertidal, shallow and deeper subtidal zones) (De Mesel *et al.* 2015), with typically mussels, macroalgae and barnacles near the surface, filter-feeding arthropods at intermediate depths and anemones at the deeper depths (De Mesel *et al.* 2015). Initial colonisation can evolve into a biodiverse community of species from a large number of phyla (Coolen *et al*. 2020).

During and post-construction, the initial speed of species colonisation depends on timing of the introduction of new surfaces in relation to the major and secondary plankton blooms. At Barrow OWF, an epifaunal survey carried out eight months after installation of the piles (RSK ENSR 2006) reported a typical fouling community dominated by barnacles, mussels, anemones (*Metridium senile*) and hydroids. Large numbers of shrimp (*Crangon* spp.*)* and whiting were observed, particularly where mussel populations were well developed; this highlights the development of complex ecologies through trophic interactions and provision of micro-habitats. The development and long term dynamics of fouling communities is well studied in various environments e.g. Butler & Connolly (1996; 1999), and oil and gas structures, and renewable energy monopiles and floating foundations, display a similar species succession.

A 10 year study by Kerckhof *et al.* (2019) identified three distinct succession states: 0-2 years (a relatively short pioneer stage, these colonizing species can include non-native species, e.g. De Mesel *et al.* 2015); 3-5 years (a more diverse intermediate stage, characterised by large numbers of suspension feeding invertebrates) and 6+ years (a third "climax" stage, co-dominated by anemones and mussels), this latter stage aligning with observations at offshore oil and gas platforms where mussels, hydrozoans and anemones dominated the older and deeper sections (Coolen *et al.* 2020). These communities in turn, can attract larger species such as crabs and lobsters (e.g. Krone *et al.* 2017).

Non-indigenous species are generally found in the intertidal and splash zones, with subtidal records of non-native species being scarce (De Mesel *et al*. 2015, Degraer *et al.* 2020, Coolen *et al*. 2020). Non-indigenous species may exploit new niches in the indigenous communities and become invasive, i.e. in outcompeting native populations of species of similar niches e.g. the intertidal seaweed *Sargassum muticum* (Farnham *et al.* 1981) which spread along the south coast of England at rate of about 30km/year, or catastrophic ecosystem change through trophic proliferation e.g. the planktonic, carnivorous sea gooseberry *Mnemiopsis leidyi* in the Caspian Sea (Ivanov *et al.* 2000, Shiganova *et al.* 2004).

In areas where natural hard substrata are rare, high numbers of artificial constructions favour the establishment of taxa such as cnidarians and mussels whose life histories include temporary or permanent attachment to solid substrates (Richardson *et al.* 2009). Many similarities have been found in the establishment, succession and distribution of epifouling communities on structures and scour protection; at Horns Rev and Nysted OWFs the differences in species composition were mainly attributable to differences in salinity between the two sites (DONG Energy *et al.* 2006). The introduction of turbine foundations and scour protection resulted in greater habitat diversity and in the affected areas changed the typical infauna communities to hard bottom communities (DONG Energy *et al.* 2006).

Van der Stap *et al.* (2016) identified a total of 30 taxa as fouling organisms on the legs of five gas platforms sampled at a range of distances offshore in the southern North Sea (Netherlands sector). Through modelling, they demonstrated a significant non-linear relation between species richness and with water depth: from a low richness in shallow waters, species richness increased with depth until 15–20 m, after which it decreased again. They also found that water depth, community age and the interaction between distance from shore and community age showed a significant effect on the species assemblages.

Faunal communities on artificial hard substrata may differ from those on natural hard substrata (People 2006, Wilhelmsson & Malm 2008, Andersson *et al.* 2010) and on soft bottoms (Barros *et al.*, 2001, Fabi *et al.* 2002, Langlois *et al.* 2006, Langhamer 2010). The colonisation of hard surfaces by epifaunal species at the FINO 1 research platform in the German Bight (28m water depth), have been described by Schröder *et al.* (2006). The overarching environmental effect from the physical presence of offshore wind parks appears to be reef creation (Lindeboom *et al.* 2011, DONG Energy *et al.* 2006).

A strategic review of OWF monitoring data associated with licence conditions (CEFAS 2010) indicated that the long term effects of epifaunal colonisation should be monitored and/or researched to address issues of concern, such as their potential as ‘stepping-stones’ for invasive species. The review concluded that epifaunal colonisation of monopiles could result in a localised increase in species diversity, but whether this was a ‘beneficial’ impact as was often predicted in Environmental Statements, was debatable and highly subjective as the colonising species were different from the original community. The review recommended that benthic monitoring associated with OWF development should link with national monitoring programmes (such as National Marine Monitoring Programme - NMMP), to support the interpretation of any community change by informing on whether similar change has been noted regionally or historically.

Monitoring of concrete wind turbine foundations 30km off the Belgian coast (Kerckhof *et al.* 2010) showed that the overall structure of the marine biofouling assemblage at the Thornton Bank site was similar to that on the foundations of other offshore wind farms in Germany, Denmark and the Netherlands, as well as on other hard structures in the North Sea. The amphipod *Jassa herdmani* was found to be a key species at turbine foundation reaching densities of up to 200,000/m^2; it is a short-lived, highly fecund, tube builder and constitutes an important food source for fish species associated with the hard substrata (Reubens *et al.* 2010).

Non-native invasive species have been recorded on wind turbine foundations (Leonard & Birklund 2006, de Mesel *et al*. 2015) during the course of routine monitoring programmes; the caprellid amphipod *Caprella mutica* was first recorded in Denmark from offshore wind turbine monopiles, along with the marine splash midge *Telmatogeton japonicus* (Leonard & Birklund 2006). *Caprella mutica* is indigenous to coastal waters of north-east Asia and was first recorded in European waters in 1995. During investigations of the macrobenthic fouling community on the concrete foundations of the first Belgian offshore wind turbines De Mesel *et al.* (2015) described the prominent vertical zonation from splash zone down to the deep sublittoral. From a species count of 80, ten non-indigenous species were recorded, the highest proportion occurring in the intertidal (eight out of 17 species).

In their study looking at benthic communities at infrastructure off the Dutch coast, Coolen *et al.* (2020) used raw data from the study of wind turbine foundations and rock dump at the Princess Amalia Wind Farm (PAWF) (surveyed between 5 and 6 years after deployment, samples taken from the intertidal zone and at 2, 5, 10 and 17m depth), for comparisons with oil and gas platform data. Eleven non-native species were identified from the PAWF data, four of which were also present from the platforms: *Caprella mutica*; *Monocorophium sextonae*; *Telmatogeton japonicus* and *Magallana gigas*.

Monitoring studies at Egmond aan Zee (Bouma & Lengkeek 2012) identified the occurrence of several non-indigenous species including the skeleton shrimp (*Caprella mutica*), the crustacean *Jassa marmorata*, these being the most abundant, the titan acorn barnacle (*Megabalanus coccopoma*), the acorn barnacle (*Balanus perforatus*), the Pacific oyster (*Crassostrea gigas*) and the marine splash midge (*Telmatogeton japonicus*); several of these species were also identified at Horns Rev.

Specimens of *Balanus perforatus* (a warm water species spreading into the North Sea) were found to have colonised the concrete foundations of the turbines at the Thornton Bank windfarm in the Belgium sector of the North Sea, but suffered mortality caused by predation and smothering. Large individuals were also found surviving under the mussel cover. As with any species with plankton larvae, spatfall success varies annually which will affect the epifauna community structure of wind farm turbines. At Thornton Bank for example, a good spatfall of *B. perforatus* was observed in 2008 (autumn) with that of 2009 being less successful.

Visual inspection of the structures and their associated subcomponents, (i.e. turbines, mooring lines, suction anchors and infield cables) at the Hywind Scotland Pilot Park, found no confirmed non-native taxa, although several individuals of lobster *Homarus* spp. were observed and it could not be determined if these included the non-native species *H. americanus*, known to be present in the North Sea. The use of ROV for the inspection survey without physical sampling, made it difficult to distinguish between *H. gammarus* and *H. americanus* (Karlsson *et al*. 2021).

In comparison to studies where non-native species have or have possibly occurred, long term monitoring of infrastructure at the Lysekil research site[156] on the west coast of Sweden (surveys conducted in 2007, 2008, 2016-2019), found no occurrence of non-native species (Bender *et al.* 2020). The review of post development UK offshore windfarm monitoring (MMO 2014a) indicated that the studies to date had not recorded non-native species present on infrastructure.

Biofouling assemblages on wave energy devices may differ to those found on marine wind energy infrastructure, these typically are in high energy environments, and isolated from the seabed. Samples from the prototype Pelamis wave energy converter deployed at the Billia Croo wave test site, Orkney were taken ~3 years after deployment for sea trials. When not at sea, the Pelamis prototype was berthed at Lyness Harbour. Samples from the shallow (0-0.25m) zone contained two non-native species, *Dasysiphonia* (=*Heterosiphonia*) *japonica* and *Schizoporella japonica*, with *Corella eumyota*, *Caprella mutica*, *S. japonica* and *Bugulina fulva* found in the deeper sections (0.5-2m) (Nall *et al.* 2017). None of these were abundant and all were already known to be present in Orkney with all (except *S. japonica*) previously recorded at Lyness Harbour (Nall *et al.* 2015, 2017). The transition from the algae-dominated shallow parts of the structure to deeper invertebrate-dominated communities displayed typical vertical zonation seen on many other offshore and coastal structures (Terry & Picken 1986; Yan *et al*. 2009; Kerckhof *et al*. 2010, Nall *et al.* 2017).

[156] First deployment of infrastructure (Datawell radar buoy) was in 2004, followed by deployments of linear generators and cables (ca. 2006) with a further 21 “ecological foundations” (foundations without generator for ecological studies) deployed in 2007; each foundation being of cylindrical shape, ca. 3m diameter, 1m height and ca 10 tonnes (Bender *et al.* 2020).

A consequence of this increase in hard substrate epifauna is the production and accumulation of faecal and pseudo-faecal pellets, detritus around OWF turbine piles (McKindsey *et al.* 2011; Coates *et al.* 2014), and suspended particulate matter (SPM). Pseudo-faeces are rejected mucus-bound pellets of fine-grained material produced discarded by filter feeders (Maar *et al.* 2009, Ysebaert *et al.* 2009, McKindsey *et al.* 2011). Increased numbers of filter feeding mussels (Winter 1973, Clausen & Riisgård 1996) may influence particle and nutrient fluxes between the water column and the sediment, thereby potentially affecting the plankton biomass (Wilhelmsson & Malm, 2008). Mussels shells provide secondary hard substrate attractive for other epifaunal organisms (Norling & Kautsky 2007). The detrital fall of mussel shells can modify the sediment grain size where shells aggregate at the seafloor, providing new habitats for sessile organisms which require solid attachment sites, and for typical hard bottom crabs (Wolfson *et al.* 1979, Freire & González-Gurriarán 1995, Riis & Dolmer 2003). Other organisms such as the amphipod *Jassa herdmani* and the hydroid *Tubularia* spp. filter the water column and build tube-like structures that trap SPM (de Mesel *et al.* 2015).

In offshore areas SPM typically consists of fine mineral and organic particles (e.g. Fettweis *et al.* 2006) with settling velocities of generally less than 1 mm/s (Manning *et al.* 2010). In contrast, the larger pseudo-faecal pellets have settling velocities of a few cm/s (Giles *et al.* 2009, McKindsey *et al.* 2009). This results in high deposition rates near the turbine foundations, causing a fining of the sediment and enrichment in organic matter at the seabed (Coates *et al.* 2014). The biogenic fluff (Orvain *et al.* 2003) favours the establishment of a benthic community dominated by opportunistic deposit feeders. In the North Sea, Krone *et al.* (2013b) observed that wind turbine foundations concentrated 35 times more macrozoobenthos biomass per unit area of seafloor than was the case for the reference soft bottom sediments. Aggregations of marine biota at wind turbines and other structures will therefore change the local invertebrate communities, biomass and the local physico-chemical conditions (Wolfson *et al.*, 1979, Freire & González-Gurriarán 1995, Page *et al.* 1999, Wilhelmsson *et al.* 2006, Falcão *et al.* 2007, Krone *et al.* 2013b).

Gas and oil platforms and pipelines in the North Sea have supplied hard substrate 'islands' for colonisation through fouling for the last 60 years and the long–term dynamics of these epifaunal communities is relatively well documented (Whomersley & Picken 2003). *Lophelia pertusa* has been found on a number of oil and gas platforms in the northern North Sea (Roberts 2002, Gass & Roberts 2006). Such observations demonstrate the ability of a species with pelagic larvae to use any suitable substrate to extend its range. The ongoing discussion around using obsolete offshore structures for artificial reefs, e.g. to aid in the conservation of *Lophelia pertusa,* and promote habitat restoration in the North Sea (Bergmark & Jørgensen 2014) highlights that marine structures and the functional pathways created may have some positive effects. The addition of artificial reefs in shallow waters is a well-established practice in the Gulf of Mexico, and the *Paguro* wreck in the Mediterranean Sea was established as a Biological Protection Area in 1995 and a number of redundant installations have been placed over it. In the North Sea (where natural reefs are not uncommon) the creation of artificial reefs from decommissioned platforms remains against UK policy, its commitments under OSPAR, and depending on water depths, obligations under UNCLOS[157].

The colonial ascidian, *Didemnum vexillum* is an invasive non-native species established in the UK. This fast growing species is usually found in low energy environments and can rapidly cover areas, smothering native organisms (including scallops, mussels and oysters) and habitats. The planktonic larval stage is short (ca. 3-4 hours) but broken off pieces of the colonies can be transported over large distances by currents before settling in new areas. A

[157] https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

three year benthic habitat and wind turbine epifaunal monitoring study was undertaken at the Block Island Wind Farm (BIWF) Project Area, some 4.5km off Rhode Island, USA. Installation of 5 turbines in water depths of 10-55m was between July 2015 and November 2016 (HDR 2020). *Didemnum vexillum* was recorded as present on all five turbines (see example Figure 5.25). Whilst the occurrence of this species at BIWF was notable, it was concluded this did not constitute a range expansion of the species, as it is already prolific in the region (HDR 2020).

Monitoring reports available to date in the UK have not recorded *D. vexillum* on renewable energy structures, nor have descriptions of marine growth on oil and gas infrastructure included reference to this species. The projected number and geographic spread of structures associated with the draft plan/programme and the increased number of vessels used may facilitate the future spread of the species.

At developments where the study of monopile colonisation continues through an environmental monitoring programme, the emerging long term data sets of species succession, annual variability and community change will be increasingly valuable in the detection and tracking of non-native invasive species. However, while inspections are carried out on oil and gas structures and there is post-construction monitoring of wind developments, which can include the requirement to identify the occurrence of non-native species, there remains a lack of systematic monitoring for the occurrence of non-native species on offshore infrastructure.

Figure 5.25: A mat of *Didemnum vexillum* growing on foundation structure (top) and on live mussels (bottom)

Source: HDR (2020).

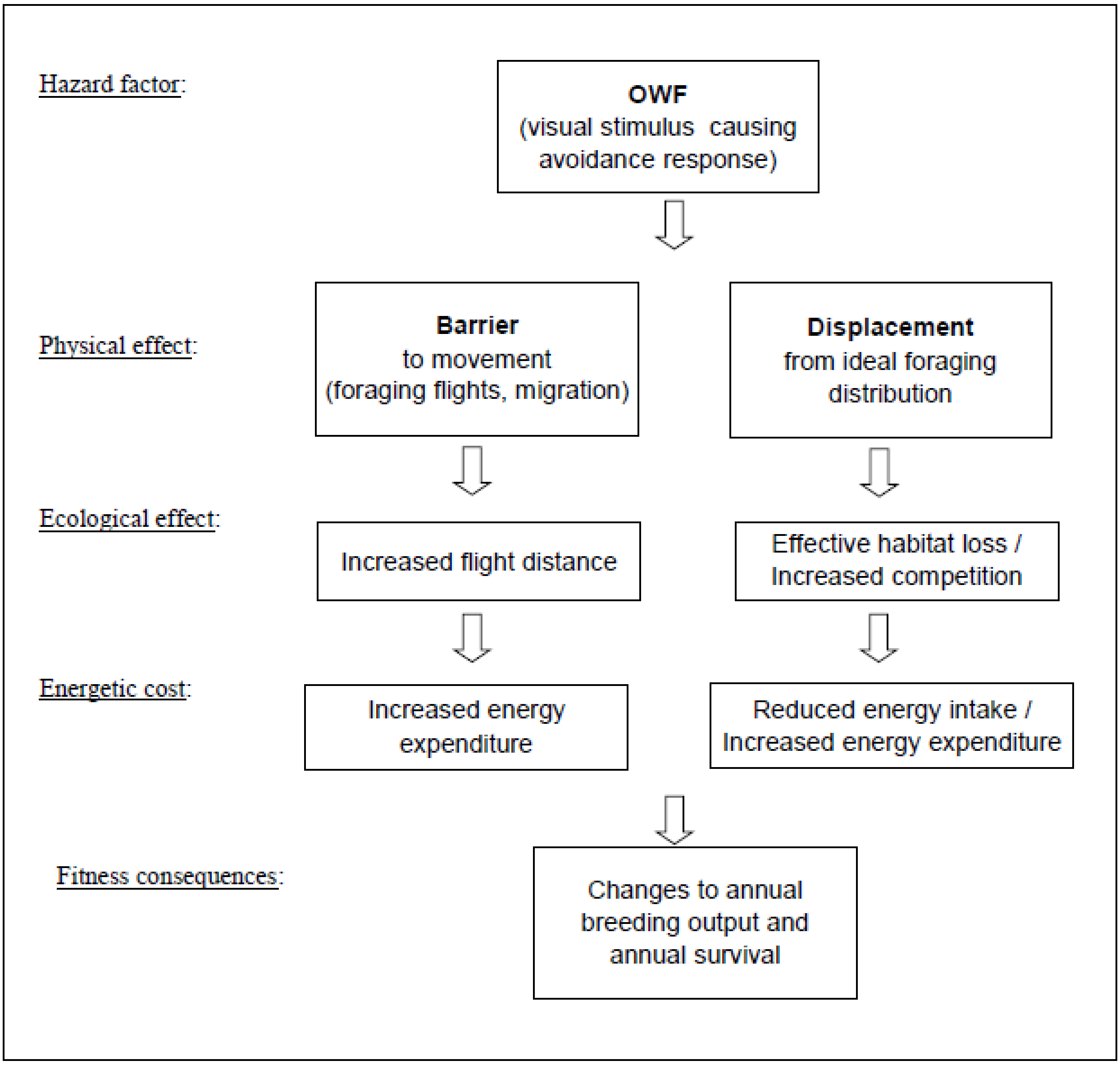
5.6.3.2 Barrier to movement, displacement and other behavioural effects – marine birds

Offshore wind farms and associated shipping traffic

In relation to birds, the potential displacement/disturbance and barrier effects of offshore wind farms and associated shipping traffic (i.e. during construction and maintenance during the operational life of the development) have been extensively recognised and previous SEAs (OESEA, OEASEA2 and OESEA3) have described studies on displacement/disturbance and barrier effect, including those from OWF developments (e.g. Petersen *et al.* 2004, 2006, 2014, Percival 2013, 2014, Drewitt & Langston 2006, Fox *et al.* 2006, Stienen *et al.* 2008, Norman *et al.* 2007, Masden *et al.* 2009, Krijgsveld *et al.* 2011, Krijgsveld 2014, Searle *et al.* 2014, Busch *et al.* 2015, Busch & Garthe 2016, Dierschke *et al.* 2016, Mendel *et al.* 2019, Fox & Petersen 2019, Vilela *et al.* 2020).

The main impacts/effects from displacement/disturbance and barrier are summarised in Figure 5.26. However, there is still little convincing data showing the mechanistic links from displacement/disturbance and barrier impacts to demographic consequences and significant effects at population levels and it remains difficult to disentangle effects from other unrelated sources of variability in seabird abundance at a OWF location e.g. changing habitat or prey availability.

Figure 5.26: Barrier and displacement effects illustrated (from NE-JNCC (2017), adapted from Petersen *et al.* 2006)



From initial publication in 2012, and following a displacement workshop in 2015, the joint SNCB[158] displacement advice note was updated (NE-JNCC 2017), resulting in a more refined, but interim, best practice approach to assess displacement impact (the intention being to update the guidance as and when empirical evidence becomes available). This guidance provides a definition of the disturbance, displacement and barrier terms (summarised below, Table 5.15) (and Figure 5.2 above), and also highlights they define displacement as affecting birds present both in the air and on the water and interpret barrier effects to mean applying to birds in flight[159]. NE-JNCC (2017) states a key distinction between barrier and displacement is that *birds experiencing barrier effects typically travel longer distances (i.e. to some point beyond the*

[158] The joint Statutory Nature Conservation Bodies for this are Joint Nature Conservation Committee (JNCC), Natural Resources Wales (NRW), Department of Agriculture, Environment and Rural Affairs / Northern Ireland Environment Agency (DAERA/NIEA), Natural England (NE) and NatureScot
[159] Joint SNCB Interim Displacement Advice Note https://hub.jncc.gov.uk/assets/9aecb87c-80c5-4cfb-9102-39f0228dcc9a

OWF) and did not intend to forage/utilise the OWF site itself. The interim guidance also provides further clarity on the application of the "matrix approach"[160] for assessment.

Table 5.15: Definitions of disturbance, displacement and barrier effects

Disturbance	Displacement	Barrier
When a bird's normal pattern of activity is interrupted by an anthropogenic activity. Birds may choose to sources of disturbance (e.g. by swimming or flying away during the disturbance event to continue their activity elsewhere) and may not return until some time later – the duration of return time coupled with frequency of disturbance event, may combine to result in longer term and potentially continual reductions of numbers in an area of impact (displacement) which may be partial or total.	In relation to offshore wind farm development, following Furness *et al.* (2013) displacement definition (see below). Displacement, as an effect, may occur both in the area of the disturbance or development and to some distance beyond it. The degree of displacement, both in terms of length of time and proportion of the original source population affected, may vary seasonally and between species. Birds that would have previously passed through the footprint of the disturbance area to a more distant feeding, resting or nesting area, but now choose either to stop short or detour around the location are said to be affected by barrier impacts.	A barrier is a physical factor that limits the migration, or free movement of individuals or populations, thus requiring them to divert from their intended path in order to reach their original destination. Barrier effects are more likely to result in individual/population level impacts, if they occur during the breeding season (and at colonies close to an OWF).

Source: NE-JNCC (2017) definitions

At present, the priority species for assessment of displacement are typically diver and sea duck species, guillemot, razorbill, puffin and gannet; of these, diver and sea duck are considered the most sensitive species groups to offshore development and as such should have a 4km displacement buffer in assessments, instead of the standard 2km displacement buffer (NE-JNCC 2017). Given the empirical evidence currently available, it is generally unlikely that cormorant and gull species require routine displacement assessment, as the evidence has shown these to be attracted to or show no noticeable reaction to the presence of OWFs.

Both disturbance/displacement and barrier effects are closely related to avoidance behaviour; the stronger the avoidance of the wind farms, the higher the potential effects (barrier and displacement) of these wind farms. Conversely, in terms of collision, the stronger the avoidance behaviour, the lower the potential collision risk (see Section 5.6.3.4 below on collision risk).

In their 2013 review, Furness *et al.* defined displacement as a reduced number of birds occurring within or *immediately adjacent to* offshore wind farms – this area adjacent to the OWF termed a buffer. Using a sensitivity index incorporating disturbance, habitat specialisation and conservation importance elements, Furness *et al.* (2013), focusing on marine birds in Scottish waters, identified populations of divers (red, black and great northern) as most vulnerable to population level impacts of displacement/disturbance, followed closely by common scoter and several other diving species (e.g. greater scaup, eider, goldeneye, certain grebes and black guillemot). Following the methods of Furness *et al.* (2013) and others, Bradbury *et al.* (2014) produced updated species specific sensitivity indices for species' populations risk due to

[160] The data on predicted displacement from an OWF site should be presented in the form of a gridded matrix table, which has the Displacement Level (% of all birds on site) against the Mortality Level (% of displaced birds that die), with cell entries presenting the estimated number of birds of a given species predicted to be at risk of adult mortality following displacement during a particular season https://hub.jncc.gov.uk/assets/9aecb87c-80c5-4cfb-9102-39f0228dcc9a

displacement relevant to English waters; this also identified divers and common scoter as high vulnerability to displacement. Although now dated, both publications represent a good initial point from which to identify the sensitivities of certain species to wind farm effects. While no value was implied by the scores, species with higher index scores are considered more sensitive to such impacts, recent research and monitoring appears to further confirm the basis of much of the work.

Dierschke *et al.* (2016) undertook a review of post-construction studies of seabirds from 20 OWFs in European waters (North Sea, Baltic Sea and Irish Sea) extracting evidence for displacement or attraction for 33 different seabird species and classifying these into five different groups: Strong Avoidance; Weak Avoidance; Indifferent Behaviour (no WF effect); Weak Attraction and Strong Attraction, see Table 5.16.

Table 5.16: Species behaviour classification

Strong Avoidance[1]	Weak Avoidance[2]	Indifferent[3]	Weak Attraction[4]	Strong Attraction[5]
Great crested grebe Red-throated diver Black-throated diver Northern gannet	Long-tailed duck Common scoter Northern fulmar Manx shearwater Razorbill Common guillemot Little gull Sandwich tern	Common eider. Black-legged kittiwake Common tern Arctic tern	Common gull Black-headed gull Great black-backed gull Herring gull Lesser black-backed gul Red-breasted merganser	Great cormorant European shag

Notes: Characterisation of behaviour: [1]Complete absence or very strong decrease in abundance in a marine area, which had been used by the species before WF construction, [2]Continued use of a marine area after construction, but to a lesser degree or at a lower abundance, [3]The presence of the WF has little or no influence on the occurrence in or the usage of the respective marine area, [4]Continued use of a marine area after construction, but to a higher degree or at a higher abundance and [5]Large increase in numbers in a marine area, which had been little used by this species pre-construction. Source: Dierschke *et al.* (2016)

In a review of priority evidence requirements of OWF impacts, which included species identified through previous advice, species flagged as possible consent risks, and species identified as ornithological constraints in sectorial marine plans, O'Brien *et al.* (2021) also identified displacement as a potential impact pathway for Atlantic puffin, black-legged kittiwake (hereafter kittiwake), Manx shearwater and razorbill.

There remains a degree of uncertainty on the impact of displacement, but there is general agreement that the species group most sensitive (compared to other seabird species) to the presence of OWF and associated support traffic (in terms of disturbance/displacement), are divers, particularly red-throated diver (e.g. NE-JNCC 2017, Cuttat & Skov 2020, also see O'Brien *et al.* 2021 for species where displacement has been identified as an impact pathway, and further evidence on impacts of OWF developments has been identified as a priority).

An estimated 1,250-1,600 pairs (RSPB website, BTO website, Dillon *et al*. 2009), of red-throated diver are thought to breed in the UK, all in Scotland (ca. 33% in Shetland, 8% in Orkney, 26% and 17% in Outer and Inner Hebrides respectively, and 17% elsewhere in Scotland) (Dillon *et al*. 2009). This is an opportunistic forager using both freshwater and marine environments. In some areas (i.e. Siberia) where birds breed far inland away from the coast, these forage in freshwater habitats, (Eriksson *et al*. 1990, Eriksson & Sundberg 1991, Duckworth *et al*. 2020b), while birds that breed closer to the coast, as seen in the UK, tend to forage in marine environments (Reimchen & Douglas 1984, Rizzolo *et al*. 2015, Black *et al*. 2015, Dierschke *et al*. 2017, Duckworth *et al*. 2021). During the early chick feeding period, benthic dives are expected to dominate, (benthic invertebrates can form a large part of chick diet, due to the small prey size), with a wider array of larger benthic and pelagic prey provided as the chicks grow (Reimchen & Douglas 1984).

The importance of a number of areas for this species has been reflected in the designation of a suite of SPAs for breeding sites (and adjacent marine foraging areas) and overwintering areas. In 2000, the breeding site SPAs were estimated to hold 30.5% of the Great Britain breeding population (Stroud *et al*. 2016). The current conservation status of seven of the ten terrestrial SPA breeding sites are in a favourable condition[161] (6 at Favourable Maintained and 1 at Favourable Declining), with the other three listed as Unfavourable Declining. The condition at sites (designated in 2020) to protect foraging areas at sea used by red-throated divers breeding at adjacent areas, are listed as not assessed.

The UK is also important for non-breeding red-throated diver, with wintering numbers estimated at between 17,000 (O'Brien *et al*. 2010) and 22,000 (BTO Website - Birdfacts) birds. Although highly mobile during this period, with marine areas in the North Sea and Irish Sea being used, individuals are thought to be relatively site faithful in winter (Dierschke *et al*. 2017). High concentrations of wintering birds are present along the coast from the Wash to the Thames and in Liverpool Bay (e.g. Lawson *et al*. 2016a,b) and the importance of these areas and the numbers they support has been reflected in SPA designations (i.e. Liverpool Bay SPA, Outer Thames Estuary SPA, Greater Wash SPA). The species can exploit a range of marine habitats (around the UK, they are thought to prefer waters over sandy substrates, of depths <20m, but can be found over deeper waters) and prey species, feeding predominantly on small fish (e.g. herring, sprats, sandeels) during winter, but able to switch to alternative prey (e.g. cod, flounder) depending on availability.

As part of the application for East Anglia One north and East Anglia Two OWF[162], MacArthur Green/Royal HaskoningDHV (on behalf of Scottish Power Renewables and in response to consultee (Natural England) representation), reviewed existing studies on the displacement of red-throated divers from OWF areas (MacArthur Green 2021a). Amongst other things, this review highlighted the differences in data collection; aerial survey (e.g. Vilela *et al.* 2020); boat surveys (e.g. Gill *et al.* 2018 Heinänen & Skov 2018) and different survey methods (aerial and boat) (e.g. Mendel *et al.* 2019, HiDef 2017) with displacement/avoidance in OWF areas recorded in all studies to a lesser and greater extent. However, care is needed when interpreting results, particularly when effects or impacts are termed significant, for example, has significance been defined; what is the spatial (size of survey area) and temporal (long or short term data set) extent of the survey and, are results transferable to other areas beyond that of the study. The majority of the studies reviewed also included data on areas near the OWF, with variability in the distance at which effects were evident.

Displacement effects for divers, and specifically red-throated divers, from wind farms have been detected at greater distances than that suggested in the interim displacement advice note (NE-JNCC 2017), e.g. 5-6km, Petersen *et al.* 2014; 5-7km, Webb 2016; 8km, HiDef 2017; 10-16.5km, Mendel *et al.* 2019, Heinänen *et al*. 2020, APEM 2021; 10km, MacArthur Green 2019b; 10-15km, Dorsch *et al.* 2019. However, this displacement is highly variable and there are likely

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[161] Site condition monitoring is used to determine the condition of the site/designated feature within the site, to ascertain whether or not the feature is likely to maintain itself in the medium to longer term under the current conditions of the site. NatureScot assigns one of eight condition categories to each of the designated features of a site and these are described here: https://www.nature.scot/professional-advice/protected-areas-and-species/protected-areas/site-condition-monitoring/assessment-condition

[162] Displacement of red-throated divers in the Outer Thames Estuary SPA – Deadline 11 Update: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010077/EN010077-005242-ExA.AS-2.D11.V5%20EA1N&EA2%20Displacement%20of%20red-throated%20divers%20in%20the%20Outer%20Thames%20Estuary.pdf

to be location-specific factors which do not necessarily make such effect distances universally applicable (MacArthur Green 2019b, Vilela *et al.* 2020).

While significant displacement effects can be detected at some distance from the boundaries of wind farm arrays (Mendel *et al*. 2019, Heinänen *et al.* 2020), this does not necessarily result in complete displacement of the species from the array or its immediate vicinity (e.g. as noted in UK windfarms monitoring data (e.g. Percival 2014, NIRAS 2016, HiDef 2017, APEM 2021).

Heinänen *et al*. (2020) also noted that displacement effects appeared greater at night, possibly in reaction to the navigation lighting of the turbines, though it is assumed that divers do not forage at night as it is too dark for these visual foragers to see their prey, or prey is not available at night (e.g. Duckworth *et al.* 2020). Season (e.g. Spring/Winter - Vilela *et al*. 2020) and other factors such as water depths, salinity and other anthropogenic factors such as proximity to shipping traffic, may also affect displacement effects (e.g. Heinänen & Skov 2018).

Shipping traffic can be a source of disturbance to some seabird species, particularly scoter and diver species (e.g. Fliessbach *et al.* 2019, Mendel *et al.* 2019, Dorsch *et al*. 2019, see also Garthe and Hüppop 2004, Jarrett *et al.* 2018), with inter- and intra-specific differences seen. The expectation is that an increase in traffic associated with windfarm construction and operational maintenance could lead to a potential increase in this disturbance. Birds disturbed by shipping traffic generally respond in one of two ways, either flying off, or escape diving (Fliessbach *et al.* 2019) and the flush distance, i.e. the distance at which the source of anthropogenic disturbance can elicit a response in the bird, will depend on how sensitive that bird is to traffic; flush distance is also variable within a species (Schwemmer *et al.* 2011). Ship speed has an effect on diver responses (Dorsch *et al.* 2019), with resettlement of the disturbed area taking longer from disturbance from high speed vessels, compared to that caused by slow or medium speed vessels. Although these behavioural responses can have an impact on the birds' foraging or resting habits (e.g. Schwemmer *et al.* 2011, Rodgers & Schwikert 2003, Kaiser *et al.* 2006), with shipping associated with OWFs alone found to have a strong negative effect on red-throated diver abundance (e.g. Mendel *et al*. 2019), the extent and significance of the effects of ship traffic is still poorly understood.

A factor influencing understanding of the impact of displacement is evidence of whether habituation[163] to the OWF will occur; is the displacement going to be long term or permanent and what implications does this have at an individual or population level. There is a general lack of evidence to show habituation (too few studies, of insufficient duration), with conflicting evidence of habituation, including between different studies of the same species (Busch *et al*. 2015 – see also Masden & Boertmann 2008 and Hötker *et al.* 2006, these looking primarily at onshore windfarms, with the latter suggesting signs of habituation by common eider, common scoter, oystercatcher, common and black-headed gull). After a period of strong avoidance, common scoter densities increased within the Horns Rev offshore wind farm area (Petersen & Fox 2007, Leonhard *et al.* 2013), in contrast, studies around Nysted showed no evidence of habituation of another seaduck species, the long-tailed duck (e.g. Petersen *et al.* 2006).

In their review, Dierschke & Garthe (2006) stated that habituation had been demonstrated for several small (coastal) wind farms, which are regularly crossed by cormorants, ducks, gulls and terns, transiting between breeding colonies, roosts and offshore foraging areas (e.g. Still *et al.* 1996, Dirksen *et al.*1998a, b, Everaert 2003, as cited in Dierschke & Garthe 2006). Leopold & Verdaat (2018), in a pilot study observed birds from a turbine foundation over 2 days, found

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[163] Habituation is the capacity of an animal to become accustomed to and not react towards a repeated action or pressure such as disturbance.

some evidence of habituation of auks (common guillemot and razorbill – flying, swimming, and diving, presumably for food) to the Luchterduinen OWF and suggested a methodology to assess the extent of habituation. Long-term (i.e. >10 years) monitoring of operating wind farms is needed to provide information on the circumstances in which habituation does, or does not, occur (Busch *et al.* 2015).

Despite some wind farms being present within UK SPAs for wintering red-throated diver for many years (e.g. London Array), there is no strong evidence of habituation of this species to windfarm presence (e.g. Leonhard *et al.*, 2013, Percival 2014). Initial studies had suggested that red-throated diver were starting to habituate to the Kentish Flats OWF (e.g. Percival 2010), but subsequent studies suggested no habituation (Percival 2014). In addition, Mendel *et al.* (2019, see also Dorsch *et al.* 2019, who used the same data set), found no evidence of habituation by red-throated diver to OWF in the German Bight.

Based on the number of existing and projected OWFs there is concern on the possible impact this may have on red-throated diver (and other species) principally from potential habitat loss, particularly in regards to future development. Whilst the UK breeding population of red-throated divers (*ca*. 1,250-1,600 pairs) are concentrated in sites in Scotland, the UK wintering population (*ca*. 17,000-22,000 individuals), are aggregated in a few areas, including the Moray Firth, Firth of Tay, Liverpool Bay and the Greater Wash/Outer Thames, the latter of these estimated to hold the majority of the wintering UK population (e.g. Lawson *et al*. 2016a, Natural England & JNCC 2016, Irwin *et al*. 2019). Breeding and wintering populations can be variable, however, although now dated, an estimated 51,000 birds are thought to be concentrated along the southern North Sea coasts of England, the Netherlands, Germany and Denmark, during winter (Birdlife International 2004). Although a small proportion of the total biogeographic population (200,000-600,000 Wetlands International 2015), the UK makes a significant contribution to the European wintering population (O'Brien *et al.* 2010).

Since displacement by OWF development could result in loss of habitat/displacement into sub-optimal habitats it is important to understand their foraging behaviour during winter, their annual energy budget (and therefore body condition requirements (Duckworth *et al*. 2021, Dorsch *et al.* 2019) and to identify changes/trends in overall numbers within these wintering areas, along with the anthropogenic and natural causes of such changes.

A change in the spatial distribution of red-throated diver in an area does not necessarily have ecological consequences, as there may be enough suitable habitat, with sufficient food resources for any disturbance effect to be accommodated without affecting population size or bird condition. In long-lived species like red-throated diver (typical lifespan is 9 years, with breeding typically at 3 years, and a maximum age known from ringing was nearly 36 years (BTO birdfacts)), effects on breeding success can take many years to manifest at a population level (Vilela *et al*. 2020). Despite a globally decreasing population trend, the wide distributions and large populations in some areas means the species is not considered threatened on a global scale (Vilela *et al*. 2020, Birdlife International 2017). It is also important to understand the causes of changes in spatial distribution in an area, e.g. the presence of the OWF (construction, operation, decommissioning), or by other factors, such as prey availability.

To get an updated estimate of the red-throated diver population in the Outer Thames Estuary SPA, digital aerial surveys were carried out in 2018, this coincided with the extension of the boundaries of the SPA to include an additional ca. 95km^2 of sea (Irwin *et al*. 2019). In 2010, the peak mean estimate of the population at site designation was *ca.* 6,466 individuals (derived from visual aerial surveys between 1989 and 2006/07 (Natural England & JNCC 2010) and a peak population estimate of 14,161 from a digital aerial survey of the SPA in 2013 (APEM 2013). Spatial distribution results showed high densities and a widespread distribution, and from the southern part of the survey area, increased densities were noted either side of the shipping lanes and the London Array wind farm. It was suggested that these concentrations were indicative of displacement behaviour, which resulting in birds clustering (Irwin *et al*. 2019).

Red-throated diver do not usually occur in large, tightly aggregated flocks, with distributions tending to be at relatively low densities of single birds or very small groups (Webb *et al*. 2009, Garthe *et al*. 2015, Dierschke *et al.* 2017); large flocks of more than 50 birds do occasionally occur, but these may be for reasons other than feeding, e.g. in preparation for migration (Dierschke *et al*. 2017).

The peak estimate of red-throated divers across the whole Outer Thames SPA area was 22,280 individuals, with 21,997 of these within the original SPA boundary, and 228 from the extension (Irwin *et al*. 2019), a significant difference from the estimate of 6,466 individuals when the site was first designated in 2010; the peak of 22,280 recorded from this survey also suggests the wintering estimates (17,000-22,000) are an underestimate (if the figures can be compared because of differences in survey methodology), as this is for all wintering locations and not just the Outer Thames area. Irwin *et al*. (2019) included a qualitative[164] comparison of previous estimates of red-throated diver populations in the Outer Thames area. Although these showed variation between years, they did show a recent increase, and whilst the authors acknowledged that a full exploration of the original data would be required, there did appear to be a genuine increase in diver numbers in the survey area.

With the growing number of OWF (size and number of developments) in the German area of the North Sea, there have been concerns about the possible impacts on bird populations reliant on these areas, particularly red (and black) throated diver, the estimated populations for which (between autumn and spring) range from around 20,000 to 35,000 individuals (counts from 2003 through to 2017) (Vilela *et al*. 2020, 2021). The first OWF in the area (Alpha Ventus) was installed in 2009 with 12 turbines, and by 2019 the number of turbines in completed OWFs totalled 1,052, with a further 152 turbines under construction. The concern for potential impacts has resulted in a shift in consenting strategy for new developments (i.e. halted new OWF around the Östliche Deutsche Bucht SPA), and the repowering of existing developments. An analysis of digital aerial survey data spanning 18 years (2001-2018, broken down to 16 years for spring and 17 years winter), attempted to better understand the effect of OWF on diver displacement (Vilela *et al*. 2020, 2021).

The study found that the number of divers staging in the German North Sea, on average, remained similar (with fluctuations seen between years); the mean spring population was estimated at 16,330 divers during 2013–2018 when most of the wind farms were built, and 15,942 divers during 2002–2012[165] with few or no wind farms built. Strong avoidance behaviour to OWF was reported for divers from all recent studies, which, when calculated in terms of area (assuming a gradual avoidance by divers of about 10km around wind farms) accounted for 12% of the German North Sea EEZ area, while the total area impacted within the main concentration area for divers estimated at 35% (Vilela *et al*., 2020, 2021) – but which has shown no corresponding decline in average population size. This being consistent with results from Irwin *et al.* (2019), where avoidance/displacement was apparent, but with no population decline evident.

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[164] The previous surveys and the surveys carried out as part of the 2018 survey programme were not directly comparable as they followed different methods, survey areas, survey effort, changes in technology resulting in improved detection rates etc and no correction was included for bias (Irwin *et al*. 2019).
[165] 2006 and 2007 were excluded from this data set as no data were available for the spring season.

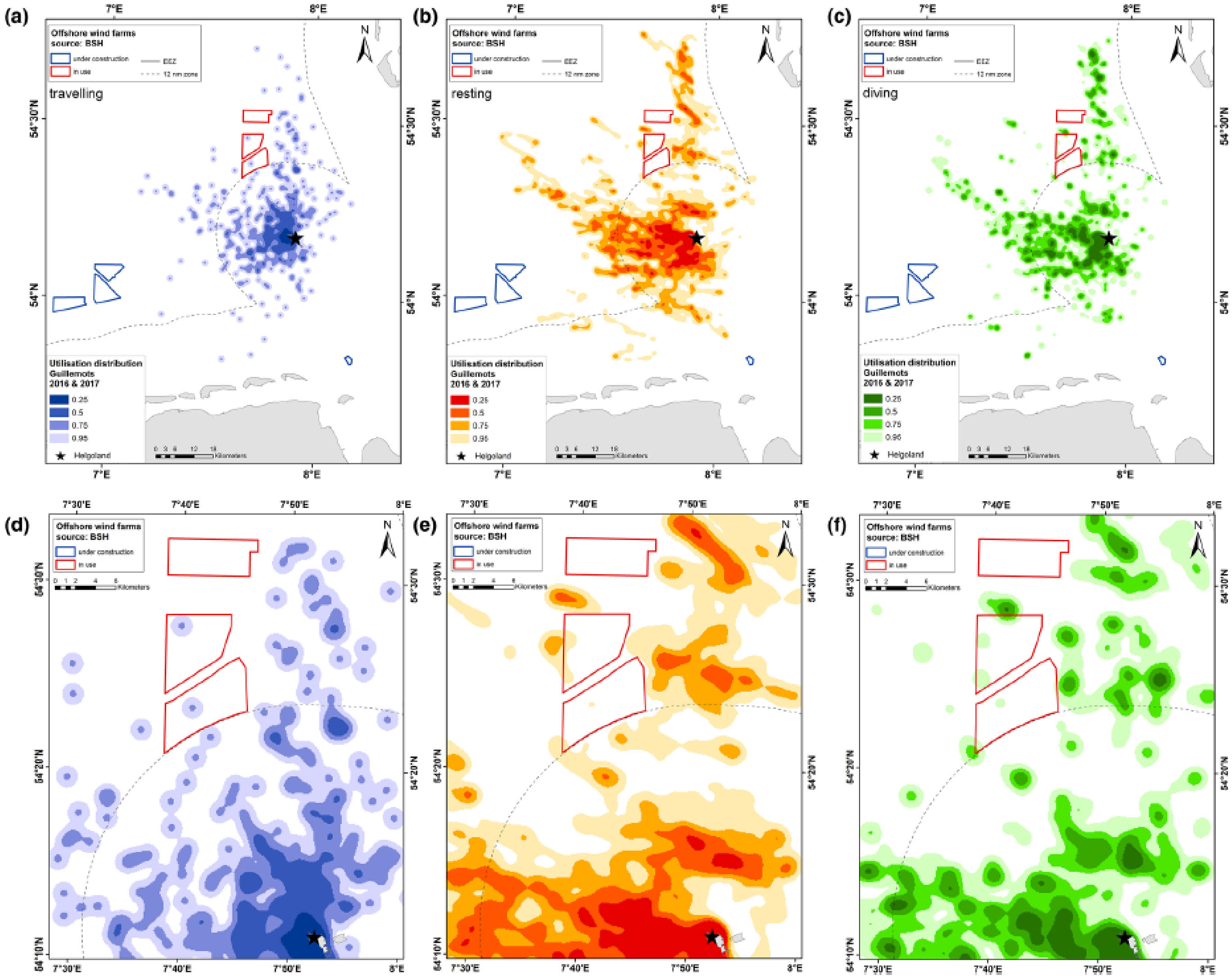
The German North Sea study indicated that since the construction of six OWFs in and around the main concentration area for divers, the population has become more localized in more central areas, increasing the density within these unaffected areas (e.g. Mendel *et al*. 2019 Irwin *et al*. 2019). This could result in a carrying capacity in these areas of concentrated diver densities being reached, increasing competition for food. This could force birds into other less favoured areas, and over time lead to a decline in numbers in the German North Sea.

For other species/groups of species, most auks, terns, cormorant and shag show intermediate vulnerability to displacement/disturbance, with auks, gulls, skuas, northern gannet (hereafter gannet) and pelagic seabirds (i.e. petrels and shearwaters) considered among the least vulnerable (Garthe & Hüppop 2004, Furness *et al.* 2013; Bradbury *et al.* 2014, MMO 2018, Fliessbach *et al.* 2019). However, other studies have shown gannet (Vanermen *et al.* 2015, Welcker & Nehls 2016, Dierschke *et al.* 2016, Garthe & Corman 2017 and Peschko *et al.* 2021) and guillemot (e.g. Vanermen *et al.* 2015 and Peschko *et al*. 2020), also show avoidance to OWF areas.

Two studies were conducted during the breeding season, one of guillemot and one of gannet, at the colony on Helgoland in the southern North Sea where three OWFs 23-35km north of Helgoland have operated since October 2015 (Peschko *et al*. 2020 & 2021). Twelve guillemots were tagged during 2016 and 2017 and GPS tracking, along with (spatio-temporal) point process model (PPM) analyses, and showed the majority of the tagged birds completely avoided the OWFs to the north (Figure 5.27), with one individual from each year entering the area on a small number of occasions.

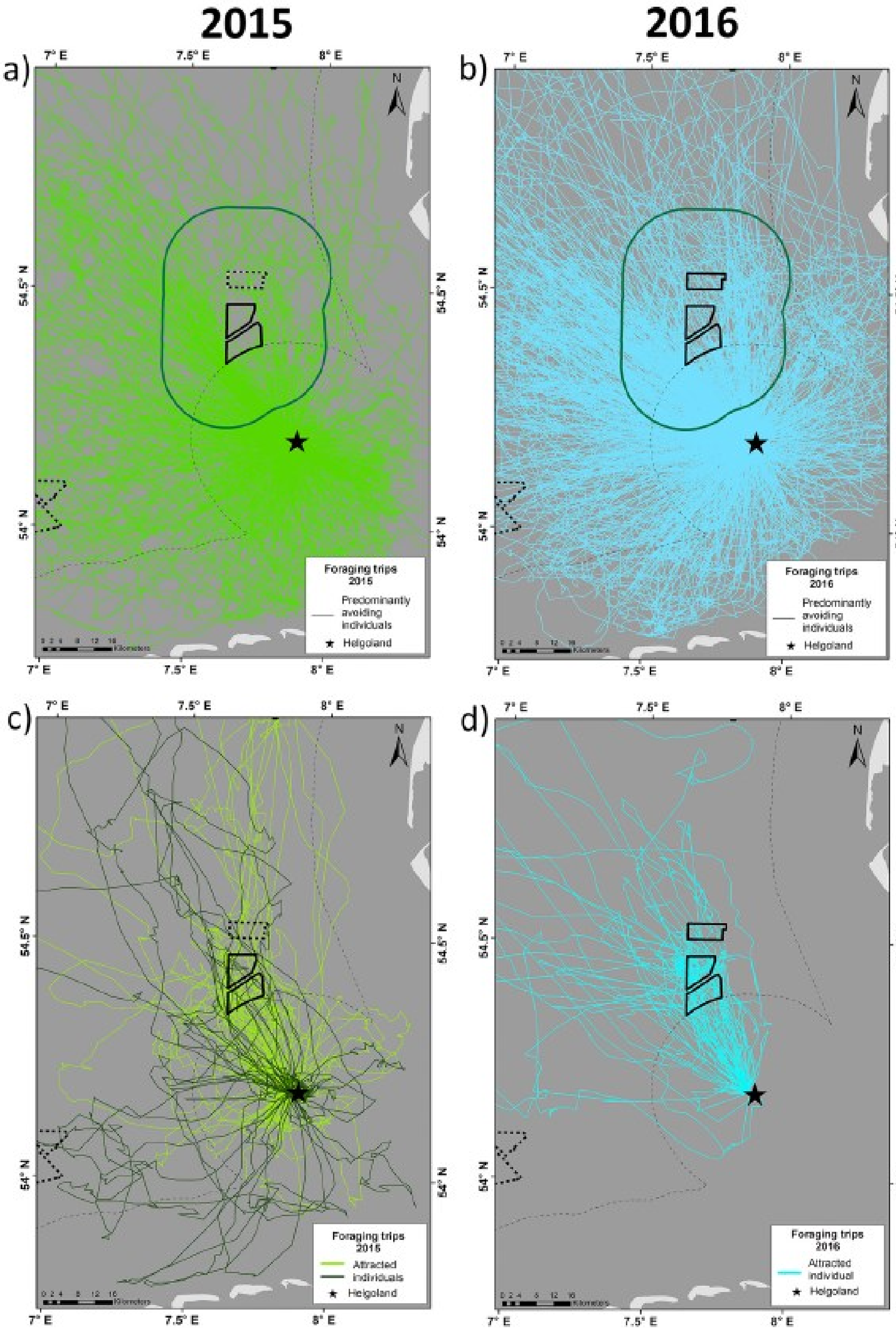
Twenty-eight adult gannets were tagged at the relatively small gannet colony at Helgoland, to record their movement and response to offshore windfarm areas, based on recorded foraging trips, behaviours and altitude (Peschko *et al.* 2021). Most (89%) were found to predominantly avoid the OWF areas; three individuals did frequently enter and mainly forage within the OWF area (see Figure 5.28). The majority of gannets were, therefore, thought to be displaced from the area during the breeding season, the implication being that loss of foraging habitat and increased flight distance at this time of year could have effects on energy and time budgets. This could reduce adult condition or survival, and in turn could reduce chick growth/survival and reproductive success. However, Peschko *et al.* (2021) acknowledged that based on current evidence, they could only speculate on whether the gannet's reaction to the OWF affected the birds in terms of energy budgets and reproductive success. Care must be taken in interpreting the significance of the results, behavioural analyses showed that birds identified as avoiding the OWFs, predominantly used areas south-west of the OWF for commuting between the colony and foraging areas, these areas were already intensely used before the OWF construction (Garthe *et al.* 2017), and no information is provided about the spatial distribution of gannets within the OWF area, prior to construction and operation.

Figure 5.27: Kernel densities of different activities of guillemots, tagged in 2016 and 2017 from the Helgoland breeding colony in relation to offshore windfarm areas.



Kernel densities of a) travelling, b) resting and c) diving positions of guillemots tagged in 2016 and 2017 and (d-f) zoomed to OWF area, smoothing factor h=650. Positions visualised as percentiles: dark colour = 25% percentile, lighter colour = 95% percentile. OWFs on the left of a, b and c were in use in 2017. Source: Peschko *et al.* (2020)

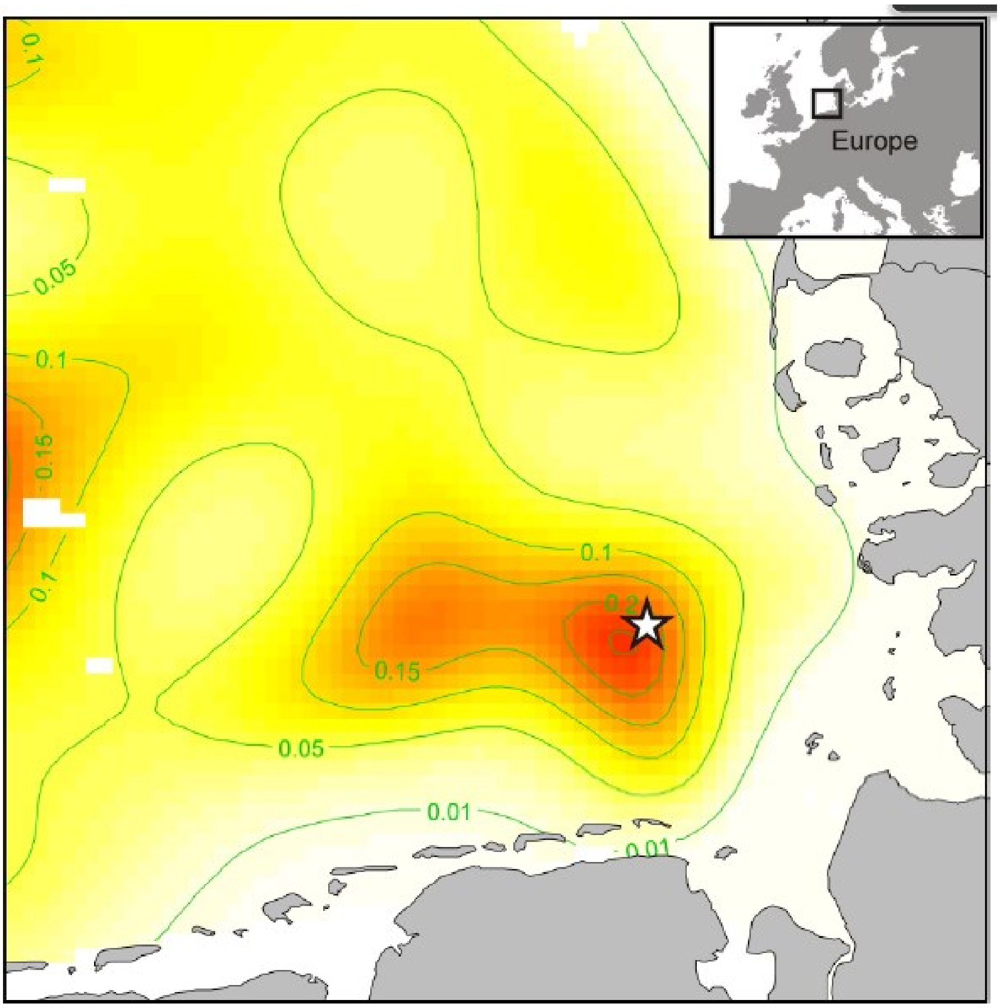
Figure 5.28: Flight behaviours of gannets tagged in 2015 and 2016



Notes: Flight behaviour of gannets tagged in 2015 (n= 10) (a) and 2016 (n=15) (b) that "predominantly avoided the OWF, gannets tagged in 2015 (n=1) (c) and 2016 (n=2) (d) that were classed as "attracted individuals. OWFs: dashed black = under construction, solid black = operating, dark green line = 15km buffer. Source: Peschko *et al.* (2021)

Gannets first established a breeding colony on Helgoland in 1991, with numbers increasing to an estimated 1,071 nest sites in 2017. From analysis of survey data (2005-2012), distribution of adults extended throughout most of the German Bight, with core areas of birds (counted at sea) to the west of the island, with another area in the far west and apparently not linked to Helgoland (Figure 5.29) (the closest gannet colony to Helgoland is >500km away) (Garthe *et al.* 2017).

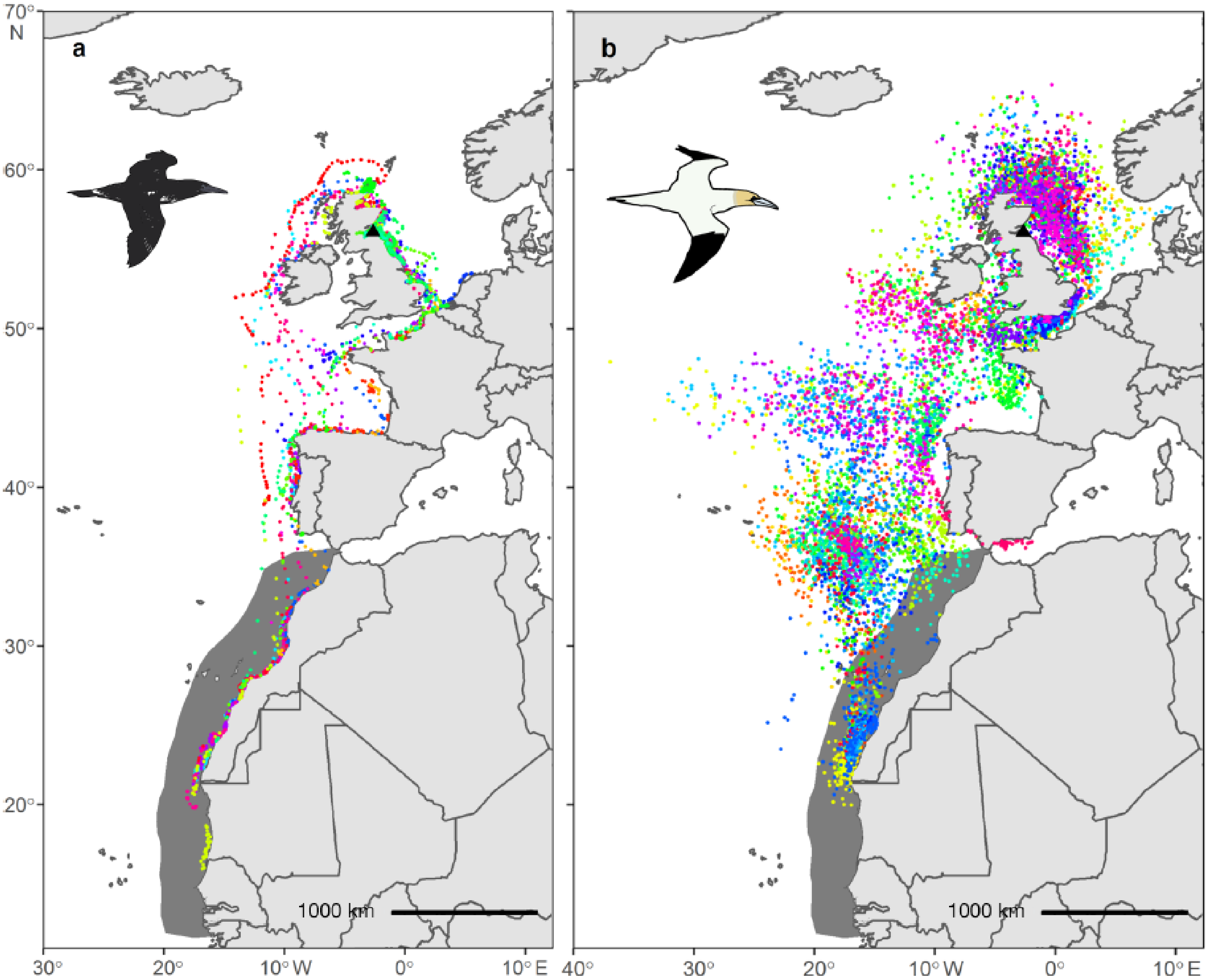
Figure 5.29: Distribution of gannet from ship based and aerial seabird at sea counts 2005-2012



Notes. Increasing gannet densities are visualised by colour from yellow through orange to red. Green contours and numbers represent the abundance (no. birds/mapping effort) of gannets, the star representing the location of the colony. Source: Garthe *et al.* (2017)

These, and other studies of OWF impacts on gannet, have been conducted during the breeding season when breeding birds are more limited in their foraging ranges, being central place foragers, with less known about year round effects (Pollock *et al*. 2020). Gannets from colonies can exhibit different overwintering and migration route strategies; some wintering nearer to the colony than others (Kubetzki *et al*. 2009, Grecian *et al*. 2019) and birds travelling south through the Strait of Dover from colonies to wintering grounds but returning via more westerly routes (e.g. Furness *et al*. 2018). This pattern can be reflected in OWF baseline surveys which record an increase in numbers of birds in the southern North Sea during November, making it difficult to determine which colonies the birds are from. Tagging studies have focused on breeding birds in order to improve understanding of their foraging behaviour, with some data collection extending into the non-breeding season. However, little is known about the seasonal movements of younger, juvenile birds, it is important but logistically challenging, to understand how juveniles disperse, use different marine habitats and overlap with potential threats (Hazen *et al*. 2012, Riotte-Lambert & Weimerskirch 2013). Adult and juvenile gannets tagged at Bass Rock in 2018/2019 (Pollock *et al*. 2021, Lane *et al*. 2021), migrated in both a clockwise and counter-clockwise direction around the UK (juveniles: 17 clockwise, 16 counter-clockwise and adults: 17 clockwise and 8 counter-clockwise). Juveniles stayed closer to the coast (within 15km) compared to adults, with these migrating further offshore (Figure 5.30) and differences were seen between age-classes in finer-scale movements and speed of travel (Lane *et al*. 2021) – all having implications for potential interactions with offshore wind farms.

Figure 5.30: Flight behaviour of juvenile and adult gannet tagged from Bass Rock

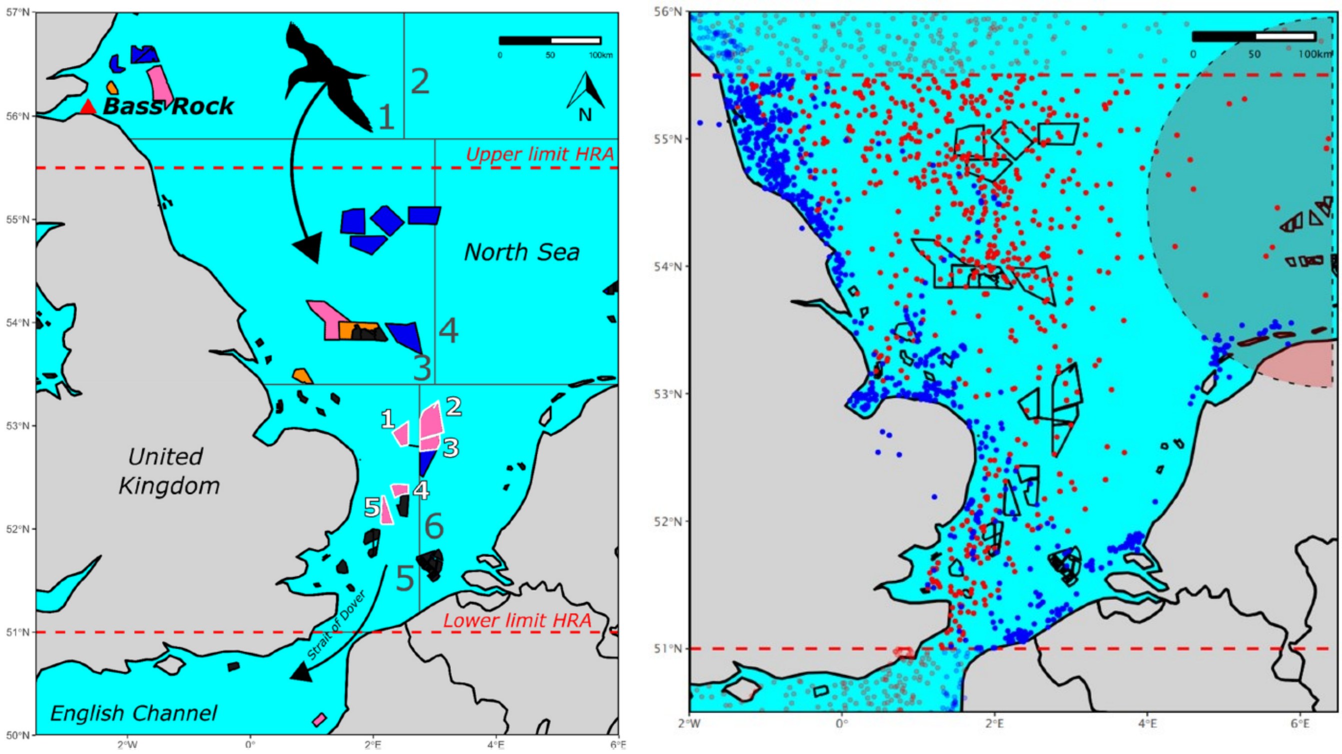


Notes: GPS locations of 41 juvenile gannets (a) (tracked between September and November 2018 and 2019) and GLS locations of 35 adults (b) (tracked between September and January 2018-2019 and 2019-2020) tracked from Bass Rock Individual birds identified by colour. Source: Lane *et al*. (2021)

The scale of current and potential future developments in the southern North Sea has meant the area has been a focus for studies of the non-breeding season movements of adult and juvenile gannets. Analyses of the same Bass Rock data used in Lane *et al*. (2021) by Pollock *et al*. (2021) focused on the distribution of birds within what they termed a high risk area (Figure 5.31); this area was defined as between 55.5ºN and 51.0ºN as many gannets migrate south through this area during autumn (returning routes may differ, e.g. Furness *et al*. 2018, Lane *et al.* 2021) it encompasses most of the OWF sites in the UK/adjacent North Sea waters, the upper boundary is sufficiently far from the Bass Rock colony (~100km) that the birds present are likely to have begun migration (Pollock *et al*. 2021).

Figure 5.31: OWF Sites and high risk area upper and lower limits (a) and location estimates of adult and juvenile gannets during autumn migration (b)

a) b)



Notes: a) OWF construction stage indicated by fill colour: pink = planned, blue = approved, orange = under construction, dark grey = operational, Polygons with white outline are OWF with aerial survey data. Dark grey diving lines and numbering indicate divisions of the North Sea into boxes for inspection of ESAS data, Bass Rock is indicated by red triangle, black arrows indicate general direction of migrating gannets in autumn. b) Location estimates of adult (red dots, n = 27) and juvenile (blue dots, n = 11) during autumn migration 2018-2019. Red dashed lines denote upper and lower limits of the high risk area . OWF indicated by black polygons. Translucent semicircle with black dashed outline shows the mean estimated error (167km) for adult GLS locations. Source: Pollock *et al*. (2021)

Seasonal peaks of adults and juveniles were seen in the southern North Sea; peaks of juveniles were in August and peaks of adults were in November. Seasonal patterns were also seen across surveyed OWF areas. However, when compared with the tracking data, adults were present in the high risk area earlier than the peak seen in digital aerial surveys and the tracked juveniles were much later than the peak detected in surveys for immature gannets. There was spatial consistency with juveniles however, as the proportion of juveniles in survey counts at individual OWF sites showed an inverse relationship to increasing distance from shore, aligning with the tracking data pattern. From previous studies (Kubetzki *et al*. 2009, Furness *et al*. 2018), many adults first travelled north towards Norwegian waters, this was suggested to coincide with stocks of mackerel in these waters with birds using this as a staging ground before travelling south. Tracked adults from Bass Rock showed a similar pattern, and then apparently taking the most direct route from the Norwegian waters, south through the Strait of Dover, resulting in an offshore distribution (Figure 5.31). In contrast, juveniles tended to migrate much closer to the coast through the southern North Sea. The authors concluded that whilst it is still unclear how these results translate to actual risk from OWF, the data suggests highest risk of interaction with OWFs for immatures gannets in summer, highest risk for adult gannets in October-November and generally low risk for juveniles during this time.

Results from the first year post-construction ornithological monitoring for the Beatrice OWF (MacArthur Green 2021b) corroborated previous findings for gannet avoidance. Virtually no gannets were recorded within the windfarm area compared to pre-construction survey data, with the statement made that the results from the Beatrice study gave a clear indication that gannets avoid the wind farm. In their summation on gannets, it was suggested that given the growing evidence base of gannet displacement, that this could be a greater potential source of impact for this species than collision risk and as such the avoidance rate of 60-80% (NE-JNCC 2017) may have to be re-assessed. It was also suggested that the 98.9% avoidance rate applied for collision risk assessment may well be an underestimate of the level of avoidance for this species (MacArthur Green 2021b).

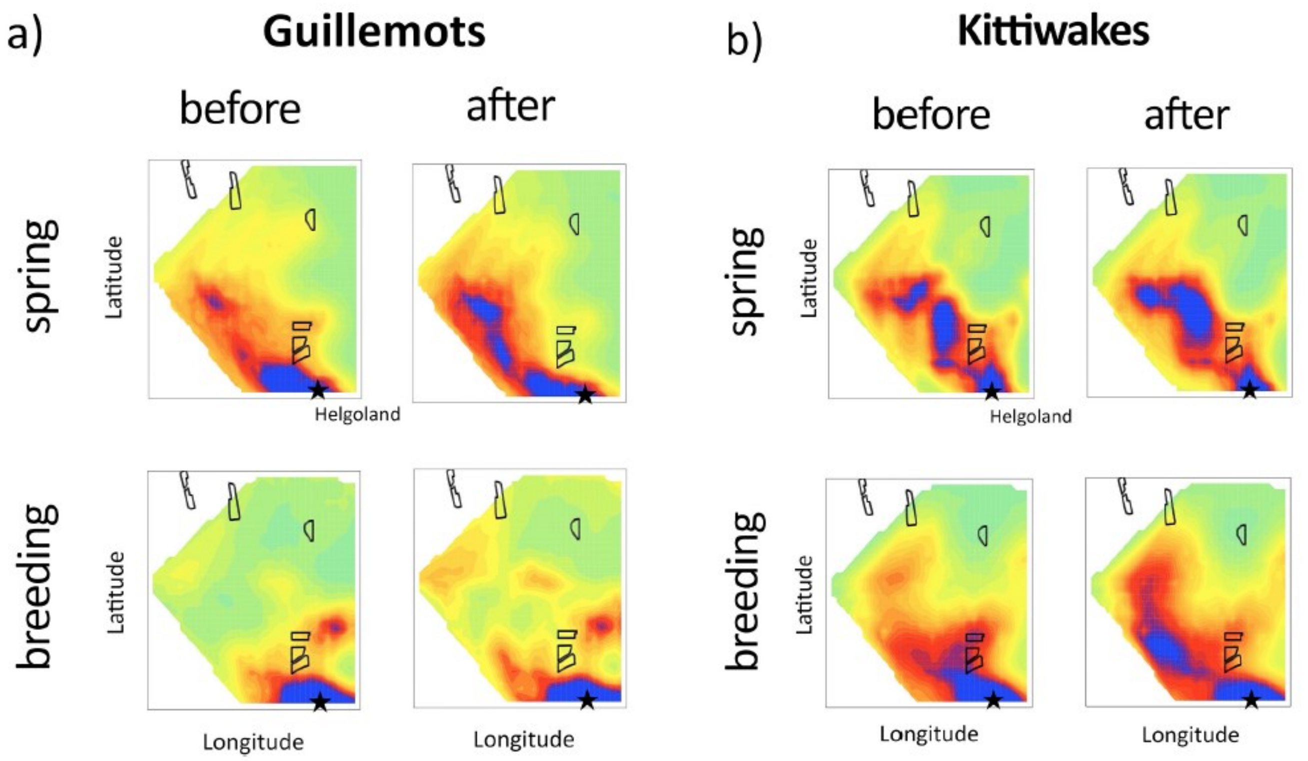
Guillemot showed no avoidance at the Beatrice OWF area, with a suggestion of elevated densities in the vicinity of the wind farm (MacArthur Green 2021b), in contrast to the results of Peschko *et al.* (2020, 2021) and others. For the other bird species examined, spatial modelling and avoidance analysis for razorbill lead to similar conclusions as that for guillemot. For Atlantic puffin, there did not appear to be a notable response to the wind farm presence, whilst results were more difficult to interpret for kittiwake. It was also difficult to draw conclusions for great-blacked backed gull and herring gulls due to low numbers (in nearby populations) and a small sample size respectively (MacArthur Green 2021b). The study also found that for three species (guillemot, razorbill and kittiwake) there were fewer birds recorded in the wind farm area at higher turbine revolutions per minute (RPM) values; the authors acknowledged that this does not conclusively show birds avoided the area when the turbines were rotating faster, as RPM is positively related to wind speed, and an increase in wind speed may make foraging conditions less favourable (MacArthur Green 2021b).

Like guillemot, observed response to OWF by kittiwake have been variable, this species reportedly showing avoidance and reduction in abundance in OWF areas (e.g. Leopold *et al.* 2013, Vanermen *et al.* 2016), attraction (e.g. Canning *et al.* 2013, Vanermen *et al.* 2016), or no response behaviour (e.g. Krijgsveld *et al.* 2011, Welcker & Nehls 2016). Dierschke *et al.* (2016) found that avoidance and attraction by kittiwakes were often equal. The study off the coast of Helgoland (Peschko *et al.* 2020) examined guillemot (spring) and kittiwake (spring and breeding season) presence. The kittiwake colony at Helgoland has been in decline since 2004 and prior to the presence of OWF in that area, although any subsequent effect caused by OWF presence through e.g. reducing foraging habitat, could have added additional pressures on an already depressed colony. They found that whilst a significant reduction in kittiwake numbers was not detected in spring, it was seen during the breeding season before and after construction of the OWF (e.g. see Figure 5.32, this showing the (“before-after control impact”) BACI-GAMM based predicted density plots for guillemot and kittiwake.

Barrier effects of birds altering their migration flyways (or local flight paths) to avoid wind farms, is also a form of displacement (Drewitt & Langston 2006) and with the possibility of increased energy expenditure when birds have to fly further.

In terms of energy expenditure, the potential energetic costs to seabirds (migrants and residents) of commuting around offshore wind farms were found to be small (e.g. depletion of <2% of available fat reserves even if birds had to travel an extra 30km), with greater potential costs to birds having to make regular deviations around a facility located between nesting/roosting sites and feeding areas (e.g. Speakman *et al.* 2009, Masden *et al.* 2010).

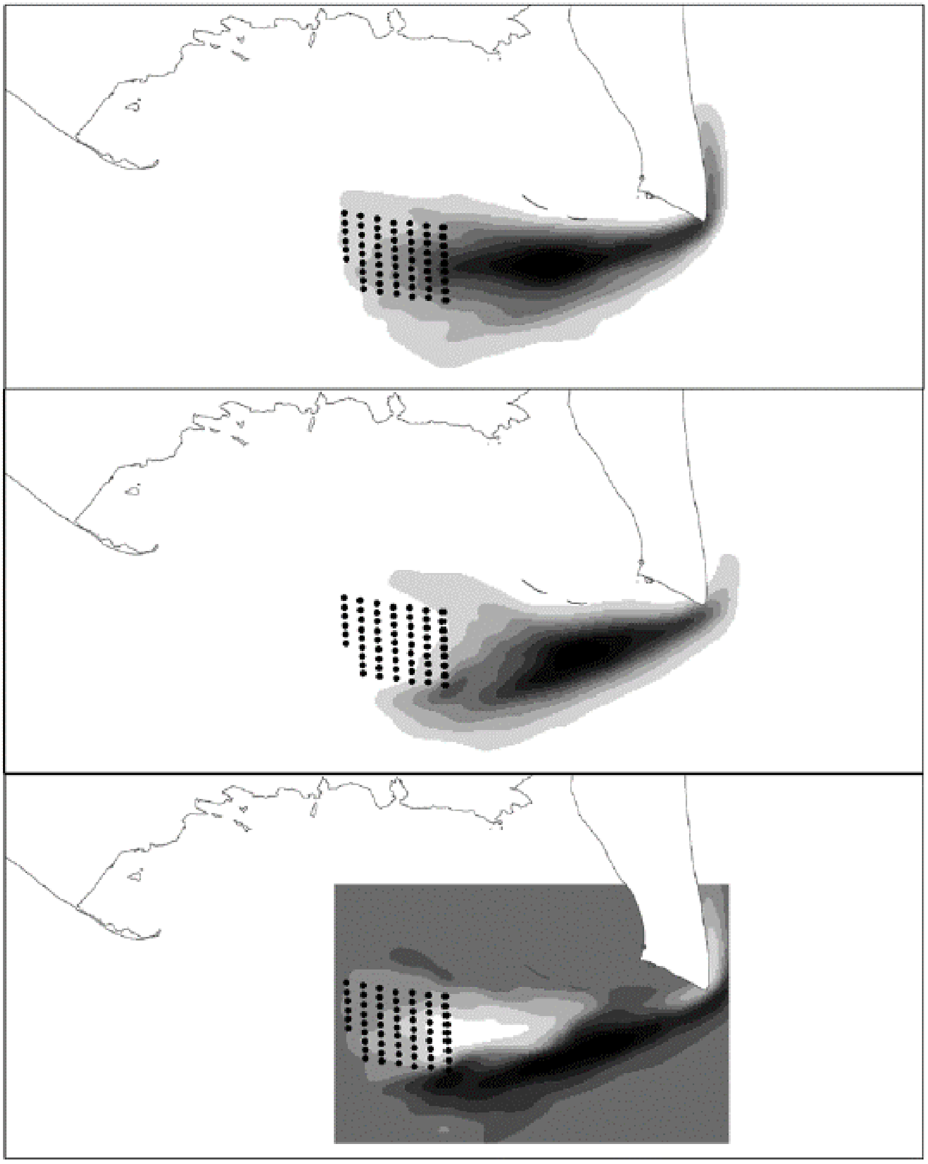
Figure 5.32: BACI-GAMM based predicted density plots for guillemot and kittiwake before and after offshore windfarm construction from the southern North Sea (reproduced from Peschko *et al.* 2020)



Notes: densities in relative scale for each species, season and period (rescaled for each plot) separately, evaluated for before and after periods and for spring and breeding season. Subfigure are rescaled in order to visualise relative spatial change. Green indicates low and blue indicates high relative densities; black lines represent boundaries of OWF; black star represents the location of the Helgoland colony. Source: Peschko *et al.* (2020)

In their review of information from Danish windfarms, Fox & Petersen (2019) acknowledged that species (e.g. common eider) have shown evidence of flight modification in the approach to the newly constructed Nysted offshore windfarm (Figure 5.33). The authors also distinguished between migrating birds and breeding/wintering birds in terms of overall impact. Slightly extended migration distances (e.g. adding just 500m to a 1,400km flight in the case for common eider migrating past Nysted), encountered twice a year on annual migration, was “biologically trivial” in terms of energy cost whilst the energetic costs to breeding or wintering birds commuting between offshore feeding grounds and breeding colonies/wintering grounds, could be considerably higher and could potentially affect survival and reproductive success. As central placed foragers, breeding seabirds have to balance the energy demands of self and offspring provisioning, within the constraints of foraging from a fixed colony site, along with the pressures of prey depletion and competition; the implication being, any significant increase in energy expenditure during this period could have detrimental consequences on the adult or offspring. Fox & Petersen (2019) go on to suggest that by siting offshore wind turbines away from important concentrations of (breeding and wintering birds) and their respective feeding areas, avoidance of conflict can be achieved.

Figure 5.33: Kernels of space use by autumn migrating common eiders flying towards area of the Nysted Offshore Windfarm, off southern Denmark



The space kernels represent the intensity of radar tracks of migrating individuals across the areas a) pre-construction, b) post-construction and c) difference in space use between a) and b) Darker shading represents greatest use, white in c) indicates reduction between a) and b). Dots = turbines. Source: Fox & Petersen (2019) (reproduced from Masden *et al.* 2009)

Whilst there is evidence that some bird species can be displaced by OWFs, and evidence of attraction and indifference, this can be variable within and between species, and throughout the year, and there remains a lack of evidence of the ecological consequences of displacement/avoidance at a population level. Recent evidence suggests that displacement could be a greater potential source of impact for gannet than previously thought and requires further study to determine the extent of this and its implications for both displacement and collision risk for the species. There is also concern with the potential level of development in the southern North Sea and what impact this could have on red-throated diver, the principal concern is potential loss of habitat. The current understanding of wintering red-throated diver concentrations needs to be improved (e.g. data underpinning abundance and distribution in Liverpool Bay is more than 10 years old, e.g. Lawson *et al*. 2016b), as does the understanding of the abundance and distribution of the species in the southern North Sea and identification of trends in populations across the region e.g. while acknowledging caveats with regard to comparison of data, survey methods etc, Irwin *et al*. (2019) suggested there has been an increase in divers in the Outer Thames Estuary SPA area from surveys spanning the period 2002-2018.

Tidal range

Tidal range power uses the difference in water level between the sea and an enclosure, the enclosure is usually formed by construction of a barrage across an estuary or seawalls, to create a lagoon enclosure across a bay or section of coastline. By closing the turbines and sluice gates located within the barrage or lagoon wall at either low or high tide, the natural motion of the tide either into or out of the estuary or lagoon is delayed until the difference in water level across the wall is sufficient to power the turbines. The enclosure consequently restricts the tidal flows, reducing the range of tidal levels within the estuary or lagoon, with ebb generation uplifting mean water levels, flood generation reducing mean levels and dual mode resulting in little change in mean water levels, but some reduction in intertidal area (Yates *et al*. 2013). The effects of tidal range developments on waterbirds are therefore not limited to the infrastructure itself but also from habitat changes, changes to quality of the intertidal habitat, and loss of or reduced access to intertidal areas for feeding.

For example, the potential loss of (and associated changes to) intertidal habitat resulting from the largest of the Severn Estuary tidal power options, the Brean Down to Lavernock Point Barrage (B3 option), was assessed to be the principal effect on waterbirds (DECC 2010g). The main, initial effect would probably follow construction, when an estimated 51% of the intertidal habitat might be lost (based on area exposed at lowest astronomical tide and not including intertidal areas of sub-estuaries); an additional 7.4% decrease in the extent of the intertidal habitat was predicted over the operational phase. The predicted level of 2.0Mm^3 of maintenance dredging per year would also affect intertidal habitat quality. This effect of the B3 option was identified as a likely significant negative effect for 30 waterbird species, including the overall waterbird assemblage, as the scale of (both immediate and long-term) habitat loss and the changes to the intertidal exposure period were predicted to outweigh any positive changes in the quality of intertidal habitat (evaluated using two complementary modelling approaches, Habitat-Association Models and Individual-Based Models, to provide a better understanding of the range of uncertainty in model predictions, modelling assumptions are outlined in DECC 2010g). Visual and noise disturbance during construction and to a lesser extent during operation of any similar project could cause behavioural disturbance and displacement from an area, potentially resulting in an effect on fitness and mortality of individuals.

Long-term monitoring studies of the effects of the construction and permanent closure of the Cardiff Bay barrage to form a freshwater lake, found that the overall number of wintering birds in the bay declined prior to closure of the barrage, perhaps due to changes in habitat quality or increase disturbance from construction work (Burton *et al*. 2010). Following barrage closure and flooding the numbers of waterbirds, particularly waders, were greatly reduced with estuarine species being displaced to a neighbouring site. Survival rates of a marked population of redshanks reduced over the three winters following their displacement, suggesting that they were at a competitive disadvantage to the resident birds. The survival of bird populations depends on the abundance of, and energy available from, prey, the size of the feeding area and the time available for feeding (Hooper & Austen 2013). Construction of a large tidal range power scheme would affect waterbirds in several different ways. It would greatly reduce the intertidal habitat available for feeding birds; changes in the tidal range would reduce the time available for water birds to feed (depending on the intertidal height distribution by each species); and the nature of the invertebrate communities would be changed by reduced salinity and changes in sedimentation rates (Burton *et al*. 2010).

It should be noted that while the concept of displacement and disturbance from tidal generation schemes during construction and maintenance phases of a development is understood, relating the concept of disturbance to the quantification of an impact at the level of local, regional and national populations is problematic (Kirby *et al.* 2013). The displacement of birds from preferred foraging areas may result in reductions in body condition and survival (e.g. Burton *et al*., 2006), however the area of displacement, foraging range, the level of competition for resources and the temporal and spatial changes in resource distribution that may occur within the environment will all play a role in determining the size of the impact for each project and each species (Kirby *et al.* 2013).

Currently there are no tidal range schemes operating or consented in the UK, although various locations with a sufficiently high tidal range have been identified as potential commercial candidates. The Swansea Bay tidal lagoon (0.3 GW) originally received development consent in 2015, however, a recent request by the developer to extend the development consent order was refused by the UK and Welsh Governments on the basis that the developer had not started the relevant works within the five year deadline – a new application would now be required for works to proceed. A number of other candidate tidal range schemes are in varying stages of pre-consent development (West Somerset Lagoon - 2.5 GW, North Wales Lagoon – 2-2.5 GW, Mersey barrage / Liverpool Bay lagoon – 1-3.6 GW, Morecambe Bay/Duddon Estuary barrage – 4 GW, Wyre Barrage – 0.1 GW, and the Cardiff Bay tidal lagoon – 3GW (BHA, 2020)).

The most commercially attractive tidal schemes tend to involve large estuaries or bays. For example one option proposed in the Severn Tidal Power feasibility study could see up to 520 km^2 of the estuary impounded, compared with the 17 km^2 at La Rance and 6 km^2 at Annapolis Royal. Another UK scheme in the Mersey River would involve an impoundment of 61 km^2 but even this would be sufficient to generate changes in the tidal range at locations all around the Irish Sea (Wolf *et al*., 2009 cited in Frid *et al*. 2012). The larger the scheme the more likely that there will not be alternative feed sites nearby. In the UK, the quantity and quality of the food on the feeding grounds of over-wintering waders is the parameter that determines survival to the next breeding season (Burton *et al*., 2010; Duriez *et al*., 2009; cited in Frid *et al*. 2012). Thus, reduced feeding areas, increased foraging costs (extra flights between sub-optimal grounds) or lower food quality will directly impact on population size (Frid *et al*. 2012).

5.6.3.3 Barrier to movement, displacement and other behavioural effects – fish and marine mammals

Concerns have been raised in relation to possible barrier effects of offshore wind farm developments to fish and marine mammals; however, these are mainly related to noise effects and EMF effects and are discussed in Sections 5.3.3 and 5.6.3.7, respectively.

The potential for wind farm structures to act as artificial reefs or fish aggregating devices in the case of floating turbines (Inger *et al.* 2009) is ranked as a behavioural effect (and often referred to as a positive impact). Preliminary evidence shows that a greater abundance of fish has been recorded within the immediate vicinity of wind turbines and that several harbour seals have been observed to concentrate their foraging efforts there (Wilhelmsson *et al.* 2006, Reubens *et al.* 2013, Russell *et al.* 2014). Large, man-made offshore structures provide shelter for fish, and the biofouling communities which develop form the basis of a new local ecosystem. Such "reef effects" have been noted for oil platforms (Løkkeborg *et al.* 2002, Soldal *et al.* 2002) and offshore wind farms (Reubens *et al.* 2014, Stenberg *et al.* 2015). Tagging studies on Cod at the C-Power OWF on Thornton Bank in the Belgian sector of the southern North Sea indicated that individual cod displayed site fidelity over summer and autumn, with little movement away from favoured locations during this time (Reubens *et al.* 2013). Summer and autumn are periods of feeding for cod, prior to migration to winter spawning grounds, and the indication is that the OWFs act as convenient feeding grounds. Fujii (2016), studying the stomach contents of predatory gadoids around the Miller platform in the central North Sea, found that communities of cod, saithe, haddock and tusk there were feeding on prey items from a range of benthic and pelagic habitats, indicative of the habitat diversity provided by these man-made artificial reefs. The diet of saithe sampled around the region was found to be influenced by the concentrations of offshore structures in the area where they were caught. Long-term effects on the wider community are unclear. Reubens *et al.* (2014) observed that the aggregation of cod (and pouting) around the turbines is biased towards younger animals; however although aggregation may lead to recruitment at a local scale, it does not necessarily mean increased species abundance at a regional scale. Methratte & Dardick (2019) conducted meta-analysis of studies that have examined the abundance of fish inside of wind farms compared to nearby reference locations (included results from 11 peer-reviewed papers and two agency reports), to investigate emerging patterns in fish abundance across numerous studies. Results of the meta-analysis, which took into consideration a number of covariates including characteristics of the wind farm, sampling design and ecosystem level characteristics, showed significant positive effects indicating greater abundance of fish inside of wind farms. Results also indicated positive significant effects for several of the covariates, highlighting the need for collaborations and standardized monitoring approaches. There is still insufficient data to determine whether the abundance of fish recorded inside wind farms is a result of attraction or an increased in production (Methratte & Dardick 2019).

Across the UKCS, marine mammal migrations, as a seasonal behavioural pattern comparable to that of many marine bird species, are seen only in sperm whales and possibly baleen whales along the continental shelf margin (see Appendix Section A1a.8); harbour porpoises and several other species have been sighted in increased numbers in inshore areas during the summer months but no specific migration ‘corridor’ has been identified. Crown Estate Scotland have recently (January 2022) awarded leasing rights to a consortium led by Ørsted to develop a 1GW floating wind farm off the Caithness coast. As part of this development research will be conducted by the Scottish Association for Marine Science (SAMS) to investigate the potential effects of floating wind developments on the marine environment and in particular the interaction of fish, marine mammals and seabirds with floating offshore wind farms. More research is needed to further our understanding of these impacts and of the management measures needed to minimize potential impacts.

The likelihood of tidal stream energy developments acting as a barrier to local movements of marine mammals and fish needs further consideration, since suitable development locations such as tidal straits and channels are spatially constrained. Current understanding of the effects is hampered by limited empirical evidence. The potential for displacement effects and barrier effects at the former SeaGen tidal stream turbine in Strangford Lough have been investigated through a comprehensive Environmental Monitoring Plan (Royal Haskoning 2011). Passive acoustic monitoring of harbour porpoises and harbour seal tracking by telemetry led to the conclusion that SeaGen did not cause a barrier effect although small changes in distribution and movement patterns were observed. Overall the observations are suggestive of small-scale local redistribution (250m) and reduced frequency in transits (overall by 20%) in relation to the SeaGen presence and operation, with the likelihood of little ecological significance (Savidge *et al.* 2014; Sparling *et al.* 2017). A recent study on the effect of a tidal stream device on fish distributions in a tidal channel in Orkney indicated an attraction effect of the tidal turbine when compared to a nearby control site without a tidal turbine (Fraser *et al.* 2018). The vertical distribution of fish in the immediate vicinity of the turbine were investigated, and increased observations of small fish schools were seen in the lower part of the water column at the turbine site when compared to the control site, particularly at night and in the wake flow of the turbine. There was also evidence of a reduction in fish school observations in the lower part of the water column (at the turbine depth range) during peak flow velocities suggesting some avoidance behaviour associated with high flow rates. This study demonstrates fish behavioural responses to the presence of a tidal turbine, the attraction effect on fish may also affect the foraging behaviour of larger predators such as marine mammals and seabirds and the associated risks of collision (Fraser *et al*. 2018).

Among fish, several species show differences in their distribution with season and in some cases large-scale migratory patterns (see Appendix Section A1a.5) but the focus of concern with regard to any potential barrier to movement are the diadromous species, e.g. Atlantic salmon, brown trout, European eel, lampreys and shad (Malcolm *et al.* 2010, Frid *et al.* 2012). Less than 2% of river lamprey tagged below the tidal barrage at the River Derwent were later recorded at their spawning habitat 50km upstream (Lucas *et al.* 2009). A number of these diadromous species are among the most threatened fish species in UK waters. Changes in the nature or physical characteristics of habitats may affect their suitability as nursery or spawning grounds for fish (Frid *et al.* 2012).

Topic papers on migratory and estuarine fish produced as part of the Severn Tidal Power feasibility study (DECC 2008, 2010) indicated that the placement of a tidal range scheme within the Severn Estuary could result in effects to fish passage and movement both for the seasonal migration of diadromous species and the daily movement of estuarine species. In a high tidal range and strong excursion environment such as the Severn Estuary, upstream migrants are likely to use tidal stream transport as a mechanism of moving up the estuary. Many species depend on currents to transport larvae (Frid *et al.* 2012). A tidal range scheme across the estuary could alter this tidal regime with resultant changes to the mechanism and rate of upstream movement of migratory fish. Furthermore, migratory fish are likely to change their behaviour as they move into the estuary from coastal waters, through the main estuary and into the inner estuaries and freshwater environments. Changes to the tidal and freshwater patterns due to the construction of a barrage structure may further the negative impacts on migratory behaviour and consequential impacts upon individuals and populations. Such changes to migratory movement may result in delayed and increased passage time, which in turn may cause further effects including increased predation and extended exposure to any changes in water quality (DECC 2008, 2010). It is likely that the development of tidal lagoons will also have effects on fish behaviour within estuaries, although the exact nature and scale of any impacts is currently unknown.

5.6.3.4 Collisions risk – birds and bats

Offshore wind farms

Due to the potential risk of injury or mortality from colliding with turbine blades as they fly through arrays, the collision risk for birds has received considerable attention in relation to both onshore and offshore wind farm development, with substantial effort expended both in empirical studies (e.g. mortality counts; infrared monitoring) (e.g. Skov *et al.* 2018) and predictive modelling (e.g. Band 2000, McGregor *et al.* 2018).

Less has been done on the occurrence of bats in the offshore environment (on migration) and their potential interactions with renewable developments. Little is known about bat migration ecology, the number of individuals migrating over sea, and the risk of mortality from interactions with offshore wind turbines (Lagerveld *et al.* 2017). Research has shown bats are more frequently recorded offshore during migration (late March until June and from late August until October), with the most frequently encountered species over the North Sea being Nathusius' pipistrelle (*Pipistrellus nathusii)*, but common pipistrelle *P. pipistrellus*, common noctule *Nyctalus noctula*, Leisler's bat *N. leisleri*, particolored bat *Vespertilio murinus*, Northern bat *Eptesicus nilssonii*, and Serotine bat *E. serotinus* are also recorded (Boshamer *et al*. 2008, Lagerveld *et al*. 2012, Hüppop *et al* 2016, Hüppop *et al* 2019). Whilst it is known that bats migrate over the North Sea, it is unknown whether they migrate across in a broad front, or show spatially distinct patterns (Lagerveld *et al.* 2017).

The few studies to date have typically resulted in small datasets and have shown contradictory results, with virtually no studies on the spatial and temporal occurrence of bats offshore.

OESEA2 and OESEA3 used several reviews and studies to discuss the evidence for collision and bird species and species group potential vulnerability (e.g. Desholm *et al.* 2006, Drewitt & Langston 2006, Langston 2010, Furness *et al.* 2013 and Bradbury *et al.* 2014) to collision and these remain relevant.

Collision risk depends on a range of factors related to bird species, numbers, behaviours (e.g. flight speed, altitude and manoeuvrability, percentage of time flying, habitat association), weather conditions, topography and the nature of the turbines being considered(size, rotor speed and diameter), including the use of lighting (Drewitt & Langston 2006, Furness *et al*. 2013, Masden *et al.* 2021) (see Table 5.1, Section 5.6.2.2 above). Avian vulnerability to wind farm collisions can also vary at different times throughout the year (i.e. across breeding seasons and at migration) (e.g. Lane *et al*. 2020, Thaxter *et al.* 2019) and within species populations and age classes (e.g. Pollock *et al.* 2021).

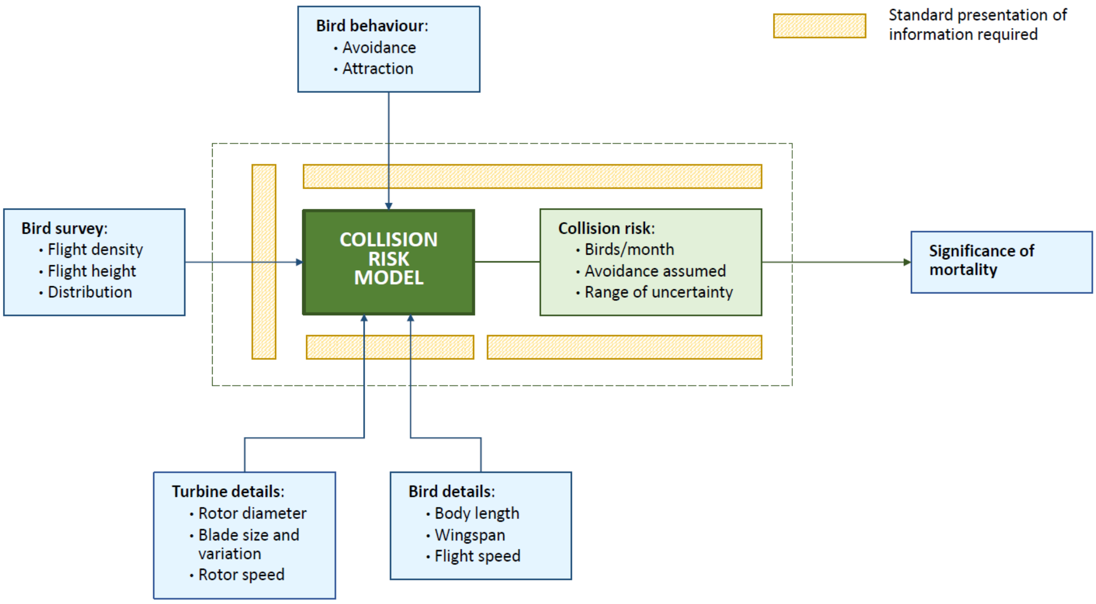
Ranked species at highest risk (Furness *et al.* 2013) and species' population vulnerability (Bradbury *et al.* 2014) to collision (both based on factors including flight height, manoeuvrability, nocturnal flight etc.) are, herring gull, great black-backed gull and lesser black-backed gull (all classified as very high risk in Bradbury *et al.* 2014), with other gull species (Iceland, glaucous, common and Mediterranean) ranked as high, along with gannet and kittiwake (Bradbury *et al.* 2014), while Furness *et al.* (2013) includes skuas (Arctic and great) in the top ten species listed. In their review of priority evidence requirements, O'Brien *et al.* (2021) included collision as an impact pathway for Manx shearwater and Sandwich tern.

Whilst direct mortality and lethal injury of birds and bats as a result of collision with wind turbines (and associated infrastructure) is widely acknowledged, unlike evidence that can be gathered for displacement/avoidance of a marine area post construction of an OWF (baseline surveys and post-construction monitoring reports looking at presence/absence of birds), the empirical evidence base for quantifying the numbers of birds likely to collide with offshore turbines is very limited. Therefore, accurately estimating collision risk is still problematic, as is determining the ecological consequence of this, i.e. the impact that the loss of individual birds has at a species and population level.

Masden & Cook (2016) reviewed a range of avian collision risk models (not all related to offshore wind farms) to raise an awareness of models available, highlight their strengths and weaknesses, qualitatively compare models and provide suggestions where future efforts should be focused to advance collision risk modelling (CRM). They identified ten distinct CRMs referring to birds and wind turbines, the earliest of which dated back to 1996 and concluded that while CRMs are useful tools in estimating collision risk and provide information on potential environmental impacts of wind farm developments, they have limitations, something that is not always recognised when interpreting their data outputs and the input values used in CRMs (e.g. avoidance rates, see below) all remain precautionary (e.g. Cook *et al.* 2014) in the absence of empirical data.

Since this review, CRMs have continued to evolve or be developed, these being refined, where available, with empirical data. The CRM developed by Band (2012), along with the sCRM (initially developed by Masden in (2015) and further refined by McGregor *et al.* (2018) are industry standard approaches used in the UK to predict potential mortality levels. The exact versions of the models (i.e. basic/extended, Options), avoidance rates, flight height data, nocturnal flight activity and other parameters for modelling are based on best available evidence at the time and guidance/advice from Statutory Nature Conservation Bodies (SNCBs). These models are used to predict the potential level of mortality as a result of collision (Figure 5.34), the determination of whether this mortality level is significant is beyond the scope of the models and should be considered in terms of sensitivity of the bird population, any protected site in the vicinity with that species as a designated feature and any legal protection afforded (Band 2012).

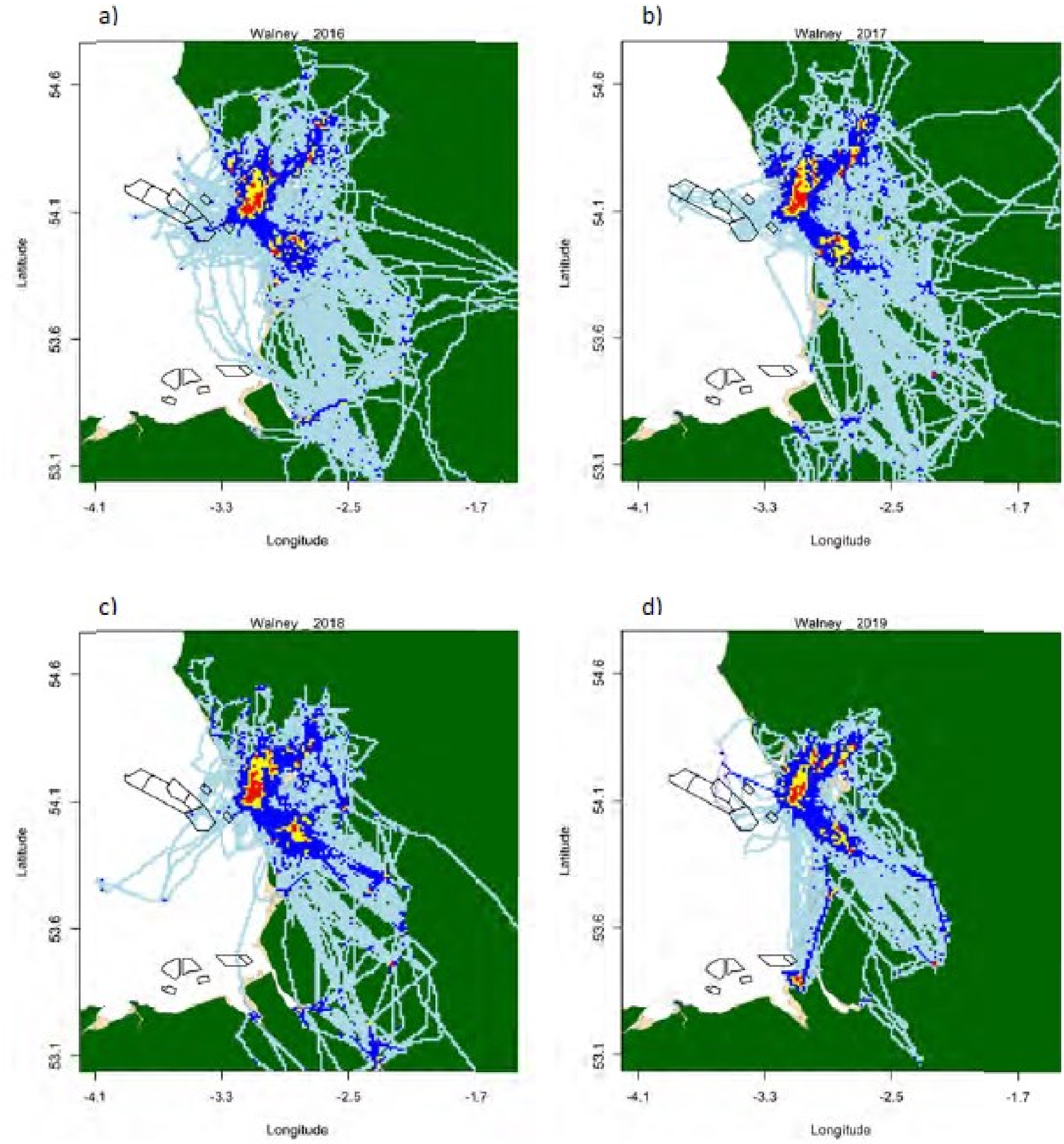
Figure 5.34: The role of collision risk modelling, after Band (2012)



CRMs calculate the probability of a collision, based on the likelihood of an individual bird occupying the same space as a turbine blade (based on factors such as (but not limited to) flight height and speed), the number of birds likely to pass through the site over a given time and an the application of an avoidance rate (this takes into account the proportion of birds likely to take action to avoid a collision, in order to more realistically predict collision events and risks) (Cook *et al.* 2018).

Building on previous SEA funded work undertaken at South Walney (e.g. Thaxter *et al*. 2014 through to 2018), Clewley *et al*. (2020) collected tag data over four breeding seasons (2016, 2017 and 2018 and 2019) and three non-breeding seasons (2016/2017, 2017/2017 and 2018/2019). Work was undertaken in this area to understand the connectivity between lesser black-back gulls and renewable developments in the Irish Sea and Liverpool Bay, (i.e. Walney and Burbo Bank developments, and the subsequent extensions of these) (see Figure 5.35 and Clewley *et al*. 2020 for further details).

Figure 5.35: Utilisation distribution for all lesser black-backed gulls tracked from South Walney during the 2016-2019 breeding seasons



Notes: Utilisation distribution calculated using a Time-in-Area approach for all lesser black-backed gulls from South Walney in the Morecambe Bay and Duddon Estuary SPA during the 2016-2019 breeding seasons (a-d) (n=36, 23, 13 and 7 birds respectively). Light blue = 100% UD, dark blue = 95% UD, yellow = 75% UD, red = 50% UD. Source: Clewley *et al.* (2020)

Lesser black-backed can travel up to 236km during the breeding season (mean max (km) (+1SD) (Woodward *et al.* 2019); annual mean foraging ranges from South Walney were reported as between 11-14km (Thaxter *et al.* 2018) and 9-14km (Clewley *et al*. 2020), with ranges appearing to be colony specific; foraging ranges from birds tagged at Barrow had significantly smaller ranges with a maximum annual mean of *ca*. 6km, with the core home ranges for both colonies indicating predominantly terrestrial foraging with very limited overlap with the wind farm extension areas.

Seabirds are also thought to be at highest risk of impact (collision or displacement) during the breeding season, when adults are restricted to central place foraging, when their movements are concentrated to enable a return to the colony. However, vulnerability can have a similar magnitude across the non-breeding season, if there is interaction with renewable infrastructure along their migratory corridors (e.g. Thaxter *et al*. 2019). Lesser black-backed gulls tagged from colonies at Orford Ness, South Walney and Skokholm were found to utilise well defined migration corridors, birds from all three travelling along the Spanish and Portuguese coastlines and passing through Galicia, which has a high density of turbines.

The selection of appropriate avoidance rates for use in collision risk models is a key part of the assessment, as different bird species exhibit different behavioural responses (in this case avoidance) to wind turbines (see also Masden 2015 and below for other important input parameters). A lack of data for marine birds and offshore wind farms, meant avoidance rates were based on values derived for terrestrial species at onshore windfarms. Cook *et al.* (2014) focused on five priority species whose behaviours and distributions make them particularly prone to collision with offshore turbines (gannet, kittiwake, lesser black-backed gull, herring gull and great black-backed gull) and other relevant species (e.g. small gulls, common gull, black-headed gull); they began their review of avoidance rates by offering three different scales of avoidance behaviour: macro, meso and micro. Macro refers to changes in flight direction and altitude that indicate avoidance of wind farm perimeter; meso refers to changes in flight direction and altitude that indicate avoidance of rotor swept zones in the wind farm; and micro refers to flight behaviour that indicates responses to single blade(s) within 10m of the rotor swept zone.

Species-specific avoidance rates have changed over time. The latest generally accepted values are those presented in Cook *et al.* (2014). Using available data from the literature and in conjunction with the basic and extended Band model[166] (Band 2012), Cook *et al.* (2014) recommended total avoidance rates for the basic Band Model for all five species, but for the extended Band Model total avoidance rates were calculated for only three species and species-specific avoidance rates for only two. Despite this work advancing the refinement of avoidance rates, Cook *et al.* (2014) acknowledged that significant data gaps remained and research is ongoing in an attempt to improve these (e.g. APEM 2014, Skov *et al.* 2018, Bowgen & Cook 2018, Cook 2021). The review by Cook (2018) points to evidence of consistent macro avoidance of OWFs by gannet and variable levels of within-wind farm avoidance among gull species. Results of the ORJIP project at Thanet[167] and ornithological work at Aberdeen Offshore Wind Fam[168] (Tjørnløv *et al*. 2021) have also provided empirical data on macro, meso and micro avoidance behaviour on several seabird species, along with data on bird flight heights.

The joint SNCB guidance on collision risk assessment recommends the avoidance rates from Cook *et al.* (2014) (Table 5.17) for use in project assessments, with the exception of that for kittiwake, where the precautionary approach of including this species in the “all gull” rather than the “small gull” category as suggested by Cook *et al.* (2014) is recommended.

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[166] The basic Band Model assumes that birds are distributed evening within the rotor-swept area of a turbine, while the extended Band Model uses a continuous flight height distribution to estimate collision risk at different points within the turbines rotor-swept area.
[167] A two and a half year project initiated in March 2014 by the Offshore Renewable Joint Industry Programme (ORJIP)[167] to improve the evidence base on bird collision avoidance rates using monitoring equipment (rangefinder observations and radar tracking) installed at the Thanet offshore wind farm. The project has completed stage 1 and is currently in stage 2, this expected to run to 2023, with an option to extend this to 2025 https://www.carbontrust.com/our-projects/offshore-renewables-joint-industry-programme-orjip-for-offshore-wind
[168] A study at the European Offshore Wind Deployment Centre (EOWDC), 3-5km off the coast of Aberdeen, the project uses radar-camera monitoring units attached to the turbines, which collect radar tracks and video footage of birds within the wind farm area https://group.vattenfall.com/uk/siteassets/wind-pdf-documents/eowdc/aowfl-aberdeen-seabird-study_annual-report-2020_v3_final-2.pdf

Table 5.17: Recommended avoidance rates for use in the basic and extended Band models[1]

Species (rate used)	Basic Band model avoidance rate (± 2SD)	Extended Band model avoidance rate (± 2SD)
Gannet (all gull avoidance rate)	0.989 (± 0.002)	Not available
Kittiwake (all gull avoidance rate)	0.989[2] (± 0.002)	Not available
Lesser black-backed gull (large gull avoidance rate)	0.995 (± 0.001)	0.989 (± 0.002)
Herring gull (species-specific avoidance rate)	0.995 (± 0.001)	0.990 (± 0.002)
Great black-backed gull (large gull avoidance rate)	0.995 (± 0.001)	0.989 (± 0.002)

Notes: [1]These are the SNCB supported recommended avoidance rates from Cook *et al*. (2014), with the exception of kittiwake; in several instances these not derived from species-specific information, and as such represent avoidance rates for species grouping (e.g. large gulls), these also included here. [2]Avoidance rate for kittiwake from Cook *et al*. (2014), was 0.992, with theoretical arguments given for including this species in the “small gull” category. However, the SNCB recommend that, until such time a species-specific avoidance rate is calculated for kittiwake, the same generic (and precautionary) approach is taken for this species as taken for gannet, and classed under “all gull”, using a recommended avoidance rate of 0.989 as detailed above. Source: Cook *et al*. (2014), NE-JNCC (2014)

Flight height and speed are also key factors in predicting collision risk (e.g. Masden 2015, Bowgen & Cook 2018, Cuttat & Skov 2020) and data for these have been collected using a range of techniques as part of boat-based surveys, tagging data and digital aerial surveys. As part of ornithological site surveys to support developments, observed birds are usually assigned to a series of height bands (Camphuysen *et al.* 2004), delineated with an upper and lower limits of the rotor-swept area of the proposed turbine, determining the birds “at risk height” (Johnston *et al.* 2014a). This method has limitations, not least of which is treating the collision risk as an even distribution within the band; collision risk is not evenly distributed due to the rotor-sweep area of the blades being circular. As for avoidance rates, ongoing research is attempting to refine flight height estimates, however, at present, collision risk modelling within assessments are using site and species specific data collected during surveys (but only if these are reliable, e.g. see Macarthur Green 2019b – regarding flight height derived from survey data), and/or flight heights (Johnston *et al.* 2014a, b, Ross-Smith *et al.* 2016), with uncertainty and variability having to be included in the collision mortality estimates (e.g. Masden 2015). Flight speed in the Band CRM is used in two different ways, for estimating the probability of collision as the bird crosses the rotor-swept area and for estimating the flux of birds through the wind farm (Cuttat & Skov 2020). In the absence of empirical data, flight speeds from studies on long-distance migration are typically used; these speeds can be significantly higher than speeds recorded from site surveys, for example, the commonly used flight speed of 13.1(m/s) (based on tracking radar) (Alerstam *et al.* 2007) for lesser black-backed gull is much higher than 10.13 (m/s) (based on all rangefinder data, both inside and outside the wind farm perimeter) (ORJIP) (Cuttat & Skov 2020).

Another required input to collision models is nocturnal flight activity through the applicable area, despite this being difficult to quantify and there being considerable uncertainty around these; for example, boat and aerial (visual) surveys only being practical during daylight hours (Furness *et al.* 2018). As a result, a correction factor relative to daytime data has to be applied which is based on existing limited evidence at the time. Garthe & Hüppop (2004), along with King *et al.* (2009) (the latter of which looked at a wider range of bird species) assigned scores to seabird species on a scale of 1 to 5, 1 denoting “hardly any flight activity at night” and being assigned a % factor of 0% of daytime flight activity, through to 5, representing “much flight activity at night” with a factor of 100% of daytime flight activity. Further work undertaken on this specifically looked at gannet. From this, it was recommended a nocturnal factor of 8% (during breeding period) and 3% (during non-breeding period) be applied for gannet in the Band model, rather than the (non evidence based) 25% currently suggested for this species (Furness *et al.* 2018). It was further recommended that, given the reduction in nocturnal flight activity seen for gannet, when evidence based derived factors are used, analysing flight activity of other species such as kittiwake, and great and lesser black-backed gulls would also be of benefit, as the use of evidence based derived nocturnal flight activity factors, rather than generic factors, would help reduce uncertainty in impact assessments (Furness *et al.* 2018). Nocturnal flight activity becomes more of a factor when assessing migrant bird risk to collision, with many migratory flights occurring during the hours of darkness.

From their literature review, looking at a range of species/groups (waterbird and seabird) and both on and offshore development, Drewitt & Langston (2006) indicated that, where collisions have been recorded, the rates per turbine are very variable with averages ranging from 0.01 to 23 bird collisions annually; contrast this with visual observations of eider movements in response to two small, relatively near-shore wind farms (seven 1.5MW and five 2MW turbines) in the Kalmar Sound, Sweden, where only one collision event was recorded during observations of 1.5 million migrating waterfowl (Pettersson 2005). Hüppop *et al.* (2006a) noted the problems of quantifying collision rate by carcass collection offshore, and Chamberlain *et al.* (2006), in a review of collision risk modelling, pointed out that calculation of post-construction mortality rates has typically relied on corpse searches (Langston & Pullan 2003), using tideline searches for offshore and coastal wind farms (e.g. Winkelman 1992, Painter *et al.* 1999). There are potential biases in estimating mortality in this way due to a number of factors: searching efficiency, corpse removal by scavengers, injured birds leaving the area before death, 'obliteration' of birds struck by turbine blades (especially smaller species) which therefore do not reach the coast and, for coastal locations, corpses sinking or being washed out to sea and, distinguishing from mortality unrelated to turbine collision.

Despite having several layers of precaution, CRMs are relied upon to estimate the potential impact of OWFs, the outputs of which are then used to estimate cumulative impacts. Wind farm developments are assessed on the basis of both their own estimated impacts and those in-combination/cumulatively with other relevant projects. The potential for birds to be impacted cumulatively through collision (and displacement and barrier effects), in relation primarily to OWFs, has received attention in recent years. Methods for assessing such potential effects have been the subject of a number of studies and workshops, and continue to be developed, e.g. NRC (2007), Hüppop *et al.* (2006b), Maclean *et al.* (2007), Maclean & Rehfisch (2008), Norman *et al.* (2007) and King *et al.* (2009).

The UK Centre for Ecology and Hydrology (CEH) was commissioned by Marine Scotland to develop a tool for assessing the cumulative effects for key receptors (the Cumulative Effects Framework[169]). The project aims to develop a framework for *assessing all impacts of all planned and constructed offshore renewable developments on seabirds over all seasons, over multiple years and at multiple population scales*; the project also includes marine mammals. The project has three key components: a Data Library; R package and User Interface, and the resulting framework will include the flexibility to add new information (e.g. empirical data).

Several recent assessments undertaken for planned offshore wind farms in the southern North Sea have presented robust cumulative impact assessments within their applications (e.g. see Triton Knoll, East Anglia ONE, Hornsea Projects 1, 2 and 3, Norfolk Boreas, from the National

[169] Cumulative Effects Framework https://www.ceh.ac.uk/our-science/projects/cumulative-effects-framework-key-ecological-receptors

Infrastructure Planning portal, https://infrastructure.planninginspectorate.gov.uk/). Despite the issues associated with input data and interpretation of results, collision risk modelling and cumulative/in-combination assessments can, using best available information, estimate the mortality risk to birds from OWFs that can be used to provide a precautionary assessment of potential impacts on certain populations. As noted above there is a lack of validation for avoidance rates applied to offshore wind farms due to the paucity of data relating to actual collisions, and while recent in-combination assessment indicate a significant increase in mortality for certain species from the rollout of offshore wind, those projects estimated to have the largest effect are yet to be constructed. There is, therefore, a lack of evidence for collision events being realised and the ecological consequences on seabird populations, is lacking. Strategic assessment would therefore benefit from strategic monitoring at key sites, to determine whether the predicted mortality from collision risk modelling estimates, are realized; monitoring at wind farms should continue to be undertaken to identify and understand avoidance rates, particularly at meso and micro levels and monitoring at breeding colonies and wintering areas, to understand population trends. For certain species, such as kittiwake, the current population decline evident at the majority of colonies in the UK is considered highly unlikely to be linked to OWF developments and instead is linked to other factors such as prey availability, and it will remain challenging to disentangle these factors from OWF impacts, without sufficient appropriate monitoring and targeted research.

Work has been undertaken to determine the population level effects of these impacts. In 2007, at a COWRIE workshop on the cumulative impact of OWFs on birds it was agreed that population viability analysis (PVA) should form the basis for assessing whether the magnitude of any change in population was likely to be significant (Norman *et al.* 2007). Although there were concerns over the information dependency and the assumptions inherent in population modelling, further development of PVA for a range of key sensitive bird species (red-throated diver, common scoter, gannet, lesser black-backed gull and common tern) was supported. PVA is frequently used to quantify these potential negative effects on seabird populations. In 2019, Natural England developed a modelling framework that enabled users to run PVA models for a range of seabird species, in the context of assessing impact from offshore renewable developments (Searle *et al.* 2019), this tool is being further tested through more recent exercises (e.g. Butler *et al.* 2020), including on how to reduce uncertainty in the model (e.g. O'Hanlon *et al.* 2021).

A SEA-programme funded PVA study on the pink-footed goose population potentially affected by wind farms off the East Anglian coast and eastern Irish Sea (WWT Consulting 2008) concluded that with an additional annual mortality of 1,000 birds per year, the increase in the risk of population decline below the specific thresholds used was less than 2%; if 10,000 birds are killed each year however, the risk of significant population decline increased considerably (e.g. 18% risk of decline below 100,000 within 25 years).

For collision risks and displacement, the effects should be assessed by summing the impacts from each component project and in some cases, further population modelling may be required. Disturbance and barrier effects accrue in a non-linear manner and these should, therefore, firstly be considered in a qualitative way making best-use of available information. Significance of a cumulative impact on a species should include a consideration of its life history parameters. Alternately, consideration should be given to life history parameters and habitat/resource use flexibility when defining a species' sensitivity with long lived species and specialists considered more sensitive (King *et al.* 2009).

Collision risk assessment and headroom

The application and consenting process for offshore wind farms tend to be quite lengthy. Applications are typically made at an early stage of project design, where some uncertainly may remain (i.e. final capacity, scale and arrangement of turbines is unknown), thus assessment is generally made of the worst case (maximum) design for the impact assessment (the "Rochdale Envelope[170]" approach). The collision risk for birds is therefore based on this worst case, with the collision risk assessment methodology itself (as noted above) also having inherent precaution and uncertainty. Where applications have been successful, the consent is then granted on this "Rochdale Envelope" design.

At the point at which the development moves into the construction phase, the overall design will have been finalised, taking into account various aspects, including advances in technology. The final design of the constructed OWF (the "as-built") tends to involve fewer but larger turbines, which alters the collision risk for the project.

The "as-built" collision impact is, generally, less than the consented impact, the difference between the assessed or consented impact and the "as-built" impact is known as "headroom" (The Crown Estate 2021). Due to the engineering available and relatively slow pace of technological advancement, the differences between the consented and "as-built" parameters for early OWF developments, were minimal (The Crown Estate 2021). The more recent pace at which offshore wind farm technology is advancing (i.e. generating capacities can be attained with fewer, larger dimension turbines), and supply chains developing, has been relatively rapid, and whilst there is now greater scope to refine design during the assessment and consenting process, consenting timescales are such that developers may be inclined to use parameters for turbines which are not yet available on the market, and may not wish to commit to a particular turbine until consenting is complete and other financial aspects of the project have been secured. Therefore, "headroom" continued to be built into projects which have been consented to date.

The accepted approach to ornithological cumulative impact assessments is that it should be based on the legally secured consented wind farm parameters, which for many projects represent a much larger source of effect than for the as-built scenario. There is presently no legal mechanism to vary existing consents so that they match the as-built scenario, such that cumulative impact assessments are now likely over-estimating potential impacts, with consequences for consenting. In theory, if the effect of the "as-built" project are less than those assessed and consented for, this "headroom" could be made available for new projects, or else reduce the overall impact of a range of projects to make conclusions indicating a lower level of significance, with implications for other assessment process such as Habitats Regulations Assessment (HRA) and the need for or scale of any compensatory measures.

Where an AA is undertaken and an adverse effect on the integrity of a site cannot be ruled out, beyond reasonable scientific doubt, then further tests must be applied; these include a consideration of alternative solutions to the project; consideration as to whether there are Imperative Reasons of Overriding Public Interest (IROPI) (derogation[171]) for the project to proceed, and consideration and assessment of proposed environmental compensation

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[170] The Rochdale Envelope approach arises from two legal cases in 1999 and 2000 and is essentially employed where some details of the project have not been confirmed (e.g. the precise dimensions of structures) and when the application is submitted, some flexibility is required to address the uncertainty. See https://infrastructure.planninginspectorate.gov.uk/legislation-and-advice/advice-notes/advice-note-nine-rochdale-envelope/ for information and background on the approach.

[171] The HRA Derogation Provisions provide that a project having an adverse effect on integrity on a protected site may proceed (subject to a positive conclusion on alternatives and provision of any necessary compensation) if there are IROPI.

measures[172] (see Section 5.6.5) to ensure that the overall coherence of the site network is protected. Most recent HRAs undertaken for projects[173] in the southern North Sea have concluded that additional cumulative wind farm capacity would result in adverse effects on species related to certain colonies. These conclusions are based on the approach that, if the site/feature in question is already in a poor state or condition, then any impact (however small), would lead to an adverse effect on the site's integrity, and thus a requirement for derogation.

As part of their application for the Norfolk Boreas OWF, MacArthur Green (on behalf of Vattenfall) submitted a position paper on headroom, with examples (Table 5.18), showing a reduction in the assessed impact on kittiwake for Hornsea Project One and Triton Knoll OWFs (MacArthur Green 2020). Where collision mortality has been recalculated (work carried out in 2017 and based on current data at that time for all UK OWFs), it was estimated that cumulative gannet mortality would be reduced by ~14% and lesser black-backed gull by 40% (with the other species looked at, kittiwake, great black-backed gull and herring gull), falling in between these two values (Trinder 2017).

Table 5.18: Assessed v as built Hornsea Project One and Triton Knoll Offshore Wind Farms and impact on kittiwakes

Wind Farm	Impact Scale	Assessed WTG	Consented WTG	Built WTG	Assessed CRM	Consented CRM	Built CRM	Headroom (reduction from assessed to built), no. & %
Hornsea Project One	EIA	332	240	174	123	107	71	52 (43%)
	HRA				41	36	24	17 (41%)
Triton Knoll	EIA	333	288	90	209	-	75.9	113.1 (64%)
	HRA				35.4	-	12.9	22.5 (63%)
EIA Total Difference								185.1
HRA Total Difference								39.5

Notes: WTG = Wind Turbine Generators, CRM = Collision Risk Model. Source: after MacArthur Green (2020)

Natural England in their response to the question raised on the Norfolk Boreas OWF, did acknowledge that headroom is an issue, but is not a straightforward one to address

As noted above, no legal mechanism exists to require consent variations to reflect the "as-built" parameters of wind farms, so at present, the reduction of the "headroom" through altering

[172] Under Section 68 of the Conservation of Habitats and Species Regulations 2017, where in accordance with Regulation 64, a) a plan or project is agreed to, notwithstanding a negative assessment of the implications for a European site or a European offshore marine site, or b) a decision or a consent permission of other authorisation, is affirmed on review, notwithstanding such as assessment, the appropriate authority must secure that any necessary compensatory measures are taken to ensure that the overall coherence of Natura 2000 is protected
[173] The HRA for the Norfolk Boreas offshore windfarm concluded that an adverse effect could not be ruled out from the project, in combination with other projects on the integrity of the Flamborough and Filey Coast SPA (kittiwake feature) and the Alde-Ore Estuary SPA (lesser black-backed gull feature) and after consideration of the compensation measures proposed by the applicant, confirmed the compensation measures would be secured and delivered through the issued Development Consent Order.

consents is at the discretion of individual operators, however, this is being remedied through changes to the National Policy Statement for renewable energy which will apply to future projects (EN-3, September 2021).

EN-3 acknowledges that cumulative impact assessments for ornithology are currently based on the consented project parameters rather than the "as-built" parameters, the latter of which may pose a lower risk to birds. As a result, future consents (i.e. Development Consent Order) will have to define the final "as-built" parameters (which may not then be exceeded); these parameters can then be used in future cumulative impact assessments. For historic consents, and the ornithological impact assessments within the applications for these, the issue remains more complex and as such, a way forward on how to reassess these impact assessment to reflect their "as-built" parameters is still being considered.

Wave and tidal stream and tidal ranges

Wet renewable devices present a collision risk to birds during construction and operational phases. The risk is generally considered greatest for diving birds whose foraging depths coincide with the depths at which tidal devices may be deployed, although the depth of deployment is uncertain, and varies with design, although these typically range from 30-50m below sea surface (Furness *et al.* 2012).

The potential impacts of wave and tidal devices on marine birds have been the topic of a number of papers (e.g. Grecian *et al.* 2010, Langhamer *et al.* 2010, Langton *et al.* 2011, Frid *et al.* 2011, Wade *et al.* 2013, Furness *et al.* 2012, Masden *et al.* 2013), with ICES (2010) also providing advice on collision risk as part of a general review of environmental interactions with marine renewable devices, and Isaksson *et al.* (2020) developing a conceptual framework to assess the effects of tidal stream devices on seabirds. Witt *et al.* (2016a, b) addressed the methodological approaches needed to assess possible effects of wave energy on biodiversity, and, more recently, Swansea University and Ocean Ecology produced a review of monitoring methodologies and technologies suitable for monitoring animal interactions with tidal devices, in high energy environments (Clarke *et al.* 2021).

Given the limited deployment of wave and tidal stream devices in UK waters, empirical evidence also remains limited. Furness *et al.* (2012) published a review of the potential sensitivity of seabird populations to the adverse effects from tidal stream turbines and wave energy devices. This provided vulnerability indices for birds interacting with tidal and wave devices, scoring several species vulnerability factors (see Table 5.19) and conservation factors, and taking an approach similar to that of Garthe and Hüppop (2004) for offshore wind farms. Due to lack of deployed devices to monitor and therefore, lack of observational data, interactions with tidal and wave devices were inferred rather than evidenced. Using the indices, species identified to be most vulnerable to adverse effects from tidal turbines are black guillemot, razorbill, shag, guillemot, cormorant, divers and puffin, while divers are the most vulnerable to wave devices. Furness *et al.* (2012) concluded that wave energy devices are likely to represent a lesser hazard to seabirds than tidal turbines, and both seemed likely to represent a lower hazard to seabirds than offshore wind farms.

Table 5.19: Vulnerability factors for tidal turbine (left) and wave devices (right).

Vulnerability factors for tidal turbines	Vulnerability factors for wave energy devices
Drowning risk – seabird vary in their susceptibility to drowning, e.g. some seem prone to get stuck in nets/traps, while others avoid. Differences likely to be caused by morphology, feeding ecology, behaviour, e.g. juveniles more prone to such mortality than adults.	**Risk of collision mortality due to structures** – some seabirds may be at risk of injury or death from colliding with wave energy devices either in flight or while swimming or diving.

Vulnerability factors for tidal turbines	Vulnerability factors for wave energy devices
Mean/maximum diving depth – depth deployments of tidal turbines uncertain and varies with design, but typically 30-50m below sea surface. Seabirds capable of diving to these depths likely to be at greater risk. Surface feeders at less risk. Scoring groups were: regularly dive to 2-3m but have max diving depth of no more than 5m; regularly dive to 5m but rarely below 20m; regularly to 20m but rarely below 40m and regularly to 30m and deeper[1].	**Exclusion from foraging habitat due to behaviour constraint** – seabirds may be prevented from foraging in important habitat maybe through being unable to land or take off easily where devices are present in the water, because other birds have been attracted to the area or because they need to spend their time avoiding devices rather than foraging
Benthic foraging – benthic foragers more likely to interact than seabirds that do not forage on the benthos.	**Benefit from roost platform** – under relatively calm sea conditions, devices may provide some seabirds with a resting platform; such an opportunity could extend their potential foraging area. E.g. cormorant and shag return to shore to dry their plumage after a foraging bout, having resting sites at sea could allow these birds to exploit areas further from shore.
Use of tidal races for foraging – few studies on the use of fast tidal flow areas by foraging seabirds; guillemots have displayed a tidal rhythm in foraging activity in early part of breeding season (but not chick rearing) in Orkney; Arctic tern and common tern in the Wadden Sea have also been recorded foraging selectively at stages of the tide and in geographical locations with relatively faster flowing (1m/sec) shallow (<10m) water	**Benefit from fish attraction device or biofouling** – devices will likely provide shelter for small fishes and so are likely to act as a fish attraction device, and also present surfaces onto which biofouling organisms will settle – both attracting foraging seabirds by providing locally high densities of prey.
Feeding range – being "central place foragers" breeding seabirds are constrained to return to the central place (nest site); during migration and winter, they are considerably less constrained. The distribution of predictable feeding hotspots may influence habitat quality; species with short feeding ranges will be more likely to be affected by the placement of devices than seabirds with greater foraging ranges.	**Disturbance by structures** – species differ in their reaction to structures; relates in part to the general responsiveness of species to disturbance and in part to their perception of the hazards represented by structures.
Disturbance by ship traffic – species differ in their reaction to ship traffic (deployment/maintenance activity); e.g. alcids can be disturbed by boats hundreds of metres away; divers are sensitive to approaching boats more than 1km away and scoters are particularly vulnerable to disturbance by boats.	**Disturbance by ship traffic** – considered the same as that for tidal devices
Habitat specialization – seabirds vary in the range of habitats they use, e.g. relating to water masses, and frontal systems, and whether they use these as specialists or generalists. Species can tend to forage over large marine areas, with little known association with particular marine features or feed on very specific habitat features such as shallow banks with bivalve communities.	**Habitat specialization** – similar to tidal devices

Notes: [1]See RPS (2010) and the description in OESEA2 (Table 5.11) for summary of dive depth behaviour. [2]the tidal flow rates reported by Schwemmer *et al.* (2009) for the Arctic and common terns (1m/sec) are relatively low in comparison to areas under consideration for deployment of tidal turbines (usually in excess of 4m/sec). Source: Furness *et al.* (2012)

The risks to seabirds posed by these devices in a particular area of open water are dependent on the foraging ranges of each species, especially the mean range within which most birds from a particular population will be expected to forage. For example, care should be taken to ensure devices are only located within the foraging ranges of birds from major colonies and SPA-designated areas if it can be established that the sites in question are of little importance or where risks to these species are assessed to be low. Placing devices within important foraging areas may mean that species are at elevated risk of collision with or entrapment within structures, construction and operational disturbance and indirect effects such as displacement of prey (RPS 2010).

Risk of collision is expected to be minimal as for many species of seabirds, including gulls, terns, kittiwakes, fulmars and skuas, their normal depth range (these being surface feeders only reaching maximum depths of 1-2m (Furness *et al*. 2012) (2-3m (Garthe & Furness 2001) or 3-5m (Furness *et al*. 2012) for northern fulmar) (Furness *et al.* 2012) would not allow them to encounter operating turbines. For some deep diving species, e.g. auks, shags, there is the chance of an encounter as these species regularly dive to depths of 45-65m. The critical issue is the relative swimming speed of the bird, and the ability to sense and respond to the turbine. The possible interactions are further complicated by the possibility that diving birds may respond to the moving blades as potential prey and be attracted to their vicinity. Further work is needed to elucidate the scale of this phenomenon and to develop mitigation measures i.e. painting the blades (ICES 2010).

A lack of knowledge of the risks of collision to birds leads to uncertainties in determining the (population) level impact from these devices and, a degree of uncertainty will remain until monitoring from larger installations becomes available.

5.6.3.5 Collisions risk – fish and marine mammals

Worldwide, collisions with vessels are a potential source of mortality to marine mammals, primarily cetaceans. Whales are occasionally reported to be struck and killed, especially by fast-moving ferries but smaller cetacean species can also be impacted by propeller strikes from smaller vessels. In areas where cetacean numbers are depleted and vessels are numerous, ship-strike mortality can be a serious cause for concern at a population level. This is of particular concern for long-lived marine species, which generally have low recruitment rates and an older age of sexual maturity, for example in the case of North Atlantic right whales during their seasonal migration along the U.S. coast (Moore *et al*. 2004, Kraus *et al*. 2005). In the UK certain areas experience very high densities of commercial and recreational shipping traffic, some of which may also be frequented by large numbers of marine mammals; despite this, relatively few deaths are recorded as results of collisions (Hammond *et al.* 2008). Since its inception in 1991 to programme completion in 2017 the Cetacean Strandings Investigation Programme (CSIP) conducted 3,744 post-mortem examinations on UK cetacean standings (primarily harbour porpoises and common dolphins), of which 39 were attributed to vessel collision, the majority of which were recorded during the last decade (35 from 1,006 post-mortems during the period 2011-2017 (Deaville *et al*. 2017). A further 150 deaths during 1991-2017 (92 deaths 2011-2017) were recorded as physical trauma of unknown origin, this category is considered likely to include some undiagnosed cases of boat/ship strike, by-catch or bottlenose dolphin attack).

Wilson *et al.* (2007) reviewed the risks of injurious collisions between mobile species and wave and tidal stream devices. Mooring equipment such as anchor blocks are similar to natural seabed structures and hence pose few novel risks for vertebrates. Cables, chains and power lines extending up through the water will have smaller cross-sectional area than vertical support structures and so produce reduced flow disruption and fewer sensory cues to approaching animals. Instead of being swept around these structures, animals are more likely to become entangled in them. Seals may use floating devices as haul-out sites and risk of injury may be associated with getting onto/off the structures and any contact with exposed, moving or articulated parts. Cetaceans do regularly surface for air and collisions could either occur through animals swimming into them or the structures pitching down onto breathing animals in heavy seas. Collision risks for surfacing mammals will depend on how aware they are of the presence of the surface structures. Overall, the potential to cause collision has been associated most strongly with rotating turbines of tidal stream energy converters; this assessment is based largely on similarities between the velocity of rotor blades and those of approaching vessels implicated in cetacean ship-strikes.

The risk of collisions with marine mammals depends on the numbers of animals at the tidal sites, their natural behaviour and any behavioural responses to encountering turbines. A first assessment of the magnitude of risk to marine mammals posed by a tidal stream development was estimated by modelling encounter rates of harbour porpoises (Wilson *et al.* 2007). Information on distribution, size, depth preference and swimming speed was included in the model but the lack of any data to evaluate the ability of individuals to avoid coming into contact with devices led the authors to exclude consideration of avoidance or close-range evasion; hence encounter and not collision rate was modelled. It was predicted that in a year of operation, approximately 4 to 11% of the porpoise population would encounter a rotating blade. Albeit preliminary, these results supported the need for caution and for new research to quantify collision. The harbour porpoise encounter rate model was further revised by Wilson *et al.* (2014) for two Scottish sites with high potential for tidal stream energy development, where high resolution harbour porpoise abundance data from *ad hoc* surveys was used; encounter rates were found to be lower reflecting the lower abundance obtained in the surveys.

As part of the Marine Renewable Energy Strategic Framework for Wales (MRESF), WAG (2010) carried out a desk-based examination of factors which may influence collision risk of marine mammals with wave and tidal stream devices. Discussions were consistent with the work by Wilson *et al.* (2007) and a similar conclusion was reached in that a detailed assessment of risks posed by tidal turbines is hampered by major knowledge gaps in several areas. It was noted that areas of high tidal energy are apparently important for different species of cetaceans and seals; better understanding of their distributions and densities in these environments, including knowledge of diving behaviour, is important for assessing encounter probability. Better understanding of sensory and motor capabilities and behaviour is important for quantifying evasion, quantifying collision risk and devising effective mitigation strategies. Field studies were carried out to improve the evidence base on the likely use by cetaceans and grey seals of high tidal-energy areas in Wales (WAG 2010, WAG 2012).

The SeaGen tidal turbine in Strangford Lough was a key test case in this respect; an active sonar system was operated from it providing real time sub-surface sonar imagery of marine mammals and other large marine animals e.g. basking sharks, within 80m of the SeaGen turbine. Between March and September 2010, the active sonar system recorded 612 targets of which 227 triggered precautionary turbine shutdowns as a result of large animals coming within 50m of the turbine (although on closer inspection 22 shutdowns were believed not to be caused by marine mammals (Royal HaskoningDHV 2010). Monitoring indicated that both marine mammals and ‘other’ targets move past the turbine in close proximity; however, due to the requirement for precautionary turbine shutdowns information on how marine mammals interact with the turbine during operation was not collected.

Since the development of the encounter rate model by Wilson *et al*. (2007) and Batty *et al.* (2012), modelling efforts have continued and a collision risk model for seals and tidal stream turbines was developed (Davies & Thompson 2011) from an original model for predicting the risk of birds being struck by wind turbines (Band 2000). These approaches were reviewed and compared by Lonergan & Thompson (2015) in an assessment of risk for seals; broadly similar results were obtained but the authors recognised that the outputs were far more sensitive to assumptions made about animals’ ability to avoid collisions than any other factor. They concluded that until data on avoidance rates become available, further refinements of the models of encounter rates may be of limited value. Among the research requirements identified (Thompson *et al.* 2015) the need for empirical evidence to support collision models was clearly identified.

Recent studies have been undertaken to provide empirical measures of marine mammal avoidance behaviour to noise generated by tidal stream turbines. Using GPS tags and shore-based observations Hastie *et al*. (2018) demonstrated that harbour seals exposed to simulated tidal turbine sound in a narrow coastal channel showed significant spatial avoidance of the sound source. This resulted in a reduction in the usage of the area by seals of between 11% and 41% at distances up to 500m from the source. Similarly Onoufriou *et al*. (2021) found a significant decrease in abundance of harbour seals within approximately 2km of an operating tidal turbine array. Harbour porpoise were also found to exhibit a significant avoidance response of an operating tidal turbine (Palmer *et al*. 2021, Gillespie et al, 2021). Gillespie *et al*. (2021) found that while harbour porpoise frequently swam in close proximity to the turbine they generally avoided the area close to the rotors (within 10m), indicating localised avoidance. While Palmer *et al*. (2021) found porpoise abundance was reduced by up to 78% within tens to 150m of the turbine when it was operating in periods of high flow. As these studies could not identify individual porpoises it was not possible to determine whether habituation may occur to the turbines. The authors note that as the tidal industry expands it will be important to balance the benefits of avoidance responses to potential collision risk with the potential effects of displacement from or barrier between important habitats.

While both harbour seals and harbour porpoise have demonstrated avoidance behaviours there remains a potential that collisions with rotating turbine blades may cause serious injury or direct mortality. To date, estimates of population level effects have been based on a precautionary assumption that all collisions result in death or permanent disablement of the animals involved (Wilson *et al.* 2006; Band *et al.* 2016). This assumption is unlikely to be true for all cases, and the models may therefore produce inaccurate predictions about the effects on populations of marine mammals. Onoufriou *et al.* (2019) conducted experimental trials using seal carcasses and a replica tidal turbine blade to assess the relationship between collision speed and the probability of inducing severe, traumatic injuries. The study found that the probability of severe trauma was highly dependent on collision speed, with pathological indicators of mortality expected at collision speeds in excess of $5.1ms^{-1}$ and consequently the majority of predicted collisions were considered unlikely to cause fatal skeletal trauma. Such empirical mortality data could be used to improve estimates of population level consequences derived from collision risk models.

Collision with the rotor blades of turbines of tidal devices can cause significant injury to fish. Although up to 50% of such collisions do not result in injury (Hammar *et al.* 2015), direct mortality of fish passing through turbines at tidal stream devices can potentially be high (Deng *et al.* 2011), and may be affected by the turbidity of the water, the design of the turbine, and the noise produced by the device. Recent flume studies (reviewed in Copping and Hemery 2020) investigating the avoidance behaviour of fish around an operating turbine found that as turbine rotation velocity increased (during constant flow velocity) the fish avoidance behaviour also increased (Zhang *et al*. 2017). While a similar flume study found that fish behaviour was affected by changes in the flow rate and suggested that fish capable of avoiding turbines blades in the absence of a current, were less capable of a similar avoidance reaction when a current was running (Yoshida *et al*. 2020). Limited field-based assessments of fish collision with turbines have been conducted, one recent study examined characteristics of fish tracks to infer potential collision with turbine blades, while 36 tracks were identified as having the possibility of a collision based on the close proximity to the turbine, there were no observations of fish striking rotor blades in the video footage analysed (Bevelhimer *et al*. 2017). Another study based on analysis of 42 hours of video footage of a river based turbine recorded three potential collisions of which only on one occasion contact was confirmed (Matzner *et al*. 2017). Both studies found that fish were able to adjust their swimming behaviour, by reducing swimming velocity and altering direction, in order to evade an oncoming turbine. While generally these studies suggest that the risk of a fish collision with a turbine is relatively low more research is required to further understand the potential risks of tidal turbines at an individual and population level. In particular, presence of fish species for both baseline and post-installation; understanding of fish behaviour during different hydrodynamic conditions, over diel cycles and before and after turbine installation; effects on fish of stimulus fields produced by the turbine such as velocity, noise, pressure and acceleration; consequences of fish collision with turbines; effect of turbine arrays on fish (Sparling et al, 2020). Hearing-sensitive fish, such as herring, may be able to detect and avoid tidal devices at distances of up to 300m; however for less acoustically sensitive species, wave and tidal devices are not likely to generate sufficient noise to trigger a response (ABPmer 2010). A modelling study conducted by Hammar *et al.* (2015) suggests that larger bodied fish are more at risk than smaller ones, particularly when encountering larger turbines, which may not be as easy for a fish to navigate an avoidance path around. Collision risk of wave devices is considered low, and unlikely to be any more significant than that of floating buoys or moored vessels (ABPmer 2010). Entrapment of fish within the reservoir of over-topping devices is a possibility, but anecdotal evidence has not identified this as a significant occurrence (ABPmer 2010). Entanglement in the mooring lines and ropes of surface deployed wave devices is a potential source of effects, particularly for large species such as basking shark. The tendency of fish to aggregate around artificial structures may act to increase collision risk (Freeman *et al.* 2013).

The risk of entanglement with mooring lines of floating renewable energy devices is considered to be greatest for marine mammals, but the overall risk to this group has been suggested to be low given that the cables and mooring lines are often taut and of a diameter large enough to preclude easy entanglement of even a large whale (Benjamins *et al*. 2014). Large migratory baleen whales (e.g. minke whales, right whales) are considered to be of the greatest entanglement risk of all marine mammals because of their migratory and feeding behaviours (Benjamins *et al*. 2014) and large pelagic elasmobranchs (e.g. basking shark) also due to their size and feeding habits (Garavelli 2020). Baleen whales and basking sharks forage by feeding with their mouths open and therefore may be entangled through the mouth, and lines may become lodged behind the jaw or baleen and be difficult to remove without human aid (Sharp *et al*. 2019). However, marine mammal species are likely to be able to detect large-diameter mooring lines, either through echolocation, vibrations or from the noise as the cables or lines drag through the current (reviewed in Benjamins *et al*. 2014).

Most available literature focusses on entanglement of marine mammals with fishing gear and lines, which can lead to serious injury or mortality. Studies using dynamic analysis software to predict the influence of different mooring configurations under various sea states on entanglement risk, predicted that catenary configurations would present the highest risk as they have the most slack in the mooring lines (Benjamins *et al*. 2014). As part of the environmental impact assessment performed for the Deep Green Utility units, an encounter model was developed to assess the potential of direct collision that could lead to entanglement between the mooring tether of the tidal kite and marine mammals (Minesto 2016). The model predicted that most marine mammals (grey seals, harbour porpoise, and bottlenose dolphins) swimming through the swept area of the device would not encounter the mooring tether when the device is operating. Even in the case of an encounter, the tether would remain taut to avoid the risk of entanglement. For single devices the encounter rate is likely to be low as the mooring lines occupy a small cross section of the water column, while a large array of devices is less certain, however given the scale of the devices and greater water depths this risk is considered to be low. Further, no entanglement has been reported for oil platforms with a similar mooring configuration (Harnois *et al*, 2015 cited in Maxwell *et al*. 2022), or for cables or mooring lines associated with the Hywind-2 floating turbines in Scotland (Maxwell *et al*. 2022).

Secondary entanglement, where derelict fishing gear (such as nets and hooks/lines) becomes entangled in the mooring lines or cables could pose a greater risk to marine mammals and fish (Benjamins *et al*. 2014). Marine License conditions stipulated by Marine Scotland for offshore floating wind farms require that marine mammal entanglement, in particular with derelict fishing gear which has become entangled on the mooring lines, is monitored and reported throughout the project lifecycle (Marine Scotland, 2017). While the effects of secondary entanglement are currently unknown, it is important to monitor for effects, particularly when sensitive or endangered species are present in turbine lease areas (Maxwell *et al*. 2022).

The Welsh Government commissioned ABPmer (2020) to collate and review available data collected from *in situ* devices and from wider literature that investigated collision between marine mammals, seabirds and fish with tidal stream devices. ABPmer (2020) provided recommendations on addressing the key information gaps, identified during the review, required to support impact assessments of tidal stream devices on marine mammals and fish.

The review found that field monitoring in the form of observational baseline and on-going impact monitoring surveys provided valuable data describing the presence, distribution and likely vulnerability of species to tidal stream devices, as well as allowing distribution shifts (far field avoidance) following installation of the devices to be assessed. Baseline density estimates of species present are a necessary input parameter for the predictive collision modelling assessment, however, it was noted that not all tidal stream developments have undertaken baseline monitoring. To date there has been limited field validation of the collision assessment models due to key evidence gaps which include avoidance / encounter rates (including an understanding of species behaviour within tidal stream areas), evidence of a collision occurring and the effects to the individual of that collision. Other key gaps are the potential implication of collision mortality at the population level and the cumulative effects of deploying multiple tidal devices and arrays in the marine environment.

One of ABPmer's (2020) main recommendations for addressing these gaps is to collect further evidence on underwater behaviour of marine mammals and fish (including near field evasion) to be able to generate robust avoidance rates. Further development of technologies such as blade mounted pressure sensors and hydroacoustic video are needed to accurately determine collision events, and more information on the physical consequences of a collision (with the blade or pressure differential) is also required to fully understand the potential for death or injury.

A recent review of techniques and technologies for monitoring interaction of tidal turbines with marine mammals, fish and birds, commissioned by the Welsh Government (Clarke *et al.* 2021), provides a comprehensive overview of existing and emerging technologies; recommendations for technologies that could be further developed to correlate species behaviour and turbine stimuli; and identifies the most suitable devices for deployment in Welsh waters. The information contained within this report will be valuable to identifying appropriate technologies for establishing baseline conditions and operational monitoring of UK wide developments, with specific consideration given to local conditions and species assemblages. The report highlights the value of combining data from multiple monitoring tools to enable tracking and classification of targets to species level, for example combining active acoustic tracking with techniques that can identify species (such as PAM, visual observations or visual camera footage) to enable fine scale observations of behaviour in the immediate vicinity of devices.

5.6.3.6 Effects of offshore lighting on birds

Over a number of years, the potential effects of light on birds have been raised in connection with offshore oil and gas activities (e.g. Weise *et al.* 2001, Bruinzeel *et al.* 2009, Bruinzeel & van Belle 2010, Ronconi *et al*. 2015). As part of navigation and worker safety, and in accordance with international requirements, drilling rigs and associated vessels are lit at night and the lights will be visible at distance (some 10-12nm in good visibility). The attractive effect of lights on birds on cloudy nights is enhanced by fog, haze and drizzle (Weise *et al.* 2001). Bruderer *et al.* (1999) noted that the switching off and on of a strong searchlight beam can influence the flight behaviour of migrating birds.

Attraction to lights can be especially true of some taxonomic groups (e.g. some burrow nesting seabird, e.g. petrels, shearwaters and Atlantic puffin) and many nocturnally migratory species (especially passerines) (NatureScot 2020), and, it is often juvenile birds that are predominantly affected (Rodriguez *et al*. 2015); although the reasons for such attraction are poorly known. Whilst the potential impact of light attraction could be significant (e.g. Longcore *et al*. 2008, 2012, 2013 (these focusing on communication towers, and caution should be taken when extrapolating these to oil and gas/renewables), Rodriguez *et al.* 2015, Deppe *et al*. 2017) the consequences of this for the viability of bird populations is well understood; mortality during migration is a significant proportion of adult/juvenile mortality, regardless of the additional effect of artificial light (NatureScot 2020).

While well-defined preferred migratory corridors are still unknown, (e.g. Wright *et al*. 2012, Furness *et al.* 2015), with birds utilising broad flyways, the cuneiform southernmost part of the North Sea (Regional Sea 2 and 3) is an important funnel for bird migration with an estimated 1-1.3 million seabirds possibly using the route annually (Stienen *et al.* 2008), with a considerable proportion of birds migrating at night (Rebke *et al.* 2019). Large numbers of species such as great skua and little gull, as well as terns and lesser black-backed gull, use the Strait of Dover to exit the North Sea.

Hüppop *et al.* (2006b) studied the migration of terrestrial birds across the German Bight, noting that each year during the migration periods several hundred million birds of roughly 250 species (dominated by passerines) cross the North and Baltic Seas on their journeys between their breeding grounds in northern Asia, North America, Scandinavia and Finland, and their winter quarters, which lie between Central Europe and southern Africa, depending on the species. They report on remote observations, including those of ‘invisible’ bird migration from the FINO 1 research platform, using ship radar, thermal imaging, video and a directional microphone from October 2003 to November 2004. While providing considerable data on the altitude of migrating birds and on seasonal and diurnal variability in migrating bird numbers, they also report that a total of 442 birds of 21 species were found dead at FINO 1 (which has no rotating turbine blades, but has a met-mast and navigation lights) between October 2003 and December 2004; of which 245 individuals (76.1% of the 332 birds examined) had outwardly apparent injuries. Over 50% of the strikes occurred on just two nights characterised by periods of very poor visibility with mist or drizzle and presumably increased attraction of the illuminated research platform. In the second of these nights the thermal imaging camera revealed that many birds flew “obviously disorientated” around the illuminated platform.

Also required to have lights for safety (all wind turbines of greater than 150m in height require visible, red aviation lights), there is little observational data on light effects from offshore wind farm developments, but behavioural responses and mortality of migratory birds have been reported from lighthouses and gas platforms in the southern North Sea (Hope Jones 1980, “Green light paper”) and are commonly observed from vessels of all sizes. Some work has looked at the influence of colour and mode (i.e. red, white, steady, flashing, strobe) on collision risk (e.g. Gehring *et al.* 2009, Kerlinger & Kerns 2003, Kerlinger *et al*. 2010, Rebke *et al*. 2019);

flashing red lights reduced attraction, compared to steady state red lights, although white lights appeared to be better than red. Mitigation that has been employed elsewhere include removal of steady state red light, and replacing these with flashing lights; adoption of green down-lights; shielding from upward transmission and an alternative approach being to only switch on lighting when aircraft are near (i.e. radar activated lighting).

There is very little information on the potential ecological impact of lighting on wave and tidal stream devices. Some installations are totally submerged while others may only protrude slightly above the sea surface. Navigational lights associated with devices may attract foraging nocturnal birds although any attraction would likely be short-lived if not associated with any foraging benefits for the birds (ABPmer 2009). Given the scale of development that could arise from adoption of the draft plan/programme is still likely to be small rather than large scale arrays, it is unlikely that lighting will have a significant ecological impact.

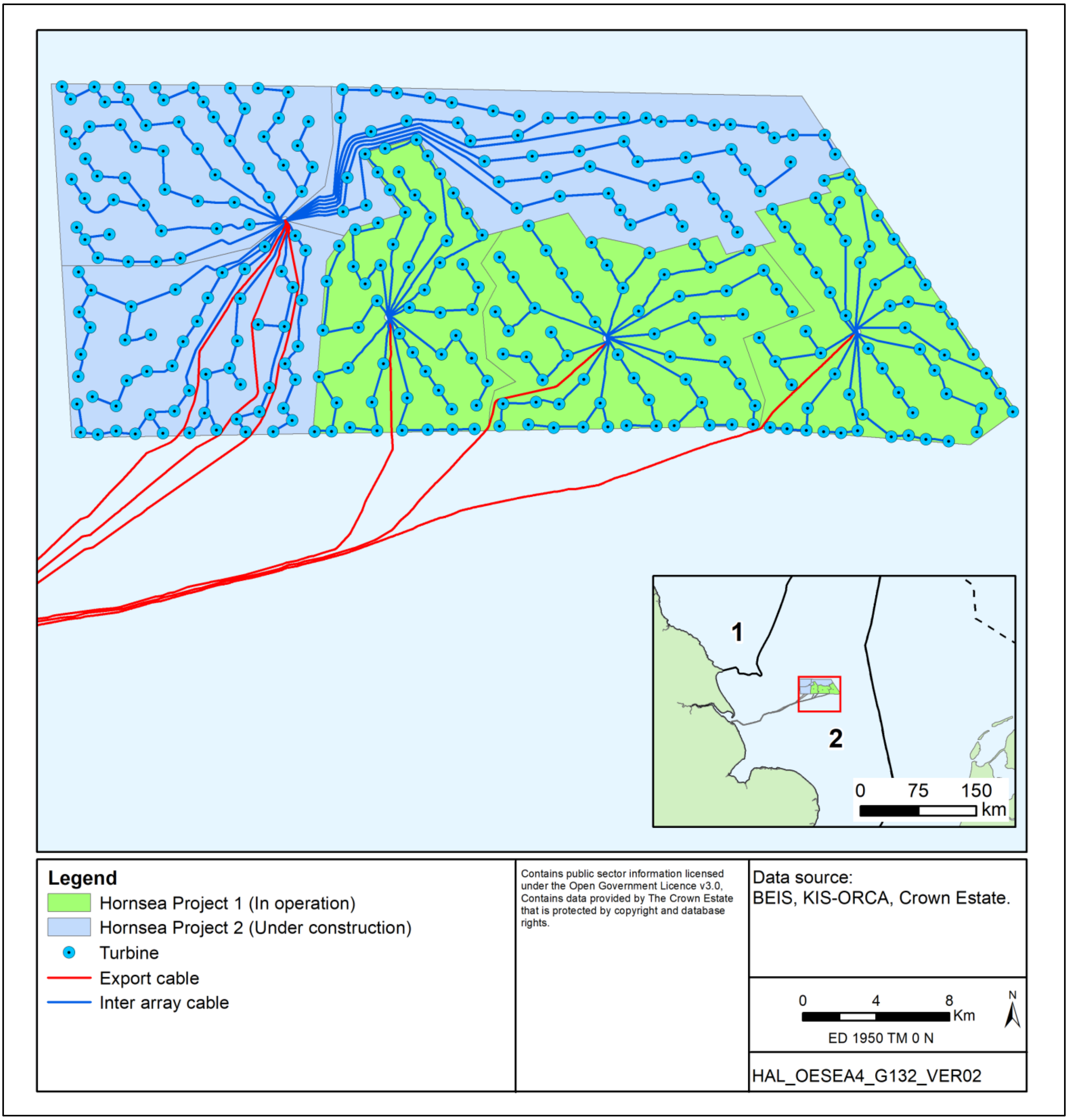
5.6.3.7 EMF

Submarine power cables have been in use since the mid-19th century transporting power from areas of net generation to those of limited or no power generation. However, environmental concerns about their potential effects are much more recent as the deployment of marine renewable energy technologies has gathered pace and with it the coverage of power cables in the marine environment (Taormina *et al*. 2018).

There are four main types of submarine power cable installed in UK waters: distribution cables which provide a link from the mainland to the islands and as interconnectors between islands; transmission cables which transport power between areas of generation to centres of demand; inter-array cables between offshore energy devices and export cables from offshore generation sites such as wave, wind or tidal energy farms (Marine Scotland 2020a, ESCAEU 2022, Hutchison *et al*. 2020a). Typically distribution, transmission and export cables follow a linear path between two locations, while power cables associated with wind farm arrays comprise intra-array cables connecting individual turbines with each other and the offshore substation (Figure 5.36). Additionally, wind farm export cables connecting an offshore substation with the onshore grid may require multiple export cables to service a single wind farm, for example, three export cables were installed for the Hornsea 1 windfarm and up to six cables are planned for the consented Hornsea 3 windfarm development (Ørsted 2018b). Consequently distribution, transmission and export cables could pass through many types of habitat, and inter-array and wind farm export cables could impact relatively large areas of a particular habitat (Figure 5.36).

Submarine power cables relay electric currents either as Alternating Current (AC) or Direct Current (DC), the transmission type being determined by the capacity and length of the transmission line as well as commercial considerations (Taormina *et al*. 2018). A DC line can transmit more power than an AC line of the same size, but is more expensive, while an AC line is typically limited to <100km transmission distance due to issues associated with power loss (Taormina *et al*. 2018). To date, AC cables have been more commonly used for offshore renewable energy technologies due to the relatively short distances to shore. However with the expansion of marine renewables into deeper waters and the associated onshore grid connections, both AC and DC cables are likely to increase in number.

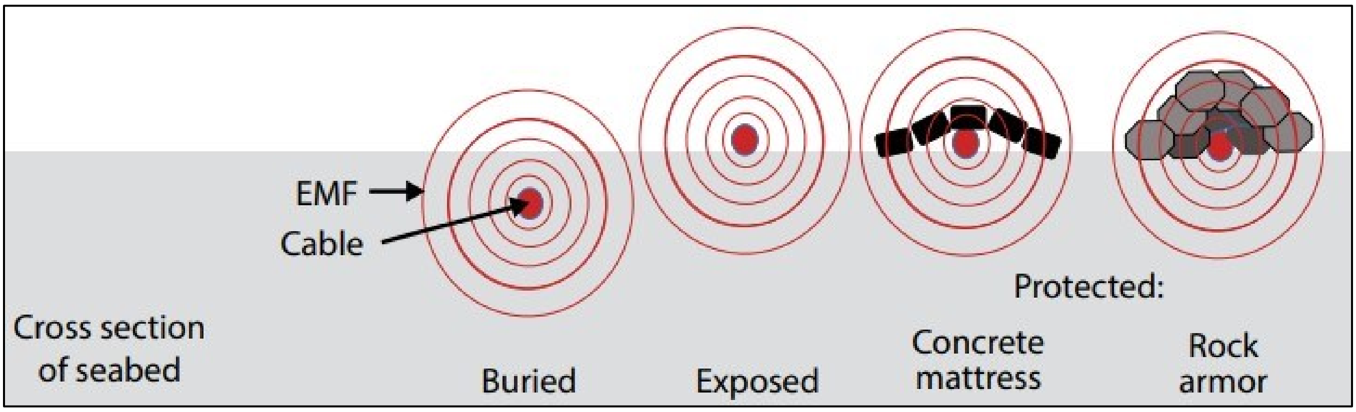
Figure 5.36: Inter-array submarine cable layout for the Hornsea 1 and 2 wind farms.



The transfer of electricity, either by AC or DC submarine cables, emits an electromagnetic field (EMF). An EMF has two components, electric fields (measured in volts per meter) and magnetic fields (measured in Telsa units, T) (Gill & Desender 2020, Taormina *et al*. 2020a). Modern cable sheathing and grounding retains the electric field within the cable but the AC or DC magnetic field is emitted into the surrounding environment. An AC cable generates an alternating magnetic field which creates a weak induced electric field of a few μVm^{-1} (Hutchison *et al*. 2020a). A secondary induced electric field (iE-fields) is also generated when an animal or water current causes motion through the magnetic field (Gill & Desender 2020). The strength of both magnetic and electric fields increases with current flow and rapidly decays with distance from the cable (Hutchison *et al*. 2020a).

The zone of effect associated with subsea power cables will vary depending on the nature of the wet renewable technology. To date the majority of offshore wind farms utilise fixed foundations in relatively nearshore waters with cables commonly laid in or on the seabed. With developing technology and a government target to deploy 1 GW of floating offshore wind by 2030, suspended or dynamic cables passing through the water column will become more common. In general, the magnetic field passes through the seabed and the water column in the same way (Figure 5.37), so while burial doesn't reduce the magnitude of the field (ICES 2019b), it does reduces the physical distance between the surface of the cable and the receptor organism on the seabed. Therefore benthic epifauna are unlikely to encounter the maximum field, but will encounter a field within the range of detection and within the range of potential effects, and benthic infauna could be exposed to the maximum field. Cables suspended in the mid-water column could potentially create larger EMF emissions than devices that have buried cables (Freeman *et al*. 2013), and have the potential to interact with pelagic species or species that move between the demersal and pelagic environment.

Figure 5.37: Example of EMFs emitted from subsea cable buried, laid on the seabed either exposed or with protection (adapted from Hutchison *et al.* 2020a)



Field measurements of the EMF zone of effect associated with buried cables are very limited. Hutchison *et al*. (2018, 2020b) reported measurements from two HVDC cables (Cross Sound Cable – providing power up to 330MW via a 300kV cable; Neptune Cable – providing power up to 660MW via a 500kV cable, both east coast USA) operating with a current of 345 and 1,320 A respectively; and one AC cable (sea2shore – providing power up to 30 MW) with results scaled to the maximum operating current of 502A. The DC magnetic fields measured deviated from the background magnetic field in the range of 0.4-18.7 µT for the Cross Sound Cable and 1.3-20.7 µT for the Neptune Cable. The observed variation along each cable route was primarily attributed to variations in burial depth of the cable. Peak values occurred almost directly above the cable location, reaching background levels at approximately 5m either side of the cable (Hutchison *et al*. 2018, 2020b).

An unexpected weak AC magnetic and electric field was also measured from both HVDC cables (Cross Sound Cable – average MF 0.15 µT, EF 0.7 mV/m; Neptune Cable – average MF 0.04 µT, 0.4 mV/m) possibly from the AC/DC converter stations (Hutchison *et al*. 2020b). The AC magnetic field reached background levels approximately 10m from the cable, while the AC electric field reached background levels on a scale of hundreds of meters from the cable.

Measurements across the AC sea2shore cable exporting power from the Block Island OWF (USA) indicated average magnetic AC-fields in the range 0.005 to 3.1 µT (scaled to 502A) and the electrical fields were 0.02 to 0.25 mV/m, significantly lower than modelled values commissioned by the grid operator, indicating that the three-conductor twisted design achieved significant self-cancellation and may mitigate possible biological effects (Hutchison *et al*. 2018).

The manufacturer of the 33kV AC inter-array cables connecting the five floating wind turbines of the Hywind Scotland pilot project calculated that the magnetic field from the buried static cable would be 15 µT 500mm from the cable surface, and 13 µT 500mm from the dynamic cable surface (Statoil 2017b). The reasons for the difference between the static and dynamic cable are not given but may be due to differences in cable design. Measurements of magnetic fields associated with cables exposed on the seabed may provide a proxy for the field strength to be expected from dynamic cables. Love *et al*. (2016, 2017a) measured mean field strengths associated with three exposed 35 kV AC cables of 108 µT (range 51-205 µT) at the cable surface (current flow not provided). They noted that EMF levels dropped significantly with distance from the cable and approached background levels at one metre from the cable. The limited information available from developers and from measurements from exposed cables suggest that magnetic field emissions associated with suspended floating windfarm cables will likely be of a similar magnitude. Pelagic organisms may encounter the higher EMF emissions present at the cable surface, when compared to benthic organism exposure from cables buried within the seabed.

The most dominant EMF in the marine environment is the Earth's naturally occurring geomagnetic field (GMF). The Earth's GMF varies in intensity with latitude, the highest intensities are at the poles (>60µT), the lowest near the equator (<30 µT) (Zapetis & Szesciorka 2018), and intensities of approximately 50 µT occur across the UK (Shanahan *et al.* 2012). Interaction between the conductivity of seawater, the Earth's rotation of the GMF and the motion of tides/currents induces a weak direct current (DC) electrical field (about 0.075 mV/m in the case of an ocean current moving through the GMF) (Snyder *et al*. 2019). Marine animals have evolved in the presence of the naturally occurring GMF and consequently many species have developed electromagnetic (EM) sensory systems including magnetite-based, photo-chemical mechanisms, lateral lines and ampullae of Lorenzini (Tricas & Sinseros 2004, Baker *et al*. 2013 and Nordmann *et al*. 2017, referenced in Hutchison *et al*. 2020a). Magneto-sensitive animals derive positional information from geo-magnetic field parameters such as field direction, field vectors (horizontal and vertical components), inclination, declination and intensity/magnitude (Anderson *et al*. 2017). These species employ either a magnetic compass and /or magnetic map enabling homing and /or migration over short and long distances, examples include most marine phyla which undergo large-scale migrations like diadramous fish such as Atlantic salmon (Scanlan *et al*. 2018) and European eel (Lohmann *et al*. 2008), elasmobranchs (Kalmijn 1978), cetaceans (Zapetis & Szesciorka 2018) and migratory crustaceans such as the Caribbean spiny lobster (Ernst & Lohmann 2016). Electro-sensitive species are able to detect weak electric fields used to detect prey and predators, to communicate, find mates and locally orientate (Tricas & Sisneros 2004). These species, particularly elasmobranchs, are also able to respond to magnetic fields using electro-sensory apparatus and some may have both electro and magneto-sensory apparatus (Anderson *et al*. 2017). Distortions of these fields by anthropogenic EMFs may have important ecological consequences (Hutchison *et al*. 2020a).

Field enclosure studies (Hutchison *et al*. 2020b) indicated that anthropogenic EMFs emitted by HVDC subsea cables were within the range of biologically relevant EMF intensities. A number of reviews and studies have sought to investigate and characterise the potential impacts of anthropogenic EMFs to magneto and electrosensitive species, these studies also highlight the significant knowledge gaps in relation to species ranges of detection and potential response impacts (Hutchison *et al*. 2018).

Magnetoreception

Magnetoreception has been demonstrated in various invertebrate taxa, particularly migratory species that use the Earth's magnetic field as a navigational cue. Caribbean spiny lobsters, *Panulirus argus*, are able to derive both directional ('compass') information and positional ('map') information from Earth's magnetic field demonstrated in their annual mass migrations and homing behaviours (Lohmann *et al*. 1995, Boles & Lohmann 2003). Concentrations of permanently magnetic material have been detected in the spiny lobster, and could form the basis of magnetoreception in the species (Lohmann 1984). Ernst & Lohmann (2016) found spiny lobsters subjected to a directional magnetic pulse were significantly directionally oriented as a group, compared to control lobsters not subjected to a magnetic pulse which walked in seemingly random directions and were not significantly oriented as a group. Ernst & Lohmann (2018) investigated whether the spiny lobster exhibits choice preference in response to increased magnetic intensity. The experiment presented the lobsters with two artificial dens, one beneath a neodymium magnet and the other beneath a non-magnetic control. Significantly more lobsters avoided the test magnetic den and selected the control den, and the group that selected the test den were significantly smaller in size suggesting a possible ontogenetic shift in response to magnetic fields (Ernst & Lohmann 2018).

Laboratory experiments on recently settled juvenile European lobsters showed individuals exposed to an artificial magnetic field gradient (maximum intensity of 200 µT) did not exhibit any change of behaviour when compared to non-exposed lobsters in the ambient magnetic field (Taormina *et al*. 2020 a). Exposure to these anthropogenic magnetic fields (225 ± 5 µT) for more than one week did not influence the lobsters' ability to find shelter or modify their exploratory behaviour, suggesting that magnetic fields of these intensities do not significantly impact their behaviour. Taormina *et al*. (2020 a) noted that further studies are required on the other life stages, which may respond differently.

Subtle behavioural responses to anthropogenic EMFs were reported in adult American lobsters, *Homarus americanus* (Hutchison *et al*. 2018). Enclosure experiments compared behavioural parameters of individuals exposed to an electromagnetic field from a subsea electricity transmission cable with those of individuals with non-treatment control enclosures. The lobsters spatial distribution was significantly different in the treatment enclosure when compared to the control enclosure, but there was no evidence that the spatial distribution of the lobsters being associated with zone of high or low EMF within the treatment enclosure. While the presence of the EMF may have biological relevance to how animals will move around in a cable EMF zone, the EMF associated with the cable did not present a barrier to movement across the cable (Hutchison *et al*. 2018).

Bochart & Zettler (2004) investigated the impacts of long-term exposure (several weeks) to a magnetic field on the survival rate and reproductive fitness of several common benthic animals in the Baltic Sea, including the crustaceans *Crangon crangon* (shrimp), *Rhithropanopeus harrisii* (alien crab), *Saduria entomon* (isopod) and the bivalve *Mytilus edulis* (mussel). Test aquaria were exposed to a 3.7 mT static magnetic field, and both the control and test aquaria being subject to the same feeding, temperature, salinity and light/dark cycle regimes. Results of survival rate and fitness observations found relatively low and non-statistically significant variations between the control and test animals (Bochart & Zettler 2004).

An investigation of the effect of anthropogenic magnetic fields on the stress responses of the edible crab, *Cancer pagurus*, found that exposure to electromagnetic fields of the strength predicted around sub-sea cables (low strength - 2.8 mT and high strength - 40 mT), had significant physiological and behavioural effects (Scott *et al*. 2018). The physiological effects were seen in changes to the circadian rhythm of L-Lactate (an indicator of anaerobic respiration) and D-Glucose (the primary fuel for maintaining metabolic processes), while the behavioural responses indicated that the presence of the magnetic field affected an individuals' ability to select a site to rest when compared to the control group. In addition, when given the choice between a shelter exposed to EMF and one without exposure, the crabs were always drawn to the EMF shelter. The authors suggest that in benthic areas surrounding marine renewable devices where there is increased EMFs, there will be an increase in the abundance of *Cancer pagurus* (Scott *et al*. 2018). This potential aggregation of crabs around submarine cables and physiological changes, brought about by EMF exposure, requires further understanding of the potential implications at a population level.

The burrowing behaviour in many invertebrate species, assessed through burial depth and sediment reworking activity, is considered to be a very sensitive indicator of sediment toxicity or water-borne toxicant (Boyd *et al*. 2002, cited by Albert *et al*. 2020). Following an 8-day exposure to a magnetic field of 1 mT (50 Hz, Helmholtz coil system), larger amounts of tracer particles (i.e. fractionated dyed sand added to the sediment surface at the start of the experiment) were found deeper (below 3 cm) in the sediment of AC-exposed cores compared to controls, both containing the polychaete worm *Hediste diversicolor* adults (Jakubowska *et al*. 2019). This observation could not be explained by exposed individuals going deeper into the sediment, since they reached a maximal depth similar to control ragworms. A possible explanation could be an increase in the bioturbation activity of exposed polychaetes, leading to a stronger mixing of particles (e.g. more time spent in deeper sediment layers, more upward and downward migrations). This explanation was reinforced by the fact that control ragworms colonised mostly the upper sediment layers, whereas the magnetic field-exposed individuals were mostly found below such layers (Jakubowska *et al*. 2019, Albert *et al*. 2020).

The effects of anthropogenic magnetic fields on fishes have been demonstrated at various stages of ontogeny from gametes, through embryonic and larval phases to juvenile and adult fish, and include both physiological and behavioural responses (reviewed in Formicki *et al*. 2019). Exposure of fish spermatozoa to both static and alternating magnetic fields were found to significantly prolong the duration of motility and viability, and to increase the speed of movement of exposed sperm considerably compared to those not exposed to the magnetic field (Formicki *et al*. 2013, Szulc *et al*. 2012, Formicki *et al*. 2019). Magnetic fields were also found to positively effect fertilization rates in brown trout (*Salmo trutta*) and Danube salmon (*Hucho hucho*), with low strength (1 mT) magnetic fields resulting in the highest fertilization rates compared to higher strength (10 mT) fields, and the control resulting in lowest fertilization rates (Formicki *et al*. 2013 and 2015). Embryonic developmental impacts were also observed in roach (*Rutilus rutilus*) exposed to a simulated strong magnetic storm event from the moment of fertilization to the period of organogenesis which resulted in significant difference in body length, mass, number of rays in ventral and anal fins as well as the number of transitional and caudal-spine bones in the fry compared with the controls (Krylov *et al*. 2010).

Fey *et al*. (2019a) found no difference in hatching time for rainbow trout, (*Oncorhynchus mykiss*), when subjected to a magnetic field of 10 mT when compared to the control. While similar experiments on northern pike (*Esox lucius*) showed accelerated hatching times of embryos developing in 10mT compared to the control (Fey *et al*. 2019b), suggesting that these effects are likely to be species specific. While neither study showed any effect of the 10mT magnetic field on the larval survival rate (Fey *et al*. 2019a and 2019b), both studies reported accelerated yolk-sac absorption rate. The authors suggest that faster yolk-sac absorption observed in the magnetic field treatment is the result of higher energy demand and enhanced metabolic rates in response to the magnetic field.

Magnetic fields are perceived and used by both teleost and elasmobranch fishes, they can ascertain their position during long distance migrations and become conditioned to a magnetic field (Formicki *et al*. 2019). Naisbett-Jones *et al*. (2017) demonstrated that orientation of juvenile European eels varies in response to subtle differences in magnetic field intensity and inclination angle. When these directional results were combined with an ocean circulation model simulations suggested that European eels utilise an adaptive magnetic map to increase entrainment of juvenile eels into the Gulf Stream System and facilitate the vast oceanic migrations from their spawning grounds to their coastal habitats. These findings are also supported by the results of orientation studies undertaken by Durif *et al*. (2013) in which adult European eels were exposed to altered magnetic fields and their responses demonstrated magnetic compass orientation.

Salmonids which undergo long-distance migration, including Atlantic salmon (Scanlan *et al*. 2018, and Minkoff *et al*. 2020), Chinook salmon (*Oncorhynchus tshawytscha*) (Naisbett-Jones *et al*. 2020, Putman *et al*. 2018); and Pacific/sockeye salmon (*Oncorhynchus nerka*) (Putman *et al*. 2013) use magnetoreception for orientation. Juvenile Chinook salmon were shown to be sensitive to the orientation of the magnetic field, laboratory experiments showed that fish exposed to a magnetic field with an inverted vertical component did not move as far upwards as fish tested in the ambient geomagnetic field (Putman *et al*. 2018) suggesting that salmon use the direction of magnetic field lines to orient vertically. A study examining a 56-year fisheries data set to determine the influence of geomagnetic field drift on the variation in spawning migration routes used by adult Pacific salmon to reach the Fraser River mouth demonstrated that field drift accounted for 16% of the variation between routes to the north or south of Vancouver Island (Putman *et al*. 2013). Naisbett-Jones *et al*. (2020) subjected juvenile Chinook salmon to a brief but strong magnetic pulse capable of altering the magnetic dipole moment of biogenic magnetite (a mechanism for magnetoreception in teleost fish). Orientation of both pulsed and control fish were compared in a magnetic coil system under two conditions i) the local magnetic field and ii) simulating the magnetic field that exists near the southern boundary of the natural oceanic range of Chinook salmon. Under local magnetic conditions control group fish were significantly oriented as a group, while fish from the pulse treatment group were randomly oriented, suggesting that exposure to a strong magnetic pulse affects orientation behaviour and supports the magnetite-based magnetoreception hypothesis. Fish exposure to the simulated magnetic field from their natural southern oceanic boundary range significantly orientated as a group in the pulsed treatment group and showed no group orientation in the control fish. It was suggested that exposure of salmon to the magnetic pulse may have affected the mechanism underlying their magnetic ‘compass’ that enables them to use Earth’s magnetic field as a directional cue and / or the magnetic ‘map’ that allows them to assess their position within an ocean basin, and that further research is required to fully understand the mechanisms for magnetoreception.

However, few studies assess interactions of migratory species with cable EMFs. Tagging studies investigating the effect of a subsea DC power cable on migrating European eels observed that swimming speed was significantly lower as the eels passed over the cable compared to speeds either side of the cable (Westerberg & Lagenfelt 2008). A tagging study of Pacific salmon smolts during their migration through the San Francisco bay found that installation of a DC transmission cable did not significantly impact the proportion of fish that successfully migrated through the bay, but, higher proportions of fish were found to cross the bay over the cable location than crossed in that location prior to installation (Wyman *et al*. 2018). While both studies indicated behavioural changes in response to the subsea power cable, the cable did not appear to present a barrier to their normal migration route. Hutchison *et al*. (2020a) note that seasonal migrations of EM-receptive species may encounter multiple offshore renewable devices and power cables which could lead to increased dwell time and exposure of the fish to cable EMFs with unknown orientation and navigational consequences.

Elasmobranchs have an electrosensory system, the Ampullae of Lorenzini, an array of receptors that allow them to detect the weak electric fields produced by prey items of around 0.5µV/m (Gill *et al.* 2005). Consequently, they are most frequently linked with potential EMF effects. Establishing response to changing magnetic stimulus in electrosensitive species, such as elasmobranchs, is not straightforward given the generation of motion induced electrical fields associated with magnetic signals which stimulates its electrosensory apparatus (Gill &

Desender 2020). A study on sandbar sharks gives support to the hypothesis that the electrosensory system of sharks may not be the sole means by which they are able to detect magnetic stimuli (Anderson *et al*. 2017). The study aimed to test for the presence of a magnetite-based magnetoreception mechanism within the olfactory system, as has been described in some teleost fishes, by exposing individuals to a constant source of magnetic noise in the region of presumed magnetoreceptor structures (by reversible placement of magnets over the sharks olfactory organs). The results showed that control sharks in the study demonstrated strong responses to magnetic stimuli, while those individuals exposed to magnetic impairment were less capable of discriminating changes to the local magnetic field. The authors concluded that it is likely the diminished responses seen under magnetic impaired conditions were as a result of impairment to a non-electrosensory magnetoreceptor structure, as if individuals were responding to an induced electrical stimulus such a signal should be no less discernible than if the magnets were not attached (Anderson *et al*. 2017).

Newton & Kajiura (2017) showed that yellow stringrays could learn to discriminate magnetic stimuli of buried magnets compared to buried non-magnetic controls, during behavioural conditioning studies where magnetic stimulus was associated a with a food reward. While this study showed that stingrays could use a magnetic stimulus as a geographic marker for food resources, it is unknown whether the stingrays used magnetite to detect the magnetic field, or their electroreceptors to detect an electrical current induced as they swam through the magnetic field in seawater as hypothesised by Kalmijn (1978) (Newton & Kajiura 2017). Studies of the potential to induce avoidance behaviour in sharks by using electropositive rare-earth metals which naturally shed electrons into seawater and create a potentially aversive electric field have met with mixed results,. Similarly strong permanent magnets have been investigated as a source of aversive stimuli to induce avoidance behaviours in elasmobranchs. However, it could not be determined from these experiments whether the individuals responded directly to the magnetic field or to an induced electrical field generated by water movement around the magnets (summarised in Newton *et al*. 2019). Further work is required to understand the mechanism for magnetoreception in elasmobranchs and how disruption to this sense could functionally affect individuals and at a population level.

Electroreception

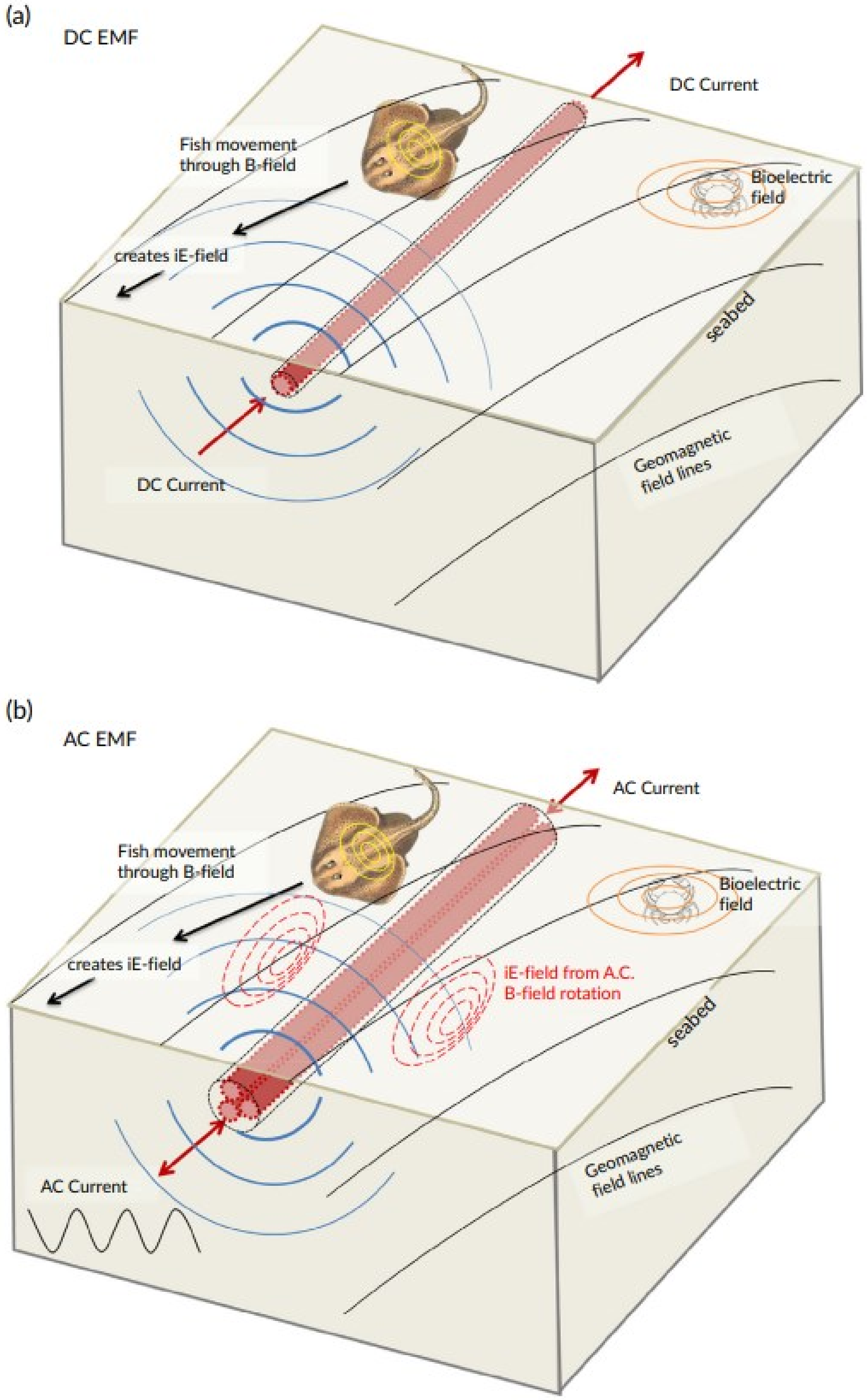
Electrosensitive species are able to sense weak electric fields used to detect prey and predators, to communicate, find mates and / or locally orientate (Tricas & Sisneros 2004). Early studies on the small-spotted catshark (*Scyliorhinus canicula*) and thornback ray (*Raja clavata*) demonstrated that electroreceptive function is used in prey detection when visual, chemical and mechanical cues were eliminated (Kalmijn 1971). A field enclosure study on Little skate (*Leucoraja erinacea*) compared behavioural responses of individuals in enclosures over a buried DC electrical transmission cable to individuals in a control enclosure at a similar site with no cable (Hutchison *et al*. 2020b). Measurements of the DC cable magnetic field revealed that strong AC magnetic and electrical fields were also emitted from the cable at comparable strength to the Earth's magnetic field. Notable behavioural differences were observed between the skates exposed to the cable enclosure and the control enclosure, with exposed skates travelling much longer distances at slower speeds, with more large turns and they swam closer to the seabed, suggesting more time was spent actively foraging (Hutchison *et al*. 2020b) in response to the cable presence. The authors note that increased exploration / foraging with no return (locality/food) infers an energetic loss to the individual unless sensitive animals are able to distinguish between natural and anthropogenic EMF's and learn from experience.

Electroreceptors can also be used for predator detection and avoidance, whereby visually concealed elasmobranchs that detect an approaching predator can alter their behaviour and physiological responses, such as their own bioelectric, olfactory and hydrodynamic signals, to avoid detection (Newton *et al*. 2019). A study of three different age groups of embryonic thornback rays (*Raja clavata*) found that exposure to an electrical field inhibited important ventilatory mechanism in all embryos (Ball *et al*. 2015). The study also found that if exposed to a continuous electrical field the embryos could habituate and resume normal activity, whereas if the electrical field was applied intermittently it resulted in a significant reduction in overall ventilatory activity in all embryo age groups. This supports earlier work on late stage bamboo shark (*Chiloscyllium punctatum*) embryos, which found that embryos in their protective egg cases cease all respiratory gill movements followed by rapid coiling of the tail when exposed to predator-simulating sinusoidal electric fields (Kempster *et al*. 2013). The authors suggested that by minimising their own electrosensory and mechanosensory output in response to predator detection they are able to reduce predation risk (Kempster *et al*. 2013). However, for some species this ability could be reduced by exposure to an intermittent electrical field, which may be representative of the EMF produced from an operational wind farm.

In addition to prey / predator detection elasmobranchs have been shown to use their electroreceptors to detect buried conspecifics during the mating season, as seen in the round stingray (*Urobatis helleri*) (Tricas *et al*. 1995, referenced in Newton *et al.* 2019). Male stingrays use their electroreceptors to detect buried females that are receptive to mating and non-receptive females use their electric sense to locate other females and seek refuge from aggressive males (Tricas *et al*. 1995). A study on the Atlantic stingray (*Dasyatis sabina*) found the physiological change underlying this behaviour involves a seasonal shift in electrosensory frequency tuning of males triggered by a shift in their seasonal androgen hormone cycle (Sisneros & Tricas 2000).

As discussed in the previous section, it is not currently understood whether the response in elasmobranchs to changing magnetic stimulus results from perception of the magnetic fields itself, or as a response to motion induced electrical fields associated with the magnetic field which stimulates the electrosensory apparatus. In Figure 5.38, the separate E-field and B-field components of the EMFs emitted by a buried subsea cable (red) are shown, as well as the ambient geomagnetic field (black) and bioelectric fields from living organisms (orange). Figure 5.38a shows the EMF associated with a DC cable; Figure 5.38b shows the EMF associated with a standard three-phase AC subsea cable with the current following a typical sine wave back and forth through each core. For both cables the direct E-field is shielded by cable material (black outer cable), but B-fields (blue) are not shielded and propagate to the surrounding environment. An iE-field is created in the fish (yellow) as it moves through the B-field emitted by the cable. Localised iE-fields will also be induced by seawater moving through the B-field and the GMF. In addition, for the AC cable, the out-of-phase B-field emitted by each core of the cable causes a rotation in the magnetic emission, which induces an iE-field in the surrounding conductive seawater (red), that is emitted into the environment above the seabed (Newton *et al*. 2019). Newton *et al*. (2020) used behavioural conditioning experiments on the magnetically sensitive yellow stingray (*Urobatis jamaicensis*) successfully demonstrated that individuals could be trained using polarity of the GMF as a cue to orient in space and repeatedly navigate a T-maze for a food reward. The results support the idea that the yellow stingray, and perhaps other elasmobranchs, might use GMF polarity as a cue to orient and maintain a heading during navigation, however, the study did not attempt to determine the mechanism of magnetic stimulus detection and further work is required to understand whether elasmobranchs solely use their electrosense for navigation of whether some species may detect magnetic stimuli directly (Newton *et al*. 2020).

Figure 5.38: Depiction of natural and anthropogenic electric (E-field) and magnetic (B-field) fields encountered by an electroreceptive fish moving across the seabed



Notes: Not to scale. Source: Newton *et al*. (2019)

The interaction between anthropogenic EMF and marine mammals is not well understood. Understanding of how marine mammals experience and use either natural magnetic or electric fields is poor, but knowledge relating to anthropogenic sources is even less (Gill *et al.* 2014). Studies of deterrents to seal predation on salmon fisheries have identified strong responses to electric fields in certain pinniped species (PSC 2009, Burger 2010). In 2007, the Pacific Salmon Commission (PSC), and collaborators, conducted tests to assess how Pacific harbour seals (*Phoca vitulina richardsi*) respond to very low electric fields and determine whether this technology could be used to deter seal predation on salmonids. Results from tests on captive and wild animals in aquarium and river environments respectively indicated that seals avoided an electrified zone of voltage gradient <0.32V/cm at surface with a maximum pulse width of 1 millisecond (ms) and frequency of 2.25Hz (Cave *et al.* 2008, cited in PSC 2009).

PSC (2009) report an extension of these experiments, with three different configurations (arrays) of electrodes tested across the width of the lower reaches of a river known to be a preferred foraging area for seals. Arrays included 3 and 4 cable configurations running perpendicular to the bank and an array of 17 elements oriented parallel to the bank spanning the width of the river. For each configuration, tests commenced at the lowest pulse width setting (1ms) and ramped up by 1ms increments to a maximum of 5ms (17 element array only). At the lower pulse width settings (1-2ms), seals that successfully passed through the array were not harmed or exposed to excessive stress. At pulse width settings in the mid-range (3ms), seals displayed more distinctive behavioural responses (avoidance of short-term discomfort or pain) while at the highest pulse width settings (4-5ms) seals exhibited more physiological responses (involuntary muscle contractions). In further field studies, seals were deterred from foraging in a test fishing gill net by using a pulsed, low-voltage DC electric gradient (Forrest *et al.* 2009). These levels did not seem to affect the behaviour of salmonid fish, and catch rates of salmon were shown to be higher at nets protected by an electric field.

Burger (2010) report results from experiments on the responses of captive Californian sea lions (*Zalophus californianus*) to electric fields, with a view to wider applications as deterrents to predation in salmonid fisheries. A pulsed DC electric field was generated within a freshwater test pool (conductivity of 509µS/cm). Sea lions were able to detect an electric gradient introduced at a frequency of 2Hz at pulse widths that ranged from 0.08-0.29ms. Strong deterrence reactions without and with food present were exhibited at pulse widths from 0.08-0.32ms and 0.16-0.44ms respectively, both with a voltage gradient of 0.6V/cm.

WAG (2010a) reviewed the studies on harbour seals in relation to potential effects from buried cables associated with marine renewable energy devices. Estimates of the electrical fields that will be generated in seawater from buried power cables bringing power ashore from marine renewable devices are orders of magnitude lower than those shown to induce responses in seals; therefore, it appears that there is no basis for expecting such strong exclusion effects demonstrated in those studies. Furthermore, consideration must be given to the differences in the environments where exclusion responses were observed and the marine environment relevant to this assessment. PSC (2009) noted that the impact of the electric field on seal behaviour deteriorated as river depth increased due to a weakening in the electric field strength at the water surface over the array, with seals often observed passing through the array during high tides. Despite this, certain caveats should be considered. Firstly, the seal exclusion trials used short pulse length electrical fields, and it was shown that seal sensitivity increased as pulses lengthened; seals might therefore be more sensitive to a continuous electrical field. Secondly, seal sensitivity and responsiveness to lower level electrical fields have not been studied and there may be effects at levels below those tested. It is not known why seals are apparently so sensitive to these electrical fields, whether they have specially adapted electrically sensitive organs, or if this is of any biological significance to them. WAG (2010) suggests the risk that electrical fields from power cables could affect seal behaviour must remain as a precautionary concern, and recommend that the issue should be more fully explored. Assessment of the impacts of electromagnetic fields to marine mammals is currently largely undetermined, and there appears to be no recent research into this area.

5.6.4 Data gaps and research

In their review of priority evidence needs around the impact of offshore wind farm developments on key receptors, JNCC (O'Brien *et al.* 2021) identified several priority bird species for which further evidence is needed in order to reduce uncertainty in assessing likely impacts (displacement, collision, or both) of OWFs. It was argued that failure to reduce this uncertainty could lead to these species becoming consent risks, and/or ornithological constraints for OWF development[174]. These species are shown in Table 5.20 below. The review did not discount the possibility that other species (e.g. great and Arctic skua, these having been identified as sensitive to collision risk by Furness *et al.* 2013) may also be identified as posing consenting risks to future developments.

Table 5.20: Species identified as potential consenting risks/ornithological constraints and requiring further evidence as a priority

Species (impact pathway)[1]	Regional Sea area with sites where species is a designated feature
Atlantic puffin (D)	1, 4/6, 7, 8, 10
Kittiwake (C&D[3])	1/2, 7, 8, 10
Common guillemot (D)	1/2, 7, 8, 10
Common scoter (D)	1, 2, 4, 6, 7, 8
Great black-backed gull (C)	1, 8
Lesser black-backed gull (C)	1, 2, 4, 6, 7
Manx shearwater (C&D)[5]	1, 4, 6, 7, 8, 10
Gannet (C)	1/2, 4, 7, 8, 10
Razorbill	1, 2, 7, 8, 10
Red-throated diver (D)	1, 2/3, 6, 7, 8, 10
Sandwich tern (C)	1, 2, 3, 6, 7

Notes: [1]D= displacement, C = collision [2]AOB = Apparently Occupied Burrows; AON = Apparently Occupied Nests; I = Individuals; AOS = Apparently Occupied Sites [3]Displacement is identified as a pathway in Scotland. Source: O'Brien *et al.* (2021), JNCC (2021b)

Empirical evidence for displacement from offshore wind farms remains relatively limited and often contradictory (NE-JNCC 2017); likely due to both the inherent complexities of species distribution data (which has strong temporal and spatial variation), difficulty in detecting changes (i.e. due to variability in baseline data) and the fact that wind farm projects are not identical in scale, density or physical location. However, patterns for species with regard to displacement have emerged and show that species most likely to exhibit displacement are red-throated diver, common scoter and auks (guillemot and razorbill, although evidence for auks is variable), northern fulmar, gannet and little gull. Whilst other species have exhibited attraction or neutral behaviour (e.g. great cormorant, herring and great black-backed gulls) or have shown

[174] Reference to possible consent risk was in respect of Round 4 bidding areas and reference to ornithological constraint was in respect of the Scottish Governments final Sectoral Marine Plan AA (ScotWInd). For full details of the review, see https://data.jncc.gov.uk/data/bc429809-ec23-47e5-ab45-44e4fe010fb2/JNCC-Report-675-FINAL-WEB.pdf

displacement, evidence is variable amongst sites, with conflicting evidence (e.g. kittiwake, lesser black-backed gull). Other species identified for possible displacement effects (e.g. O'Brien *et al.* 2021) include Manx shearwater and Atlantic puffin, but the evidence for this remains limited.

Although there is also a lack of empirical data for collisions there is a general consensus that those species at highest risk of collision with wind turbines are gulls (e.g. herring, lesser black-backed, greater black-backed) gannet and kittiwake, with Manx shearwater and sandwich tern also identified as priority species. These species are considered most at risk due to factors such as abundance and distribution (in and throughout project areas), biological characteristics that make them potentially susceptible (e.g. estimated flight height corresponding to risk height) and potential vulnerability to impacts (e.g. conservation status). Consideration must also be given to level of risk throughout the year. The focus of many studies has been on breeding birds during the breeding season which are more spatially restricted than during the non-breeding season where birds are more widely dispersed.

Work is ongoing to identify and collate ornithological data gaps. An industry-led, multi stakeholder forum, the Offshore Wind Strategic Monitoring Research Forum (OWSMRF[175]) and the Scottish Marine Energy Research (ScotMER[176]) programme, established by Marine Scotland, and having a focus on offshore renewable energy developments in Scottish waters aim to better understand the impacts of renewable energy developments on birds (the ScotMER programme also has a focus on other impact receptors including marine mammals, fish and benthic communities). Both have developed a framework of knowledge gaps to guide research programmes.

The Offshore Wind Evidence and Change Programme[177] (OWEC), a five year programme by The Crown Estate, commenced in 2020 and aims to create an enhanced evidence base, into a single source (the Marine Data Exchange) to facilitate the growth of the offshore wind sector, in such a way that best protects and enhances the environment. This has brought together key stakeholders to gather and share evidence, including through the compilation of an offshore wind environmental evidence register (OWEER[178]) of data gaps and relevant research projects across four key areas, one of which is seabirds. Recently announced projects include: seabird, marine mammal and fish behavioural changes in response to offshore wind development (PrePARED (Predators and Prey Around Renewable Energy Developments); a project trialling new tracking techniques (tags on seabird leg rings and receiver systems on offshore turbines, looking at seabird movements and survival in the North Sea, and POSEIDON (Planning Offshore Wind Strategic Environmental Impact Decisions).

A number of SEA-programme commissioned bird related studies have been carried out[179], with research ongoing in several areas (a selection of these are summarised through this section, with more detailed descriptions provided in the baseline, Appendix 1a.6). Since OESEA3 (2016), results from studies which examined the potential interaction of bird species with offshore wind farms have been published on the foraging behaviour of gannets (Langston &

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[175] JNCC OSMURF forum https://jncc.gov.uk/our-work/owsmrf/
[176] Marine Scotland ScotMER programme https://www.gov.scot/policies/marine-renewable-energy/science-and-research/
[177] https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/offshore-wind-evidence-and-change-programme/
[178] https://beta.marinedataexchange.co.uk/details/3480/2021-jncc-offshore-wind-evidence-and-change-programme-offshore-wind-environmental-evidence-register-/summary
[179] Details of SEA commissioned research projects can be found in previous SEAs and https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process#offshore-energy-sea-research-programme

Teuton 2018), and potential interaction between gannets and lesser black-backed gulls with OWFs (Lane *et al.* (2020, 2021), Clewley *et al*. (2020, 2022), Grecian *et al*. (2018), Thaxter *et al.* (2017, 2018, 2019), modelling flight heights of lesser black-backed gulls and great skuas (Ross-Smith *et al.* (2016), and a pilot tracking study of migratory movements of the common shelduck completed to inform potential interactions with offshore wind farms in the North Sea (Green *et al.* 2021).

Studies on the spatial and temporal variation in foraging of breeding red-throated diver (Duckworth *et al.* 2021), to improve knowledge around diver energetics and provide information on whether or not this species may face an energetic bottleneck during the non-breeding season, when they are more likely to be displaced from OWF areas; if divers are already energetically constrained in the non-breeding season, they may struggle to meet the additional energetic demands following displacement (Duckworth *et al*. 2020, 2021). Preliminary results included data from ring recoveries (Duckworth *et al*. 2020), found Scottish and Icelandic birds remain close to their breeding grounds, wintering in north western Scotland/Ireland and northern Iceland respectively; ringing recoveries and GLS data suggests Scottish divers are not using Liverpool Bay (Duckworth *et al*. 2020). In contrast, birds tagged from Finland (n=4) moved westwards from the Baltic Sea, to Denmark, with two individuals moving into the North Sea.

There has been recent research on the movements of auks (guillemot, and razorbill) during the non-breeding season (Buckingham *et al.* 2022); tags have been deployed over three years (2017-2019) at a number of colonies throughout the UK and showed relatively short distance movements during this period.

There needs to be an understanding of the spatial and temporal distribution of birds in order to carry out a robust assessment with several distribution maps for seabirds available (e.g. Bradbury *et al*. 2014 (SeaMaST), Bradbury et al 2017, Wakefield *et al*. 2017, Cleasby *et al*. 2018 (FAME and STAR), Waggit *et al*. 2020 (MERP), and Kober et al 2010, 2012 the data from which underlies some of these, Lane *et al*. 2021, Pollock *et al*. 2021) and other tools such as the Seabird Oil Sensitivity Index (SOSI), which identifies areas at sea where seabirds are most likely to be sensitive to oil pollution; gaps in data coverage is acknowledged as an issue with this, and an approach to spatially or temporally extrapolate the index as a pragmatic way to extend the months available for assessment has been developed (JNCC 2017).

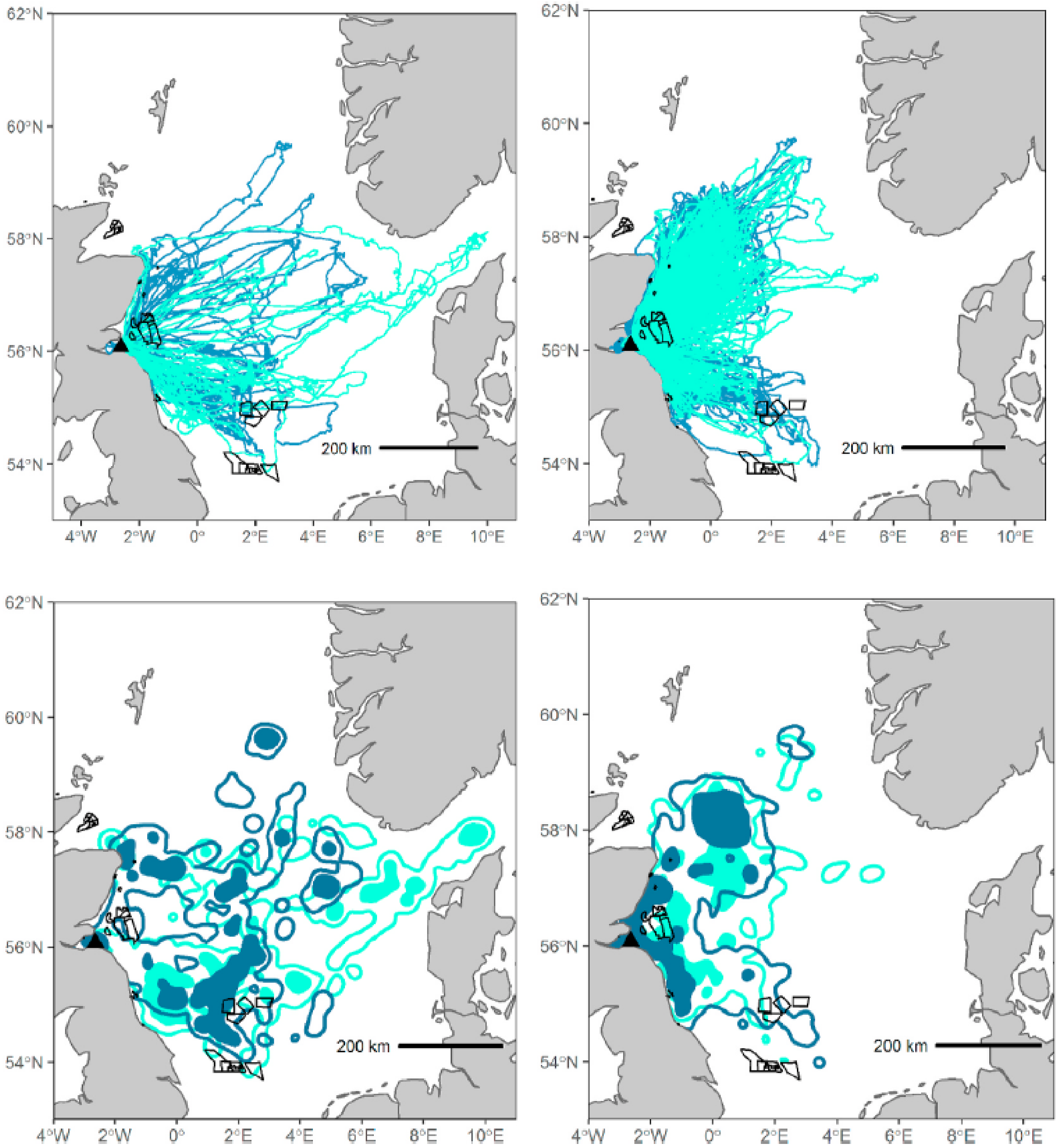
A robust information base is essential to inform collision (and displacement) assessments and several other elements of information, in addition to distribution are required (e.g. see Figure 5.10, Section 5.6.3.4 of the Band (2012) Role of Collision Risk), including foraging ranges (e.g. Thaxter *et al.* 2012, Woodward *et al.* 2019, Critchley *et al.* 2020), flight heights and speed (e.g. Johnston *et al.* 2014a,b, Johnston & Cook 2016, Masden *et al.* 2021), and avoidance (Cook *et al.* 2014, Bowgen & Cook 2018) as well as looking at recent scientific literature on the potential impacts on birds from OWF (e.g. Pollock *et al.* 2021).

There are many factors that influence the risk of an impact, and, several of them are species-specific; the large number of bird species (migrating and resident) that may encounter wind farms in UK waters introduces a considerable challenge to the assessment of risk, particularly in determining those species to likely be most at risk. Risk can also differ within a species, with differences seen between sexes (Lewis *et al.* 2002, Cleasby *et al.* 2015, Lane *et al.* 2020).

Examination of data from gannets tagged at Bass Rock from the pre-egg laying period (April, years 2017-2019) and while attending chicks (June-August, 2015-2019) found birds made significantly longer (up to 2.5 times longer on average) and further (1.5 times longer on average) foraging trips during pre-hatching periods than chick rearing. Core foraging ranges covering a much broader range of latitudes and longitudes were found during the pre-hatching period than during chick-rearing (Figure 5.39). Females also made significantly longer trips than males and while both sexes flew higher when actively foraging than when commuting, females were found to be flying higher than males during these activities – parameters that have implications for increased collision risk (Lane *et al*. 2020).

A key aspect of determining the significance of the collision risk is determining the potential population-level consequences of this mortality. Using a population prediction model (PPM), focused on the impact of changes in female survivorship on population growth, an estimated additional mortality of ~3,300 breeding females per year would be needed to halt population growth (Lane *et al*. 2020).

Figure 5.39: Foraging tracks of female and male gannet from Bass Rock prior to and during chick-rearing



Notes (Top) foraging tracks (bottom) utilization distributions (UDs) of female (green) and male (blue) gannets from Bass Rock (black triangle) prior to chick hatching (Left) and during chick-rearing (Right). UDs are based on active foraging locations and shading denotes UD contours (filled, 50%; unfilled 95%). Wind farms sites are outlined in black. Source: Lane *et al*. (2020).

While risks to marine life from EMFs associated with submarine power cables are not considered to constitute a major impact such as those posed by noise during construction phases or by potential collisions with seabirds during operational phases, significant data gaps need to be addressed with regards to the biological impacts of EMF so that a meaningful risk assessment can be conducted (Taormina *et al*. 2020b). A number of authors have identified key areas of further research required to reduce the uncertainty of EMF risk assessments and to fully understand cumulative and population level impacts. These recommendations are summarised as follows (Gill & Desender 2020, Hutchison *et al*. 2020a, Hutchison *et al*. 2020b, Taormina *et al* 2018, Taormina *et al*. 2020b):

- Gain a better understanding of the factors that influence EMFs
    - Develop standards for appropriate measurement and reporting of EMF environments, as relevant to receptive species
    - In situ measurements of the strength of magnetic fields produced by submarine power cables, relate these measurement to cable properties and power transmission variations
    - Measurement of the local geomagnetic field, and its geometry
    - Measure the interactions of the geomagnetic field with anthropogenic EMFs
- Improving the “effects” knowledge base using model species
    - Understand the likely encounter rate for different species
    - Incorporate aspects of life history and movement ecology - related to the likely encounter rate
    - Determine species sensitivity thresholds to EMFs
    - Determine if behavioural effects may result in a population level impact,
    - Increase the number of in situ effects studies
    - Conduct long-term impact studies
    - Improve the understanding of the potential interaction of pelagic species with dynamic cables
- Cumulative effects
    - Strategic studies to determine where and how encounter rate could be affected by an increase in number of locally sited cables.
    - Improve understanding of how biological behavioural and physiological effects may interact, early life history experiences may influence later life stages, and a single encounter may inform the next exposure.
    - Improve the understanding of the cumulative impacts associated with electrical substations of offshore renewable energy farms where the power generated by all the converters converges before being transformed and exported to the onshore grid by export cables. For example mobile benthic organisms may have to cross several differently oriented power cables which could potentially involve different responses.

Recent reviews of the current understanding of effects of marine renewable developments have identified critical evidence gaps needed to support the consenting process of tidal stream and wave energy devices (2020 State of the Science Report (Copping and Hemery 2020), ORJIP OE 2020, Clarke *et al*. 2021). A number of the critical evidence gaps are of particular importance in assessing the potential impacts from marine renewable energy devices to marine mammals, seabirds and fish. These have been summarised as follows (Clarke *et al*. 2021; aligned with ORJIP OE 2020,):

- Presence or absence of a species in the area of a development and the abundance or proportion of key populations of at-risk species in the resource area.

- Occupancy patterns, fine scale distribution and behaviour of mobile species in tidal stream habitats.
- Near field interactions including monitoring of avoidance behaviour and collisions. Including frequency, nature, and consequence of near field interactions between mobile species and tidal turbines, evasion responses and rates.
- Behavioural data for different species such as swimming speeds (including burst speeds) and depth utilisation
- Understanding sensory perception and near field responses to tidal turbines, including the behavioural consequence of noise, to move beyond using audibility as a proxy for behavioural response

Clarke *et al*. (2021) recommends specific approaches (methods and techniques) to monitoring animal interactions with marine tidal energy devices and to address each of these critical evidence gaps. While these recommendations are specific to developments within Welsh waters they provide a useful basis for UK-wide developments. Further detail on each research area and necessary research outputs and their application are provided in ORJIP OE 2020.

5.6.5 Controls and mitigation

To reduce the risk of introduction and spread of non-native species posed by international shipping, controls are in place to minimise transmission via exchange of ballast water and hull-fouling. The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM) was adopted by the UK in 2004; it has been ratified by 30 States, representing 35 per cent of world merchant shipping tonnage. It aims to prevent the spread of harmful aquatic organisms from one region to another, by establishing standards and procedures for the management and control of ships' ballast water and sediments. Under the Convention, all ships in international traffic are required to manage their ballast water and sediments to a certain standard, according to a ship-specific ballast water management plan. Eventually most ships will need to install an on-board ballast water treatment system.

The risk of introduction and spread of non-native species is also managed by the use of anti-foulant coatings on ships and energy devices, best practice for vessel maintenance and could be further controlled by the use of biofouling resistant materials and the implementation of biofouling cleaning regime. As with ballast water, anti-foulants are an international concern and are managed to prevent unwanted ecosystem effects (i.e. The International Convention on the control of Harmful Anti-fouling Systems on Ships, adopted in 2001 and the principal legislation, The Merchant Shipping (Anti-fouling System) Regulations 2009. Marine energy devices are not subject to this legislation, however the selection of anti-foulant systems is an important component of development environmental statements.

To minimise or ideally avoid collision risk between birds and infrastructure associated with the implementation of the draft plan/programme, a range of measures can be implemented, primarily at the project level. A description of these is provided in general terms, but in practice these measures need to be adopted according to the site characteristics of each marine renewable energy development, since a measure that may reduce the risk for one species, may increase the risk for another. Considerations must include the diversity, abundance, and distribution of all species that occur in (and transit through) that area (seabird and non-seabird species, breeding and non-breeding birds and during breeding, non-breeding and migration season), along with the current population levels and conservation status of species.

It is generally acknowledged that one of the most effective ways to reduce potential impacts on birds is to avoid siting offshore wind farms in areas of high bird abundance, or in areas particularly sensitive to life cycle requirements such as breeding areas, feeding areas and on migration routes. However, as the nature of cumulative/in-combination impacts and assessment approaches are such that it will not always be possible to site development in such areas, and more recently adverse effects on the integrity of sites is being concluded in HRA. To proceed, the project will have to be shown as IROPI, and compensation measures identified, assessed and applied. Compensatory measures are not defined in the Habitats Directive but are described in the broadest sense (e.g. DEFRA 2012a, European Commission 2021, see also Government website[180]) as measures which aim to *minimise or cancel the negative impacts on a site that are likely to arise as a result of the implementation of a plan or project and are independent of the project (including any associated mitigation measures); they are intended to offset the negative effect of the plan/project so that the overall ecological coherence of the Natura 2000 network is maintained.*

A range of possible compensatory measures have been identified, several of which have had demonstrable success in enhancing seabird population growth rates such as eradication of invasive non-native mammals on islands (Brooke *et al*. 2018), and a strategic programme of conservation measures (protection, habitat restoration and creation) at 29 little tern breeding sites across England and Wales (Wilson *et al*. 2020).

Windfarm specific measures have been variously considered e.g. MacArthur Green (2019a, 2021c) and some compensatory measures have now been included in Development Consent Orders for OWF projects (e.g. Norfolk Boreas). Compensatory measures included in recent DCOs with respect to the Flamborough & Filey Coast SPA (kittiwake) and Alde-Ore Estuary SPA (lesser black-backed gull) are the establishment of a kittiwake steering group and a kittiwake implementation and monitoring plan and the funding for a coordinator to facilitate the organisation of a stakeholder working group for lesser black-backed gull, to review the factors affecting the status of the population (at the Alde-Ore Estuary SPA) and proposals for conservation measures. Given the focus in UK OWF assessments and consent deliberations on various seabirds which feed extensively on sandeels, and in the context of the energy transition towards net zero by 2050, strategic compensation through selective restriction or closure of sandeel fisheries should be given consideration at a policy level.

Various other forms of mitigating actions are available. Temporal activity planning may be effective; for example at night, when birds are more vulnerable to collisions, activities such as installation and maintenance could be avoided. Turbine shutdown on demand should be considered, i.e. where turbines are shut down/slowed down at times of high bird collision risk or when birds are detected within a safety perimeter (this requires real-time surveillance for effective triggering of shut-down). Other mitigation includes increasing device visibility and the use of acoustic or laser deterrents. Although effective in the short term, the long-term use of auditory deterrents has proven to be ineffective due to habituation by birds to certain stimuli; laser deterrents may be a useful tool during night-time. Deterrents which can be activated by real-time surveillance systems are also useful, although they may have unpredictable effects on a bird's flight path and would have to be activated at sufficient distance for an effective avoidance. For tidal turbines, shiny blades should be avoided, as diving birds mistake these for fish and the use of protective netting or grids may be effective.

Enforcing vessel speed limits and establishing a code of conduct for vessels operating in areas of high seabird abundance or high sensitivity may reduce disturbance induced displacement of

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[180] Guidance on Habitats regulations assessments: protecting a European site, https://www.gov.uk/guidance/habitats-regulations-assessments-protecting-a-european-site#derogation

some bird species, although species such as red-throated diver and common scoter may still be displaced.

In July 2021, DEFRA launched a consultation (closed September 2021)[181] on best practice guidance for developing compensation measures in relation to marine protected areas (MPAs) (DEFRA 2021a, b). The guidance was developed as a framework to enable developers to consider how best to reduce and mitigate against impacts on the environment/features within MPAs, and where this was not possible, how to deliver compensatory measures. In developing the guidance, DEFRA worked with key stakeholders, including BEIS, the Devolved Administrations, The Crown Estate, Natural England and the Joint Nature Conservation Committee, as well as marine industries and non-governmental organisations. The guidance will apply to all marine industries in English waters and aims to provide further clarity and guidance to streamline the planning process, whilst improving the implementation of environmental regulations.

In 2015, the OSPAR Commission published guidelines (applicable to both existing and new offshore installations) aimed at reducing the impact of offshore installations lighting on birds in the OSPAR maritime area (OSPAR 2015).

Potential mitigation measures to reduce the probability and severity of the effects posed by wave and tidal stream devices to marine mammals (collisions, avoidance, barrier to movement) have been outlined by Wilson *et al.* (2007) and WAG (2010a). A careful choice of location is currently the best available tool to help avoid or minimise the collision risk that has been identified between marine mammals and tidal stream devices; however, in most cases this requires targeted efforts to improve the evidence base of marine mammal use of any proposed development area at the appropriate spatial and temporal scale. The importance of ensuring marine mammal surveys are fit for purpose has been highlighted within guidance to inform marine mammal site characterisation requirements at Welsh wave and tidal stream energy sites (Sparling *et al.* 2015). In addition to site identification, the selection of turbine design, turbine spacing and the size of array are important considerations (WAG 2010a).

One of the most significant barriers to the commercial scale development of tidal energy is the level of uncertainty around the potential environmental effects posed by operating turbines to protected marine life (Hutchison *et al.* 2020c). A variety of monitoring approaches have been implemented to date and as the data grows this will help reduce this uncertainty and improve understanding of near-field behaviour of ecological receptors around operating devices. For example, mitigation and control measures employed for the Strangford Lough tidal turbine included shore based marine mammals surveys and active sonar deployment which could trigger turbine shutdown if a marine mammal approached within 50m of the device. Over the three year operational lifetime a total of 342 precautionary shutdowns of the Strangford Lough turbine occurred, with no recorded mortality to marine mammals attributable to the turbine operation (Royal Haskoning 2011). In addition to the land based observations and active sonar, monitoring was conducted during turbine operation using telemetry studies of seal and T-POD acoustic monitoring of harbour porpoise. The monitoring objective was to prevent or minimise impacts resulting from the turbine installation and operation and to determine any immediate or emerging adverse impacts on the local habitats and species. Active sonar triggered Acoustic Deterrent Devices (ADD) have been proposed as key monitoring and mitigation options for the Morlais tidal stream energy development (current in the consenting process) off Anglesey (Royal HaskoningDHV, 2020a). It is proposed that these technologies may be used in conjunction with an array of Passive Acoustic Monitoring devices which would record baseline

[181] https://consult.defra.gov.uk/marine-planning-licensing-team/mpa-compensation-guidance-consultation/

presence / absence and changes in marine mammals (in particular harbour porpoise) in the vicinity of the tidal turbines. The PAM and Active Sonar could also be used to tigger the operation of an acoustic deterrent device which has been proven to be effective at deterring marine mammals during piling operations at offshore windfarms (Sparling & Plunkett 2015, DOWL 2016 cited in Royal HaskoningDHV 2020a). In the case of the MeyGen tidal development in the Pentland Firth a phased development was consented, with a small number of turbines initially consented in order to provide detailed monitoring information which would inform the design, monitoring requirements and consenting process additional turbines within the next phase of the development.

For fish and fish communities, the design and placement of rotors are key elements in minimising collision risk and potential behavioural disturbance. Avoidance of known spawning or nursery sites and migration routes of diadromous fish will limit impact at vulnerable life stages. Likewise, reducing the activity of devices at times of annual migration or spawning periods will limit impact. There is still a knowledge gap concerning detailed corridors of movement and likely depth preferences of a number of diadromous fish species and these may also vary between estuaries and between life-stage (Freeman *et al.* 2013). The Environmental Statement for the Brims Tidal Array includes consideration that sufficient clearance is allowed in the turbine design between the blade tip and the seabed to allow safe passage of demersal and benthic species under the device, and between the blade tip and sea surface to allow pelagic species to pass over the device (BTAL 2016).

Mortality of fish as a result of rotor blade strikes appears to be minimised at turbine speeds of 25-30rpm (Pelc & Fujita 2002) and adopting simple measures such as blunted blade edges is effective in reducing the incidence of laceration injury in the event of rotor strike (Hammar *et al.* 2015). Hammer *et al*. (2015) suggested that smaller turbines may pose a smaller risk of collision than larger turbines, as the avoidance response required for escape is much less severe. Collision risk modelling conducted in support of the Brims Tidal Array in the Pentland Firth indicated that a greater number of turbine blades presented an increased risk of collision for Atlantic salmon smolts and adults passing through the Pentland Firth each year, with three blades per turbine resulting in a lower predicted collision rate than ten blades per turbine (Xodus 2016). Conversely, collision risk modelling conducted in support of the Torr Head Tidal Array suggested an increased risk of marine mammal encounters with a three blade turbine when compared to a ten blade turbine as a result of the increased blade size combined with faster rotation speed of the three bladed turbine (Tidal Ventures 2015). Consequently it is likely that larger fish are at greater risk from turbines strikes than smaller fish, with large, slow-moving elasmobranchs perhaps the most likely to incur injury.

The use of strong colours, high contrast patterns on moving parts, lighting at night, acoustic fish deterrents and bubble curtains around devices have all been proposed as methods to reduce risk (ABPmer 2010). Strobe and fluorescent lighting have been used as fish deterrents at power station cooling water extraction plants (McIninch & Hocutt 1987, van Anholt *et al.* 1999); and variable sound signals (with frequencies of 20-600Hz), close to the mouths of intake pipes have also been successfully used (Maes *et al.* 2004). A high level of deterrence of clupeid fish (*i.e.* herring, sprat) was achieved, with numbers of herring reduced by 95% and sprat by 88%. Deterrence was variable, however, and related to species type and hearing ability.

With respect to EMF, accepted mitigation measures include burying cables to a depth of 1-3m. This successfully isolates marine organisms from the very highest electric and magnetic fields but is ineffective in insulating the B field (and resultant iE field) (Gill *et al.* 2005). An industry standard AC cable, buried to a depth of 1m is predicted to create an induced electric field of 91μV/m at the seabed; this is within the boundary of emissions expected to attract and/or repel elasmobranchs (CMACS 2003). To date, there are no environmental standards or guidelines for subsea cable deployment or the measurement of EMFs. Synthesizing current knowledge requires a number of assumptions due to the variety of methods used and to date, because the nature of the knowledge is patchy, no specific significant environmental impacts have been identified as requiring regulation (Gill & Desender 2020). However, as the knowledge and understanding base grows, along with the growth in number and scale of marine renewable energy arrays this assessment will ned to be revisited.

5.6.6 Likelihood of significant effects

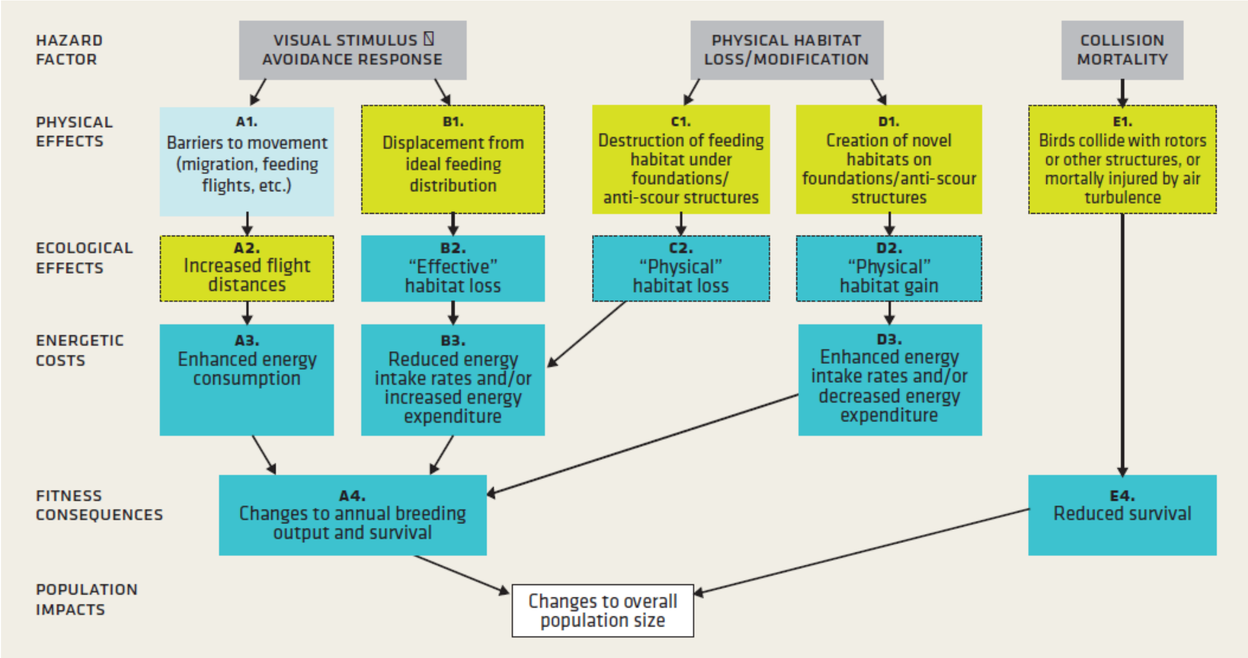
The following section considers the likelihood of significant effects for the receptors described above and combines these across the different elements of the plan/programme.

Non-native/non-indigenous benthic species have been recorded from offshore wind farms, primarily in the southern North Sea; however widespread species success and geographical population spread, including to the level where they have become invasive, are not apparent. Since natural 'islands' are widespread and numerous in continental shelf areas, it is considered very unlikely that any of the offshore energy technologies or developments will result in any significant effect on benthic species.

For mobile species, potential effects of interactions with infrastructure and support activities associated with the draft plan/programme have been discussed under the headings of collision, displacement and barrier effects. However, these do not represent simple causative relationships. Their assessment is often complicated by subtle and unpredictable interactions between a number of processes: functional ecological processes (e.g. between behavioural modification and energetic cost), feedback processes (e.g. mortality resulting from wind farm collisions may reduce competition for resources, thus reducing the rate of natural mortality Maclean *et al.* 2007), the importance of stochastic events, particularly to small populations (Maclean *et al.* 2007), habituation, and the presumed functioning of processes which are difficult or impossible to measure (as noted by Drewitt & Langston (2006), e.g. habitat loss causing a reduction in bird numbers in the area, which may then reduce the risk of collision).

This complexity is illustrated by the "Danish Model" which describes the three main hazard factors of OWF to birds and is shown below (Figure 5.) (similar diagrams for displacement/barrier effects are shown above (Figure 5.2, Section 5.6.3.2), from NE-JNCC 2017, adapted from Petersen *et al.* 2006). Although devised for birds, the principles are equally valid for other receptors/infrastructure interactions. The model distinguishes between measurable effects and processes that need to be modelled. There is a considerable range in the quantity and quality (confidence) of information relating to these various issues. Some, for example, displacement and collision risks for birds, are the subject of considerable research effort, with growing empirical evidence for the former, but evidence of the latter is still lacking. Others (fouling) have been monitored over a substantial time period, but systematic surveys for non-native species remains limited and some (link to vital rates) are relatively speculative.

Figure 5.16: "Danish model" flow chart for the three major hazard factors to birds



Source: Dong Energy *et al.* (2006) (a similar chart is used by Fox *et al.* 2006)

Of the receptors reviewed, greater potential effects have been identified for birds which are therefore the focus of much of this section. First however, key points relevant to all other receptors are given:

For marine mammals, tidal stream devices have been identified as a concern with respect to both collision risk and barrier effects but a lack of empirical evidence hampers efforts to evaluate the real magnitude of any potential effect. Collision risk is most strongly associated with rotating turbines but the behaviour of animals in response to these devices is largely unknown so that only 'encounter' risk can be reliably modelled to inform assessment. Given that suitable areas for exploitation of tidal stream resource are to a certain extent constrained to tidal straits and channels, the potential for barrier effects cannot be excluded.

Multiple factors likely to influence collision and behavioural effects have been reviewed; these are related to the specific characteristics of each species, device and locality. Therefore, modelling predictions and comprehensive risk assessments are best carried out for each deployment at the appropriate spatial scale and with specific knowledge of device characteristics. At the strategic level, the limited scale of development resulting from implementation of the plan allows the conclusion that any effect is unlikely to be significant at the population level.

The most likely sources of significant effect on fish are tidal energy devices. Collision and barrier effects risks apply particularly to migratory, diadromous species which are present in estuaries and river mouths at sensitive and critical stages of their life-cycles. Exact migratory routes will vary between species and possibly within species and so assessment at a local scale, using specific knowledge of the area of the proposed development and the devices to be installed, is required for more comprehensive risk assessments. Habitat change arising from the placement of tidal energy devices may also have significant effects on spawning or nursery aggregations of fish, particularly at sensitive habitats such as estuaries and bays. Such aggregations of fish are often associated with particular habitat conditions and will therefore be vulnerable to a change in environment. A review conducted of underwater video data at three operating tidal turbine sites (MeyGen tidal turbine in the Pentland Firth, SR2000 and HyTide deployments at the European Marine Energy Centre (EMEC)) to establish near-field behavioural data of marine wildlife around tidal turbines recorded changes in fish and diving bird behaviour associated with the turbine operational status and current speed (Hutchison *et al*. 2020c). The review comprised 128 samples representing the firsts two minutes in each hour of available data for the tidal stream developments. Only 28 of these samples contained receptor observations, with the remaining 100 out of 128 two-minute samples showing no wildlife. No collision events were observed in the selected datasets. Fish were observed to shoal around the device and investigate the nacelle when the turbine was static and at current speeds less than 0.8m/s, demonstrating fish aggregating effects. At current speeds in excess of 0.9m/s fish and birds were more frequently observed to move with or across the current, and birds were more likely to be observed in current speeds between 1.2–2.9m/s. No collision events were observed in any of the samples reviewed. In addition to analysing the video data the study identified 36 recommendations to improve the quality of underwater video monitoring for the purpose of understanding the environmental impacts of tidal turbines. The report suggests that higher quality data suited to the purposes of environmental monitoring, would allow a more informed opinion on the ability (or inability) of marine wildlife to avoid and evade tidal turbines and enable the consenting process.

The potential ‘reef effect’ introduced by underwater structures may result in variations in foraging opportunities for fish, birds, seals and cetaceans at the local scale but its wider ecological significance is unclear.

Recent research has shown that EMFs generated by subsea power cables can possibly interact in a negative way with several sensitive marine species, especially benthic and demersal organisms through effects on predator/prey interactions, avoidance/attraction and other behavioural effects, effects on species navigation/orientation capabilities and physiological and developmental effects (Hutchison *et al*. 2020b). Albert *et al*. (2020) noted that interpretation of these effects need to be made with caution, as it has not been shown that these impacts at an individual level reveal real biological impacts at a population level. Based on evidence to date, Gill & Descender (2020) concluded that the ecological impacts associated with marine renewable energy subsea power cables may be weak or moderate at the scale that is currently considered or planned. However, their review also indicated that the future scale of development of marine renewable energy arrays, required to meet renewable energy targets, will increase EMF sources in the marine environment, and consequently may increase the potential risk to sensitive receptors through cumulative encounters with EMFs.

Based on the expected levels of ecological effects and associated levels of scientific knowledge Taormina *et al*. (2018) developed a hierarchical model of potential impacts caused by submarine power cables to different marine compartments and main taxa. The potential impacts of EMF were identified as one of the main priorities of impacts associated with submarine cable, with a medium extent of impact to elasmobranch and diadromous fish (Table 5.21). A medium to high level of uncertainty was assigned to the EMF impact score based on the substantial data gaps on sensitivity thresholds and tolerance of several large taxa (cetaceans, pinnipeds, fishes, crustaceans and many pelagic species). Taormina *et al*. (2018, 2020b) concluded that better knowledge of the different sensitivity thresholds is needed to fill these data gaps, especially for several key species at different stages of their development. In the context of this assessment, marine plan policies (e.g. those CAB-1 policies of the most recently adopted English inshore and offshore plans) set a preference for all subsea cables to be buried.

Table 5.21: Assessment of the importance of potential EMF impacts caused by submarine power cables on different marine compartments

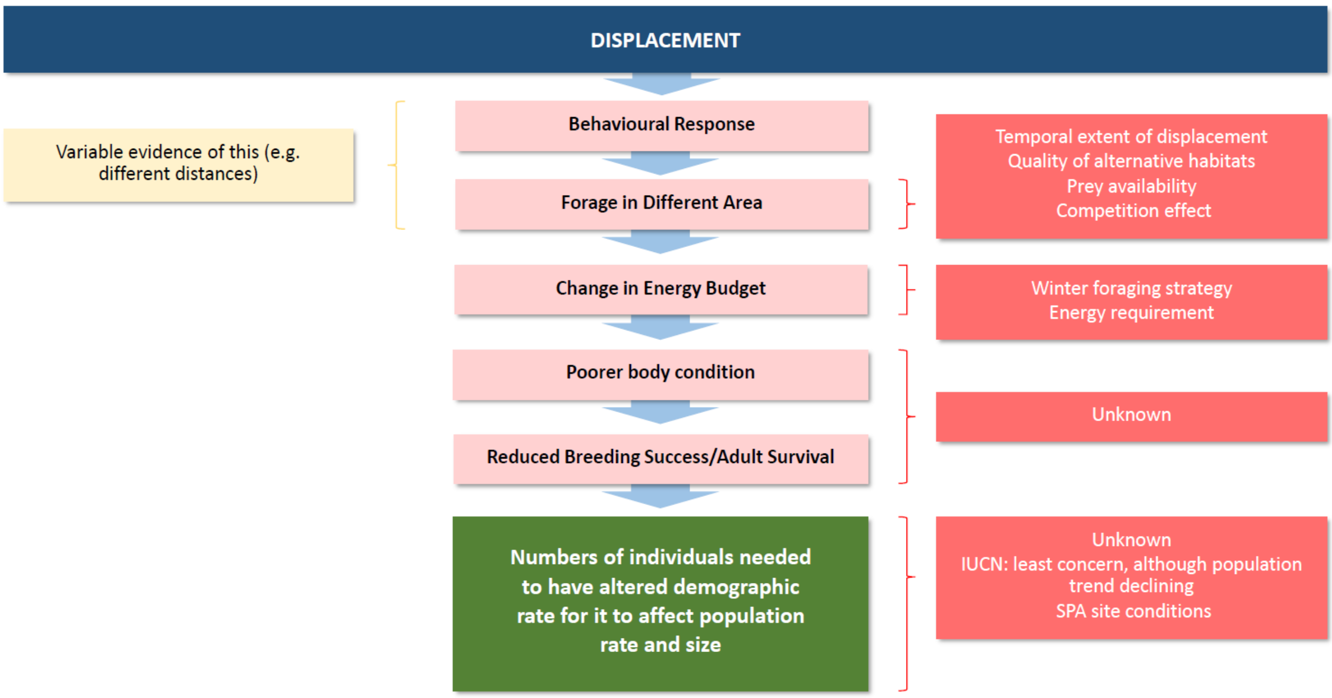
	Invertebrates			Fish			Elasmobranchs and Diadromous fish			Marine mammals		
	Bur	LD	Dyn	Bur	LD	Dyn	Bur	LD	Dyn	Bur	LD	Dyn
Extent of impact	Low	Low	Low	Low	Low	Low	Low	Med	Med	-	-	Low
Uncertainty	High	High	High	Med	Med	High	Med	Med	High	-	-	Med

Notes: For each interaction, the extent of impact and associated uncertainty are quantified as 'Negligible', 'Low', 'Medium' or 'High'. Bur = Buried LD = Laid-down; DYN = Dynamic. Source: adapted from Taormina *et al.* (2018)

For birds, the evidence, at project level, has shown that the risks of collision and displacement effects are strongly associated with offshore wind farm developments, particularly for some bird species. However, methods for assessing potential impacts (e.g. displacement matrix and collision modelling) are highly precautionary, and a high level of uncertainty in interpreting their outputs, remains.

Accurately quantifying the magnitude of an impact (collision and displacement) and determining the population-level consequences (e.g. changes to productivity or mortality levels) as a result of these impacts, remains one of the key challenges in the assessment of wind farm effects, and one of the largest consenting risks. For example, whilst displacement effects have been reported in several studies for red-throated diver, there is no verifiable evidence of negative ecological consequence of this; for displacement to cause a population level effect, a number of causal events need to occur (see Figure 5.40) however, the mechanistic links from displacement to consequences at a population level remain unknown.

Figure 5.40: Simplified diagram showing causal events for population-level effects from displacement



Notes: Boxes on left hand side indicates where information is available, boxes on the right indicate where information is lacking. SPA site conditions for 7 of the 10 SPAs designated for breeding red-throated diver are classed as in favourable condition; for SPAs where non-breeding red-throated diver are a feature, site condition is still to be assessed. Source: modified from Dierschke *et al*. (2017)

There are many factors that influence the risk of an impact, and, several of them are species-specific; the large number of bird species (migrating and resident) that may encounter wind farms in UK waters introduces a considerable challenge to the assessment of risk, particularly in determining those species to likely be most at risk. For an assessment to be effective and a useful tool in identifying potential significant impacts, there needs to be common analytical approaches, so data from individual projects are comparable, with robust and reliable empirical evidence enabling improvements in assessment tools, by reducing uncertainty; in the absence of empirical evidence, precautionary approaches are and will continue to be used, which can result in over estimating the scale of an impact.

Understanding the spatial and temporal distribution of birds is particularly important for understanding connectivity with and apportioning impacts to, relevant Special Protection Areas (SPAs). Impacts on birds from these protected sites are a particular concern, especially for the southern North Sea, given the current level of operational wind farms and the potential future development; with assessments undertaken for projects in this region (mainly Habitats Regulations Assessment) concluding that for certain species related to certain colonies, where site status is considered poor, additional cumulative wind farm capacity would result in adverse effects, despite the high level of precaution in the collision risks assessments informing such decisions, This applies to breeding bird features of sites (e.g. kittiwake, gannet), non-breeding (e.g. red-throated diver) and also the impact on birds migrating through the area (e.g. gannet), the latter group also considered against contributing SPA populations. The collision risk assessments informing such decisions are based on a high level of precaution both in terms of project design, which is typically a worst case in terms of scale in keeping with the Rochdale Envelope approach to assessment, and in terms of assessment; significant information gaps remaining on actual levels of bird avoidance, mortality associated with wind farm operation, and with the monitoring of populations subject to multiple stressors, including, for example impacts of climate change on prey availability.

To effectively determine if an impact is significant or not, an understanding of the condition of the feature within a SPA is essential, such as population abundance estimates, any trend in population, and any existing pressures and the effects of these. For example, the majority of the wintering population of red-throated diver in the UK occurs off eastern England (Wash-greater Thames area), with other concentrations in Liverpool Bay and in Scotland's east coast Firths. Long-term data from the Outer Thames Estuary SPA indicates increasing red-throated diver numbers for the SPA as a whole (Irwin *et al*. 2019), albeit that the presence of the OWF resulted in marked displacement and the birds were in more concentrated areas. A similar study has not been carried out in Liverpool Bay (survey data from this area now over 10 years old), although the pattern is thought to be similar (i.e. displacement seen, but no overall decline in population) (pers. comm A Webb, as cited in Dorsch *et al*. 2019); this has also been seen elsewhere, e.g. Vilela *et al*.2020, Dorsch *et al*. 2019).

Outcomes for recent projects have required the implementation of compensation measures for lesser black-backed gull from the Alde Ore Estuary SPA, as these developments[182] would be within the mean maximum (+1SD) foraging range for this species and connectivity with the windfarm could not be ruled out. In their review of breeding season foraging ranges, Woodward *et al*. (2019) highlighted that there was a record of a breeding lesser black-backed gull making an extremely long trip in excess of 500km (Camphuysen 2013), but noted that unlike studies of

[182] For the Norfolk Boreas development, this was located 112km from the Alde Ore Estuary SPA, therefore deemed within foraging range for this species.

foraging trips for Manx shearwater and herring gull where long trips appeared to be common, these were very unusual for lesser black-backed gull and that the mean foraging distance was 38km based on numerous tracking studies (e.g. Thaxter *et al*. 2012, etc), resulting in the estimate of the mean foraging distance falling from 72km to 38km (Woodward *et al*. 2019). The highest mean max (+1SD) foraging range for birds from the South Walney/Barrow study was 32km (2019 South Walney) and 14km (2018 Barrow) (Clewley *et al*. 2020) with little connectivity with the adjacent wind farm developments. Tracking studies at lesser black-backed gull colonies have indicated terrestrial foraging strategies; although some birds do forage in the marine environment.

A basis for the HRA conclusion was the state of the population at the SPA, although no data is available on the condition of the population and the population counts have been variable. Data from Orfordness Beach (Orford Ness 1), Alde Ore Estuary SPA from the SMP database shows highly variability with counts of 5,500 (Apparently Occupied Nests AON) in 2001, down to 640 AON in 2012, after which counts continued to fluctuate between 2013 and 2018, when the last count was taken. Therefore determining the likelihood of a significant effect is challenging, relying on a precautionary approach and, given the outcome in respect of lesser black-backed gull and the Alde-Ore Estuary SPA for example, similar precautionary assessments could lead to consenting risk for developments in the Irish Sea.

Table 5.22 lists SPAs[183] and associated species (after O'Brien *et al*. 2021) for which evidence is a priority and which could present further consenting risk.

Table 5.22: SPA sites, species and pathways for impact that may present consenting risks

SPA Site	Species (Population at designation[1])	Site condition, status[2]	Pathway for impact/risk for consent
Regional Sea 1			
Outer Firth of Forth and St Andrews Bay Complex	Gannet (10,945 I) Red-throated diver (851 I)	CNA	Collision/displacement due to migration through southern NS (gannet), displacement (red-throated diver)
Forth Islands	Gannet (21,600 I) Sandwich tern (440 P) Lesser black-backed gull (1,500 P) Atlantic puffin (14,000 P)	FM UD FM FD	Collision/displacement due to migration through southern NS (gannet), collision (Sandwich tern and LBBG), displacement (puffin)
Northumberland Marine	Sandwich tern (4,324 I)	CNA	Collision risk, foraging (breeding)
Farne Island	Sandwich tern (862 P)	CNA	Collision risk, foraging (breeding)
Coquet Island	Sandwich tern (1,590 P)	CNA	Collision risk, foraging (breeding)
Flamborough & Filey Coast	Gannet (8,469 P) Guillemot (41,607 P) Razorbill (10,570 P) Kittiwake (44,520 P)	CNA	Collision and/or displacement, due to foraging (breeding season) and migration movement (non-breeding)
Regional sea 2			

183 The seabird assemblage may include species which are present in nationally important numbers, but which do not qualify at a European population level.

SPA Site	Species (Population at designation[1])	Site condition, status[2]	Pathway for impact/risk for consent
Greater Wash	Red-throated diver (1,407 I) Common scoter (3,449 I) Sandwich tern (3,852 P)	CNA	Displacement (red-throated diver and common scoter, non-breeding – habitat/foraging area loss), collision (sandwich tern, foraging during breeding season)
North Norfolk Coast	Sandwich tern (3,700 P)	CNA	Collision risk, foraging (breeding season)
Alde-Ore Estuary	Sandwich tern (170 P) Lesser black-backed gull (14,070 P)	CNA	Collision risk (foraging breeding season)
Outer Thames Estuary	Red-throated diver (6,466 I)	CNA	Displacement (habitat/foraging area loss, non-breeding)
Regional Sea 4			
Skomer, Skokholm and the Seas of Pembrokeshire	Manx shearwater (150,968 P) Atlantic puffin (9,500 P) Lesser black-backed gull (20,300 P)	CNA	Collision and/or displacement (habitat/foraging area loss) (breeding season)
Grassholm	Gannet (33,000 P)	CNA	Collision and/or displacement (habitat/foraging area loss), breeding and migration routes
Regional Sea 6			
Copeland Island	Manx shearwater (4,800 P)	CNA	Collision and/or displacement (habitat/foraging area loss)
Irish Sea Front	Manx shearwater (12,039 I)	CNA	Collision and/or displacement (habitat/foraging area loss)
Dee Estuary (Extension)	Sandwich tern (957 I)	CNA	Collision risk (foraging during breeding season)
Liverpool Bay	Red-throated diver (1,171 I) Common scoter (56,679 I)	CNA	Displacement (habitat/foraging area loss, non-breeding)
Morecambe Bay and Duddon Estuary	Lesser black-backed gull (9,720 I) Sandwich tern (1608 I)	CNA	Collision risk (foraging during breeding season)
Anglesey Terns	Sandwich tern (460 P)	CNA	Collision risk (foraging during breeding season)

Notes: [1]I = Individuals; P = Pairs. [2]Current status is latest assessed condition at the site, CNA =Condition not Assessed, FM = Favourable Maintained, FD = Favourable Declining, UD = Unfavourable Declining Source: Natural England website (SPA site information), NatureScot website (SPA site information), JNCC website (SPA site information).

Project applications for offshore wind farms in the southern North Sea are proposing compensatory measures in relation to certain species and SPAs, and therefore, any further incremental effects for these sites and species may reasonably expected to require suitable levels of compensation. For other sites and species for which such measures have not been proposed, it is important that understanding of the conservation status of a site is documented and monitored over time as without such information conclusions of adverse and no adverse effect may not be accurate. This presents a future consenting risk, particularly if limited compensatory measures are available.

From the information presented above and in the Appendix 1a.6, a list of species considered to be particularly vulnerable to further offshore wind development in each of the Regional Sea areas is shown below (see also Table 5.22 above for relevant European sites and impact pathways):

Regional Sea 1[184]: kittiwake, gannet, Sandwich tern, red-throated diver,

Regional Sea 2: kittiwake, red-throated diver, common scoter, lesser black-backed gull, gannet, Sandwich tern

Regional Sea 3: Sandwich tern

Regional Sea 4: common scoter, gannet, lesser black-backed gull, Manx shearwater

Regional Sea 5: None

Regional Sea 6: red-throated diver, common scoter, Manx shearwater, gannet, lesser black-backed gull, Sandwich tern

Regional Sea 7: kittiwake, Manx shearwater

Regional Sea 8: gannet, kittiwake

Regional Sea 9, 10, 11: None

Other species present within these areas are not listed as they are considered not sensitive to collision or displacement (e.g. Furness *et al*. 2013, Bradbury *et al*. 2014, Dierschke *et al*. 2016). However, these may also trigger consent risks if cumulative assessments conclude an adverse impact on site integrity for these features (e.g. O'Brien *et al*. 2021): guillemot (Regional Sea 1 and 2); razorbill (Regional Sea 1) and Atlantic puffin (Regional Sea 1 and 4).

Consideration of the above, and the findings and recommendations below, will assist in the appropriate siting of OWFs, wave and tidal devices to reduce the risk of cumulative effects.

For any new offshore renewable developments, the extent of any potential transboundary impact on bird, fish and marine mammal populations using waters adjacent to the UKCS from this SEA plan/programme are based on assessments using current available frameworks, information and the application of precaution, meaning confidence will remain relatively low until new empirical evidence is available.

Lack of empirical evidence applies particularly to wave and tidal stream device effects; adaptive management should ensure that this situation will be improved prior to the deployment of full scale arrays. Tidal devices will only be sited at very specific locations, determined by the available tidal resource. Therefore, the range of bird species potentially at risk from a development will be limited by proximity of the development to seabird breeding colonies, other foraging areas and species specific diving abilities in strong tidal flows. Bird species at most risk from tidal range schemes are likely to be waterbirds which rely on intertidal habitats for

[184] kittiwake and gannet are listed in both Regional Sea 1 and 2 due to the location of the Flamborough & Filey SPA and also for gannet from the Bass Rock colony, evidence for which shows migration through Regional Sea 2 to exit the North Sea

feeding which may be significantly affected by such schemes, as well as diving birds if the prey species are altered.

The overall potential impacts to marine birds from offshore oil and gas, gas storage and carbon dioxide storage are considered negligible given the range of controls and mitigation measures in place. These include assessments required at project specific level, mitigation of impacts required for exploration and appraisal activities and the installation of new developments, with operational control of chemical use and discharge, flaring and venting, oil spill mitigation and responses, and guidelines associated with lighting.

The offshore wind and marine renewable industry is still relatively young, although technological development in for example, turbine size, rotation speed, and foundation structure, is developing at pace, as is floating wind technology, allowing developments in deeper offshore waters.

5.6.7 Summary of findings and recommendations

Although the evidence base of our understanding of the potential ecological effects of the physical presence of the infrastructure associated with energy developments has improved significantly in recent decades, some important gaps remain. This applies to all elements of the draft plan/programme but particularly so in the case of offshore wind (fixed and floating) and marine renewable developments. Insufficient knowledge of ecological receptors and their interactions with energy infrastructure, in particular seabird interactions with offshore wind turbines and marine mammals and fish with tidal turbines, hinder accurate predictions of impacts, which leads to precautionary assessments; this can then lead to consenting risks, which can delay or prevent the development of renewable developments. This is a critical issue given the imperative of energy transition and decarbonisation towards net zero by 2050.

The physical presence of offshore infrastructure and support activities may potentially cause behavioural responses in fish, birds and marine mammals through a range of different mechanisms. Previous SEAs have considered the majority of such interactions with offshore oil and gas infrastructure, including for e.g. light attraction and collision (whether positive or negative) to be insignificant because the total number of surface facilities is relatively small (low hundreds) and the majority are far offshore and in relatively deep water.

This assessment is considered to remain valid for the potential consequences of future rounds of oil and gas licensing (including for carbon dioxide and gas storage), and also any offshore surface infrastructure associated with hydrogen production. However, the large number of individual structures in offshore wind farm developments, the presence of rotating turbines, and their potential location (e.g. in relation to foraging areas for coastal seabird breeding colonies and wintering locations for waterbirds), indicate a higher potential for physical presence effects.

In relation to birds, these include displacement, leading to effective habitat loss, associated with exclusion from ecologically important (e.g. feeding, breeding) areas, barrier effects and disturbance of regular movements (e.g. foraging, migration), potentially increasing flight energy demands and collision risk.

Assessments undertaken for recent southern North Sea wind farm projects (mainly Habitats Regulations Assessments) have concluded that for certain species from certain colonies (kittiwake, lesser black-backed gull), additional cumulative wind farm capacity would result in adverse effects that require compensatory measures. The collision risk assessments informing such decisions are based on a high level of precaution both in terms of project design, which is typically a worst case in terms of scale (the Rochdale Envelope approach to assessment), and in terms of assessment; significant information gaps remaining on actual levels of bird avoidance, mortality associated with wind farm operation, and with the monitoring of populations subject to multiple stressors, including, for example, impacts of climate change on prey availability.

Cumulative and in-combination assessments to date rely on assessments based on consented wind farm parameters that reflect the worst case noted above. To date, the difference in the number of turbines in a wind farm consent compared to that constructed can be one third to one half, such that there is also likely to be a significant difference in the estimated bird mortality between these scenarios. This could reduce the significance of effect for ongoing and future in-combination effects assessment, resulting in more realistic assessments. No legal mechanism currently exists to require consent variations to reflect the as-built parameters of wind farms, so the reduction of this "headroom" through altering consents is at the discretion of individual developers, however, this is being remedied through proposed changes to the National Policy Statement for renewable energy. Building on other work commissioned as part of Offshore Wind Evidence and Change programme, it is recommended that further work be undertaken to define the magnitude of the collision risk mortality headroom that exists, to determine whether agreement can be reached on the level of effect for future in-combination effects assessment, and to encourage the variation of consents to reflect the as-built parameters of projects.

Evidence suggests that diving birds, and in particular red-throated diver, are highly sensitive to displacement by offshore activities and installation presence. A high level of displacement has been observed for red-throated diver from offshore wind farm arrays (up to 12km), though this does not appear to result in complete displacement, and the level of displacement is variable between locations. While evidence exists for displacement, evidence is lacking on any related level of mortality or reduction in size or fitness of the population. Concerns are acute in relation to certain areas around the UK which have been designated for red-throated diver, with the main areas in English waters all having been subject to some wind farm development (e.g. Liverpool Bay, Greater Wash, Outer Thames).

The issue primarily relates to the potential scale of cumulative habitat loss resulting from displacement (though note that displacement is not 100% and therefore the term habitat degradation may be more appropriate), and the potential effects on the conservation status of the species, despite limited to no evidence of negative population trends in these areas. It is recommended that until further information is available on the scale of habitat degradation across operational wind farms in areas designated for red-throated diver, and it is understood how this loss translates into population level effects for the species, future rounds of offshore leasing should avoid further impingement on diver habitat. It is also recommended that monitoring and/or scientific research be undertaken to understand diver distributions within sites and population trends in the species to allow future consideration of the issue at strategic and project levels. Without this new evidence, with the conservation objectives for sites designated for red-throated diver as written and in particular "by maintaining or restoring:…the distribution of qualifying features within the site" could mean that no further windfarm or other development will be possible in or immediately adjacent to such sites. This issue requires policy level discussion to ensure that the UK's conservation objectives can be met without unnecessarily constraining energy related or other economic activities.

Recent evidence suggests that displacement could be a greater potential source of impact for gannet than previously thought and it is recommended that current data be reviewed to determine the extent of this, and its implications for both the displacement rate and collision risk for the species.

Given the current levels of uncertainty in relation to the scale and nature of impacts of tidal turbines with birds, marine mammals and fish at both individual and population levels more detailed monitoring is required on existing demonstrators and future developments to inform project design, mitigation measures and the immediate consenting process. As the body of empirical data increases, in particular in relation to the ability of marine wildlife to avoid colliding with tidal turbine, this will help inform future monitoring requirements and to ensure that they are proportionate and fit for purpose (Hutchison 2020c). Therefore the SEA recommends that for the deployment of single devices and small arrays (potentially in phased developments when sited in new areas), appropriately focussed baseline, construction and operational surveys of animal activity and behaviour, in particular with respect to turbine avoidance behaviour, aggregation around devices, evidence of displacement from important feeding or breeding areas and changes to behavioural patterns over tidal and diel cycles should be undertaken to inform commercial scale deployment risk assessments and consenting.

Seabirds (and waterbird populations) can decline (or increase) due to a number of different external factors (unconnected to the presence of offshore energy infrastructure) including food availability, predation, disease, exploitation, by-catch and extreme weather events – with many of these factors interlinked and several thought due, at least in part, to climate change. In the UK, climate change is considered to be one of the primary causes of the declines in seabird populations and for the growing number of red-listed species (Daunt & Mitchell 2013; Daunt *et al.* 2017; Eaton *et al*. 2015; McDonald *et al*. 2015; OSPAR, 2017a, b; Mitchell *et al*.,2018a, b). Whilst certain species can exhibit declines across their entire population, there can be regional differenced, i.e. as seen in kittiwakes, a pressure on which is prey availability and quality, and the precise causes of which are unclear. Disentangling these external factors, and possible regional pressures, from the effects of offshore energy projects will be challenging; whilst significant progress has been made in development frameworks for assessing cumulative impacts, an understanding of other external pressures acting on populations, and the extent of the effects of these, particularly for species such as kittiwake is essential in quantifying the effects from OWF. It is recommended that, at least for kittiwake, that a review of regional populations, and the identification of current pressures these regional populations, is undertaken.

The above should be complemented by continued work to expand the evidence base to reduce precaution and uncertainty in assessments including through:

- Foraging ranges/distribution (breeding/non-breeding seasons) (connectivity to SPAs) (in collision risk assessments, foraging ranges based on Woodward *et al.* (2019), levels of uncertainty in data)
- Flight height distribution of birds and reducing uncertainty/bias around this (flight height based on Johnstone *et al.* 2014, level of uncertainty in data)
- Flight speed
- Nocturnal flight activity rates
- Distribution of birds within the OWF footprint
- Population estimates
- Avoidance and displacement (and mortality) rates
- Identification of and the assessment of the efficacy, of compensatory measures
- Development of the Cumulative Effects Framework for Ecological Receptors

5.7 Physical presence and other users

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Interactions with fishing activities (exclusion, displacement, seismic, gear interactions, "sanctuary effects")	X	X	X	X	X	X	X	X
Other interactions with shipping, military, potential other marine renewables and other human uses of the offshore environment	X	X	X	X	X	X	X	X

5.7.1 Introduction

Interaction between offshore energy installations and other users of the marine environment is a prime concern for stakeholders. Issues relate to the potential or actual exclusion from areas which may be relatively isolated and widely separated in relation to oil & gas, CCS and gas storage (e.g. 500m safety zones around surface installations and some subsea infrastructure) or much larger for offshore wind (e.g. between <10km^2 and >700km^2 for proposals to date) and other wet renewables (there have been no commercial scale developments in the UK to date, and though some lease areas may be comparatively large (e.g. the Menter Môn lease off Anglesey is ~35km^2) the largest commercial project is MeyGen in the Inner Sound with a coverage of some 3.5km^2). The installation of renewables may not necessarily lead to exclusion as the density of devices may be low (>1,000m between devices in some instances), but the nature of certain activities (e.g. aggregate extraction, bottom towed fishing gear) is such that interactions with cables or mooring lines may hinder or preclude activity, and there are safety issues relating to the maintenance of obstacle free areas (e.g. for commercial shipping, aviation). Tidal range developments may vary significantly in size and differ in that they are typically shore connected impoundments, either forming a hard physical boundary or having dedicated navigational locks; the proposed Swansea Bay and Cardiff lagoons would enclose 11.5km^2 and 70km^2 respectively.

An overview of other users of the marine environment is given in Appendix 1h and this section is a consideration of the potential for interactions between the offshore energy infrastructure covered by the draft plan/programme and these other users. Interactions between shipping, navigation and fishing activity with offshore renewables probably represent the greatest potential for conflict. The interaction of multiple users of the marine environment and the role of marine planning in activity management is discussed in Section 5.15. Policy directions given in the Marine Policy Statement (MPS) and regional marine plan policies are discussed with reference to specific activities below.

5.7.2 Sources of potentially significant effect

5.7.2.1 Navigation

Navigational risks associated with the installation of offshore energy infrastructure are well-recognised. For oil and gas (and by association also gas storage and CCS given they largely fall within the same regulatory regime) there is a long history of risk assessment as part of the initial licensing process, and subsequent exploration and production activities. Anatec (2012) undertook a strategic consideration of the potential navigational effects relating to offshore wind farms (OWF) which included stakeholder consultation, with strategic issues identified as including: wind farm project site boundary and structure alignment, radar implications (vessel detection), congestion and displacement, emergency response demand/provision and potential for restricted access, effects on adverse weather routes, access and transboundary effects. A number of actions were suggested and presented to the Nautical and Offshore Renewable Energy Liaison (NOREL) group, and these issues remain pertinent to the discussion below.

Guidelines have been issued on the assessment of navigational risk for offshore renewables developments (e.g. MCA 2021, MCA Marine Guidance Note (MGN) 654). As with oil spill risk assessment for offshore oil and gas developments, the regulatory approach is risk-based, and therefore has elements in common with the regulation of health and safety in an industrial context; for example in the process of assessing risk through a quantitative process (here termed Formal Safety Assessment, FSA) and judging acceptable levels of risk against what is ALARP (As Low As Reasonably Practicable).

Offshore wave and tidal device deployment is not currently on the same scale as offshore wind and the likely spatial extent of development for the associated technologies in the near to medium term is expected to be at a demonstrator or small scale rather than in the form of large commercial arrays, and their impact on navigation is currently, therefore, less extensive than for offshore wind. This is due to a combination of technology maturity, and for tidal stream devices, the paucity of resource area compared to other renewables. For tidal stream devices mounted on the seabed, location within deeper waters should mitigate their impact on shipping (e.g. AECOM & Metoc 2009), however, both wave and tidal devices could form a potential hazard both during their construction and operational phases and are subject to the same offshore hazard regulations and assessments as for offshore wind (e.g. EMEC 2009, Halcrow 2006). The NOREL group, chaired by the Department for Transport (DfT), provides a forum for Government, developers and stakeholders to discuss navigational issues. Guidance on renewables developments (primarily tidal stream but there are also partly or fully submerged wave devices) in relation to vessel under-keel clearance was issued by NOREL in 2014 such that minimum depths could be set whereby vessels could still transit sites without deviation, or conversely, where deviation would be required (for a worked example see MeyGen 2015). No set figure for under-keel clearance is provided, but the guidance indicates how a maximum safe height of a device above the seabed may be calculated based on a study of vessel types and draughts in the area of interest, and the specific design of any device and site specific characteristics (i.e. water depths, variations in sea level due to the state of the tide). Water depths vary greatly in the resource areas identified for wave and tidal devices, however, it is likely that should devices be deployed in the shallowest parts of these areas (e.g. 5-10m depth – see Section 2.6.2), then under-keel clearance could be significantly reduced. Charting requirements, notices to mariners and aids to navigation, in addition to risk assessment as part of activity consenting, would be required for any deployment of such devices.

Under the International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA) O-139 recommendations for the marking of offshore manmade structures (IALA 2008, revised 2013), wave and tidal devices extending above the sea surface must be marked in accordance with the marking regulations for OWF, and the level of marking should be decided after risk assessment. Appropriate navigation buoys (with lighting visible for 5nm) at the corners of arrays and above sub-surface devices which still pose a hazard to surface vessels is required; active or passive radar reflectors, retro reflecting material, racons and/or AIS transponders are also expected to be fitted as the level of traffic and degree of risk requires (e.g. if specific structures are not considered to be sufficiently radar conspicuous from all seaward directions). Fog signals may also be required.

MCA MGN 654 indicates that its recommendations should be taken into account by developers, "*…in the preparation of Scoping Reports (SR), Environmental Impact Assessments (EIA), Navigational Risk Assessments (NRA) and resulting EIA reports and in any post-consent documents.",* and be used to evaluate, "…*all navigational possibilities, which could be reasonably foreseeable, by which the siting, construction, extension, operation and de-commissioning of an OREI could cause or contribute to an obstruction of, or danger to, navigation or marine emergency response*". MGN 654 advises that a traffic survey of the area concerned should be undertaken within 12 months prior to submission of an Offshore Renewable Energy Installation (OREI) EIA Report. However, if deemed necessary in order to cover seasonal variations or perceived future traffic trends, the survey period may be required to be extended to a maximum of 24 months.

The project-specific EIA should also assess potential navigational or communications impacts and difficulties caused to mariners or emergency response services using the site area and its environs. Those difficulties which could contribute to a marine casualty and lead to injury, death or loss of property, either at sea or amongst the population ashore, or damage to the marine environment, should be highlighted; as should difficulties affecting emergency response. Consultation with local and national search and rescue authorities should be initiated and consideration given to the types of aircraft, vessels and equipment which might be used in emergencies. This should include the possible use of OREI structures as emergency refuges and any matters that might affect emergency response within or close to the OREI. All OREI generators and transmission systems should be equipped with control mechanisms (for example, shutdown) that can be operated from a central control room or through a single contact point. Development EIA should also consider whether any feature of the installation could create problems for emergency rescue services, including the use of lifeboats, helicopters and Emergency Towing Vessels (ETVs). Throughout the design process for an OREI, assessments and methods for safe shutdown should be established and agreed, through consultation with MCA's Navigation Safety Branch, Search and Rescue Branch and other emergency support services (e.g. through the Emergency Response Co-operation Plan (ERCoPs) process – also see below in relation to helicopter based SAR. All of the above need to be addressed to the satisfaction of MCA prior to consenting of a development.

MGN 654 also indicates that an EIA should consider whether any features of the OREI, could pose any type of difficulty or danger to vessels underway, performing normal operations, including fishing, or anchoring; OREI features include auxiliary platforms outside the main generator site, mooring and anchoring systems, inter-device and export cabling. Dangers would include clearances of wind turbine blades above the sea surface[185], the burial depth of cabling[186], and lateral movement of floating wind or tidal turbines.

Specific guidelines on navigation risk assessment (NRA) for offshore renewables developments have been produced by the MCA (2021). These set out a requirement for assessing risk by Formal Safety Assessment (FSA) using numerical modelling and/or other techniques and tools of assessment acceptable to government. The FSA is required to: estimate the "Base Case" level of risk based on existing densities and types of traffic and the existing marine environment; and predict the "Future Case" level of risk based on the predicted growth in future densities and types of traffic and reasonably foreseeable future changes in the marine environment. Both Base and Future Cases are to be assessed with and without the development in place; and with or without the identified hazards which are caused or changed by the introduction of the development, together with the risk associated with the hazard, the controls put in place and the tolerability of the residual risk. For consenting to proceed, risk must be assessed as "Broadly Acceptable" or "Tolerable" on the basis of "As Low As Reasonably Practicable" (ALARP)", based on criteria set out in the Methodology's "Mechanism for Assessing Tolerability of Marine Navigational Safety and Emergency Response Risk". This considers both the tolerability of individual risks, and of societal concerns.

On the basis of risk assessment, offshore wind farm developers are required to indicate whether navigation in and/or near the site should be prohibited by specified vessel types, operations and/or sizes; in respect of specific activities; in all, or specified areas or directions; in specified tidal or weather conditions, or simply recommended to be avoided. Relevant information concerning applications for safety zones under the *Electricity (Offshore Generating Stations) (Safety Zones) (Application Procedures and Control of Access) Regulations 2007* for a particular site during any point in its construction, operation or decommissioning, should be specified in the Environmental Statement (ES) accompanying the development application. In practice, few offshore wind developers to date have made use of the potential to incorporate operational 50m safety zones around devices. Wave and tidal devices may be considered differently in that they may be partly mobile and have tethered moorings which may not make the safety zone approach taken for offshore wind appropriate (DECC 2011).

Developers are also required to provide researched opinion of a generic and, where appropriate, site-specific nature concerning whether proposed structures could produce radar or radio interference such as reflections, blind spots, shadowing, or phase changes; with respect to any frequencies used for marine positioning, navigation or communications, including Automatic Identification Systems (AIS), whether ship-borne, ashore or fitted to any of the proposed structures. MCA guidance (2021) requires that all vessel types are covered in NRA, and where AIS and shore based radar techniques are not comprehensive enough to understand the full range of vessels in an area, visual and other methods may need to be used.

The MCA (2021) NRA methodology notes that levels of navigational risk associated with offshore renewables developments and their tolerability are likely to be dependent on a number of variables. These include the size of the water space, its bathymetry and hence the sea room available for manoeuvring, and the variety of marine operations taking place in the water space.

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[185] Recommended minimum safe (air) clearances between sea level conditions at mean high water springs (MHWS) and wind turbine rotors are that they should be suitable for the vessel types identified in the traffic survey but generally not less than 22 metres, unless developers are able to offer proof that no risk exists to any vessel type with air drafts greater than the requested minimum. Typical air gaps in recent consent orders are between 22 and 35 m, and have generally increased in recent years in response to potential impacts on bird collision risk.
[186] See East Marine Plans Policy CAB1, which indicates that preference should be given to proposals for cable installation where the method of installation is burial.

The spatial scale of existing leases is relatively large, and are comparable in spatial scale to the range of proposed Round 4 projects. Any lease area is likely to include a wide range of shipping traffic densities, though most are selected based on some initial understanding of the major shipping routes and densities in an area. Although there is an established methodology for FSA of individual developments (MCA 2021), the output from this process does not facilitate an assessment of cumulative risk (i.e. there is no straightforward approach to sum the risk associated with individual developments). Several studies have been undertaken to understand how major shipping routes have changed in relation offshore wind, or to inform how they might change, which are described below (also see Section 5.15).

A NRA for the Wave Hub site off Hoyle, north Cornwall (Halcrow 2006) calculated, on the basis of existing shipping information, a risk of collision of a vessel with one of the devices (both in a powered and drifting scenario) as 1 collision per 169 years (a conservative estimate as it assumes a collision of every ship entering the site). The risk of ship to ship collision in the area was actually reduced from 1 in every 77 years to 1 in every 94 years by the installation of the devices, due to vessels tending to navigate either side of the deployment area. The study also recommended a 500m safety zone around each device and a movement of the whole deployment zone 4km to the east to reduce impact on navigation and potential collision risk.

For the MeyGen development in the Pentland Firth (MeyGen 2015), operational risks were regarded to be very small (frequency of 1 collision per 18,400 years, and much lower frequency for shallow draught vessels) mainly due to the minimum potential draught of 8m over the operational turbines. Installation activities carry a greater risk due to vessel presence, but the imposition of a safety zone to ensure vessel safety, together with notices to mariners and other consultation is considered to reduce the risk to tolerable (see above for context).

A number of NRAs were undertaken for the EMEC test sites between 2019 (Shapinsay Sound, Billa Croo, Scapa Flow) and 2020 (Fall of Warness)[187] and considered a variety of possible tidal stream devices that could be deployed at the sites. Analysis of contact risk with the devices showed a very low likelihood of a passing or disabled vessel contacting a device (e.g. for passing vessels at Fall of Warness, between 50 and 628 years depending on the test berth in question and at Billa Croo, 857 years), with the most likely contact involving vessels associated with device installation, operation and decommissioning. Following an analysis of under keel clearance using the worst-case scenario vessel draughts of passing vessels, it was concluded that a clearance of 10m should be maintained, however, at Billa Croo some inshore devices were in water depths which could not meet that criteria and these would need to be subject to marking and risk controls.

The NRA undertaken for the Tidal Lagoon Swansea development (Anatec 2014) acknowledged a number of potential navigation and safety related effects, most of which could be reduced in scale through mitigation measures. Potential issues identified included:

- Increase of vessel to vessel collision risk and vessel to structure allision[188] risk
- Displacement and changes to transit routes of fishing vessels, recreational vessels and tugs
- Impacts on navigable water depths and effects of wave reflection
- Impact on SAR and pilot operations

[187] https://www.emec.org.uk/services/provision-of-wave-and-tidal-testing/consents/
[188] the striking of a vessel with a stationary object.

- Impacts from lighting (potential to create confusion)

The nature of these sources of effect varies depending on project phase (construction, operation, decommissioning), but in general, standard mitigation includes the provision of additional aids to navigation, extensive notification of works, use of safety zones where appropriate (including around sluices and turbine housing for the duration of operations), maintenance of access to ports, additional hydrographic survey and dredging, guard vessels in construction areas and also the movement of a pilotage area further from the lagoon walls. This is in addition to mitigation from adherence to guidance including MCA MGN 654, IALA lighting and marking recommendations and vessel compliance with the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs). In almost all instances, Anatec (2014) concluded that the effects described above could be reduced to being “minor adverse” on adoption of the above mitigation, or “moderate to minor adverse” for vessel allision.

Numerous NRAs have been undertaken for offshore wind farms which have been consented relatively recently. In English waters these include Race Bank, Dogger Bank A & B (formerly Creyke Beck A & B), Sofia and Dogger Bank C (formerly Dogger Bank Teesside A & B), Rampion, East Anglia One, East Anglia Three, Hornsea Projects One, Two, Three and Four, Galloper Wind Farm, Triton Knoll and Walney extension, all of which are available through the Planning Inspectorate website[189].

As well as the navigational risk discussed above, the physical presence of OWF, wave and tidal devices has additional potentially significant implications for other aspects of ports and shipping, such as displacement and increased journey times. A DECC report of AIS tracking data of ship navigation around OWF (DECC 2010a) presents information on the changes to vessel routes before and after the construction of the Barrow, Thanet and Greater Gabbard developments. The report showed that at the Barrow OWF, NW/SE shipping into Morecambe Bay that previously passed through the site had been displaced to the south (Figure 5.41), with the width of the navigation corridor reducing from 60% of the tracks within 1nm of the mean to 80% for the Stena Line ferries. The shipping in the vicinity of Barrow OWF is dominated by ferries which have adjusted their position to achieve a safe clearance of 0.5-2nm. A study was commissioned as part of OESEA3 (Anatec 2016) to understand the main changes to commercial shipping routes following the development of offshore wind in English and Welsh waters for a wider range of sites. The study covered the three major areas of wind farm construction and operation to date: the East Irish Sea, the Humber and Wash and the Thames Estuary. AIS tracks for vessels were considered in advance of the construction of each wind farm so that areas with multiple build out of wind farms over time could be reviewed for the individual and additive effect of OWF construction, noting that in some cases the data preceded the wider deployment of AIS. A number of changes in specific routes were identified, either directly as a result of wind farm construction (including cumulatively) or indirectly resulting from other development (see Table 5.23). Changes in the major routes were also plotted as areas containing the 90th percentile of shipping activity. Generally it was concluded that:

- For case study areas in the Irish Sea, route changes resulting from wind farm construction were consistent with the navigational risk assessment undertaken for specific developments.

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[189] https://infrastructure.planninginspectorate.gov.uk/ archived documents are available via: https://www.nationalarchives.gov.uk/webarchive/

- Where major route changes were minor or not apparent, OWFs had typically been constructed in areas outside of major shipping routes, thus avoiding major effects on commercial routes.
- Understanding of small vessel movements is improving with AIS coverage, but it is variable and far from comprehensive.

The studies of major changes in shipping routes for each area are shown in Figure 5.41 to Figure 5.46 below, together with a summary of the route changes. Three offshore wind farms have been constructed since the completion of this work; Walney extension, Race Bank and Triton Knoll. For Race Bank and Triton Knoll, construction has taken place in areas of low or lower vessel traffic separating some high density shipping routes associates with the Humber (Figure 5.44). Recent annual anonymised AIS vessel tracks have been used to provide an update to routeing since the construction of Walney extension (Figure 5.42). Route alterations have generally been minor, with the greatest addition to traffic being wind farm operation and maintenance vessels. In general, the description on major changes to shipping related to those wind farms most closely associated with higher vessel traffic areas of the UKCS remain current.

A consideration of potential cumulative effects of OWF deployment on navigation routes in the southern North Sea led to suggestions for a wider set of routes by the Southern North Sea Offshore Wind Forum (SNSOWF), these were included in the NRA document for Hornsea Project One (Anatec 2013). If these were taken to accurately reflect the changes which could result from construction of all wind farms presently consented or in-planning, then in anticipation of future wind farms being located in this and other areas such as the east Irish Sea, there is the possibility that further measures could be necessary to ensure ship safety and to maintain commercial routes. This could include future routeing measures, or alternative approaches could be adopted such as used in the Netherlands, whereby major routes are maintained as "clearways" within which development cannot take place, nor within a 2nm buffer (Dutch Ministry of Infrastructure and the Environment & Ministry of Economic Affairs 2014). The 90th percentile routes that make up the draft, unpublished MCA "OREI 1" primary navigation routes (DECC 2011) and Anatec (2013) have been considered against recent, publicly available AIS data (MMO 2014c, EMODnet human activities data[190]), to understand the recent, and potential future, implications of the current set of wind farm proposals in relevant English and Welsh waters. The output from this has been incorporated into the overall spatial consideration discussed in Section 5.15.

Strategically important shipping routes are also reflected in marine planning, initially in the East Marine Plans PS2 policy map, which represented key shipping routes as the 90th percentile of traffic in the marine plan area. This related policy indicates that developments should not be authorised if they encroach on these routes unless there are exceptional circumstances and similar policy wording and related spatial data has been used for the other marine plans covering English inshore and offshore waters. The Welsh National Marine Plan (WNMP) includes a general "safeguarding" policy (SAF_01) which applies to "main shipping routes", such that proposals need to demonstrate compatibility with the activity, or else a convincing case to progress under exceptional circumstances. With these factors in mind, and recognising that maritime traffic distribution can change, the main shipping/navigation routes presented in marine planning should be periodically reviewed, with the results made available to applicants.

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[190] https://www.emodnet-humanactivities.eu/view-data.php

It would be anticipated that this would be part of the review required under the statutory marine plan process.

Table 5.23: Summary of commercial shipping route changes

Area	Summary of route changes
East Irish Sea	The majority of routeing changes within the area are linked to RoRo or passenger vessel movements (e.g. Fleetwood to Larne, Heysham to Belfast). These may be the result of offshore wind farm development or localised operator/vessel changes. The most frequent area where changes were noted included the approaches to the river Mersey (port of Liverpool) for vessels bound to the Isle of Man, the Republic of Ireland or Northern Ireland. Other infrastructure impacted on vessel routeing decisions (i.e. South Morecambe and Calder Gas Fields) but could not be demonstrated to significantly impact the routeing in isolation. Changes were generally noted as minor route alterations or increased passing distance (0.6-0.9nm).
	The development of the Douglas Platform in 2006 and the Liverpool Bay Traffic Separation Scheme (TSS) in 2009 have formalised traffic routeing in Liverpool Bay. Although the TSS was developed for a number of traffic management issues, Gwynt y Môr OWF was in the early stages of planning pre-2009 and may therefore have contributed to its implementation, and has further dictated traffic movements given its proximity to the southern boundary of the TSS following its construction and commissioning. It was noted that smaller, more inshore OWF located in shallow waters have not impacted commercial vessel movements post their commissioning.
Humber and Wash	The Humber TSS was established in 2009 solely due to a combination of general traffic increases in the area, the deep water anchorage and proposed OWF (Humber Gateway). Vessel traffic altered into more defined routes following the implementation of the TSS. Generally, route changes within this area have been noted as increasing closest point of approach (CPA, directly associated with development of a wind farm) or minor route adjustments (cumulative), due to changes within the wider navigable area. There are Round 1 wind farms within the southern study area in close proximity to The Wash that are nearshore and therefore out with areas where commercial navigation generally occurs. However when Round 1 developments are considered in combination with Round 2 developments these have caused some isolated vessel displacement as well as increased CPAs for the main commercial vessel routes in the area.
Thames Estuary	The Thanet OWF is an example of where traffic has been significantly altered, but not significantly impacted around an offshore wind farm development. Traffic prior to the development of Thanet OWF was generally unrestricted. Post development (which includes the implementation of a north cardinal buoy to the north of the site) the traffic has become more organised into denser routes and resulted in minor re-routeing for some vessels. The north cardinal buoy[191] has also had notable positive effects by ensuring that most traffic maintains a 1nm passing distance from the development boundary. A number of commercial vessels were noted to have been displaced when assessing the pre and post AIS data. However, the actual number of vessels requiring alterations was considered to be insignificant with the majority of commercial vessels remaining within defined deeper water channels, thus avoiding the shallower water area within which London Array was constructed.

Source: Anatec (2016)

The number of vessels recorded as intersecting OWF developments increases in areas with higher traffic densities and a variety of different types of shipping (DECC 2010a). At Greater Gabbard, Burbo Bank, Scroby Sands and Kentish Flats the vessels tracked inside the OWF were all fishing vessels (see below), recreational craft, lifeboats, harbour pilot vessels or small passenger/inland waterways vessels. This interaction of cargo ships (and other vessels) with OWF developments and the displacement of vessels in all directions is partially addressed at several OWF sites with the introduction of traffic separation schemes (TSS). At Greater

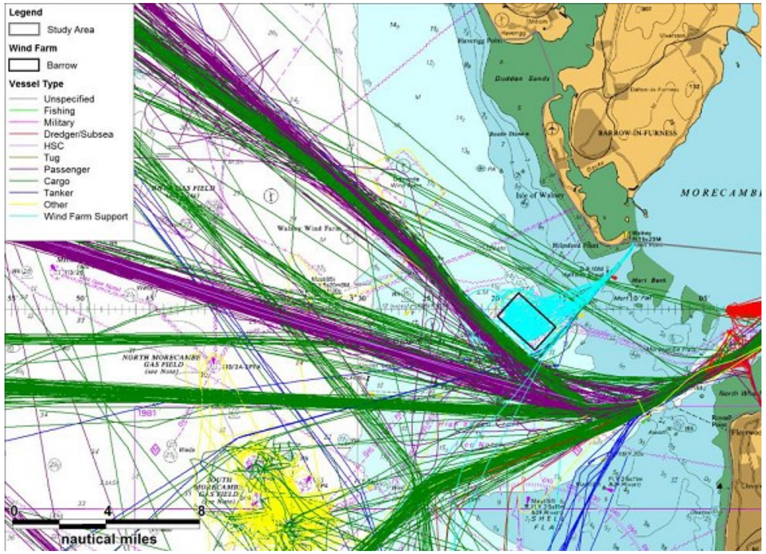
[191] Cardinal buoys are used to indicate where the deepest water is located, used in conjunction with the compass to indicate the direction from the mark where the deepest water is. The top mark of the buoy includes two cones arranged to indicate the direction of deepest water (e.g. north, south, east, west).

Gabbard (Figure 5.46) the introduction of the TSS has helped manage routeing in the vicinity of the wind farm, with the east traffic lanes located between north and south developments separating traffic by direction to minimise the risk of head-on encounters (DECC 2010a). An updated TSS scheme exists at the Humber Gateway OWF site, in part to assist port traffic management and safety and also to move traffic away from the OWF. The routeing measures on approaches to the Humber were updated in 2009. This means that the subsequent impact of the OWF on traffic will be much reduced. Similarly the introduction of a TSS scheme at the Gwynt y Môr OWF site due to a combination of routeing issues (e.g. in relation to the Douglas Field) has resulted in routeing that avoids the OWF site.

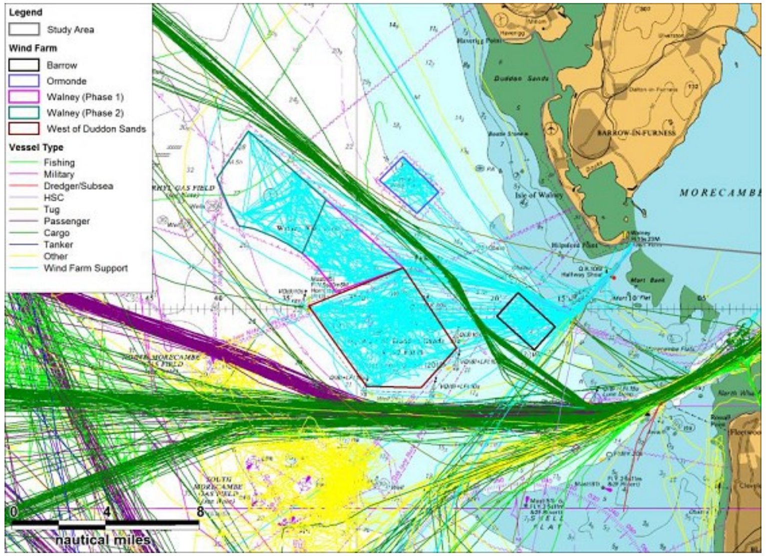
There are a number of 'pinch points', which are either constrained locations within UK waters where there are currently high densities of shipping or areas of navigational importance such as turning areas. Often these constrained locations have strong tides and heavy seas and as such may be candidate areas for tidal stream/wave development. Care needs to be taken that when siting these devices, areas of high vessel activity and limited manoeuvrability are not compromised. Similarly caution needs to be extended to siting devices in the entrance to estuaries/harbours where they may either restrict access or produce a hazard risk especially in areas prone to bad weather conditions, though risk assessment and adherence to relevant marine planning policies that specifically limit such siting should ensure that this is appropriately assessed.

Figure 5.41: Vessel AIS track and route changes following OWF construction: East Irish Sea (north)

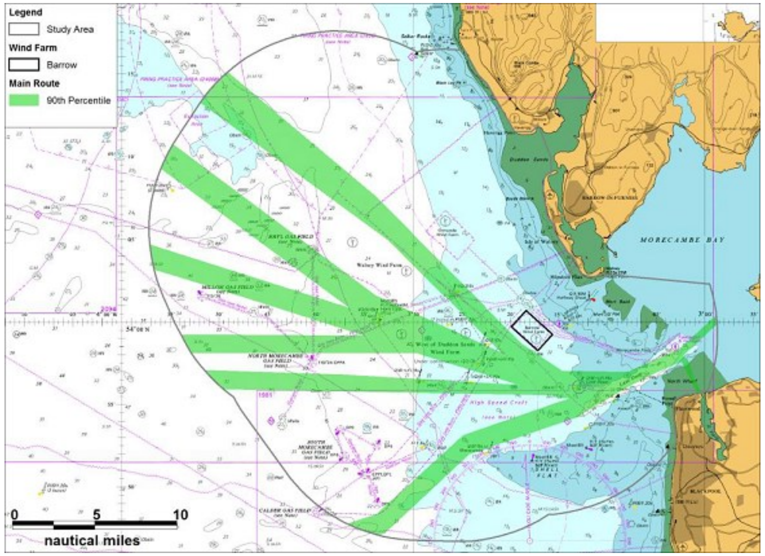
February 2010

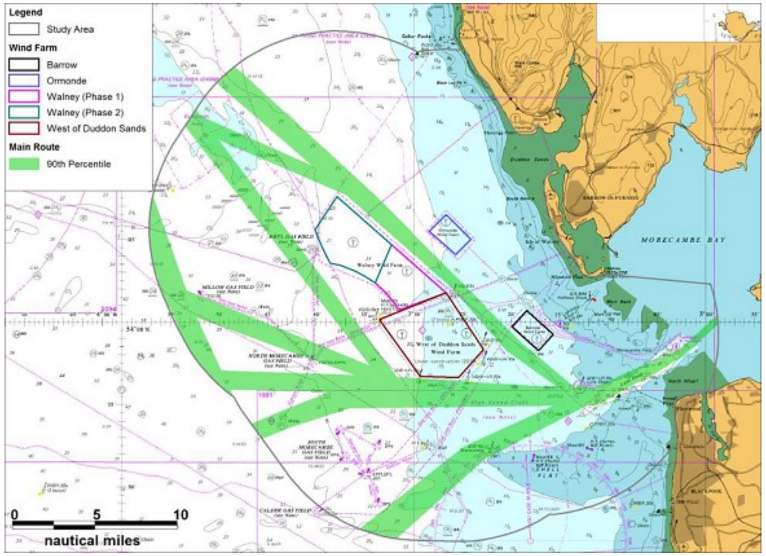


January 2015



90^th^ percentile routes





Source: Anatec (2016)

Figure 5.42: Annual vessel AIS track changes following OWF construction: East Irish Sea (north)

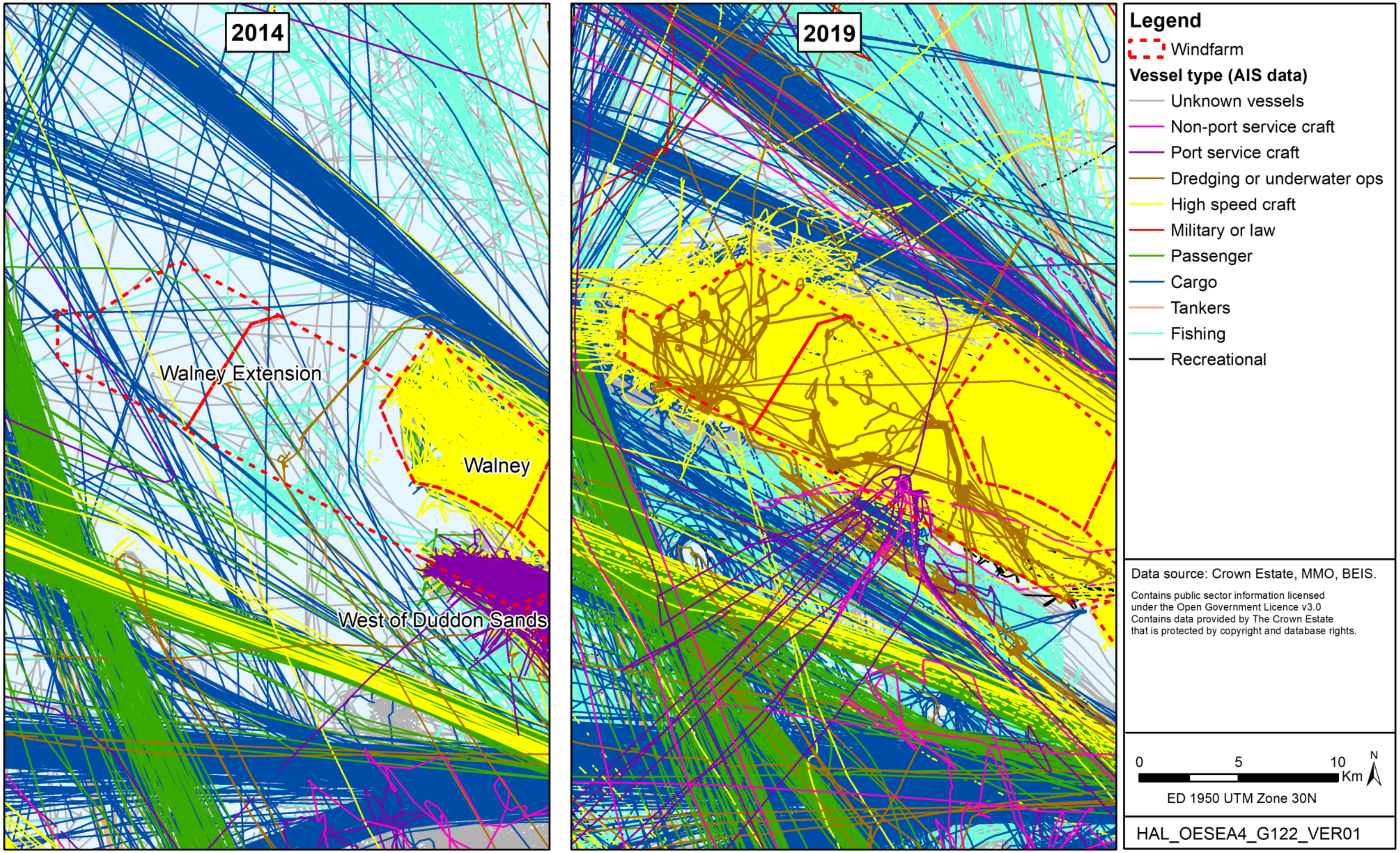
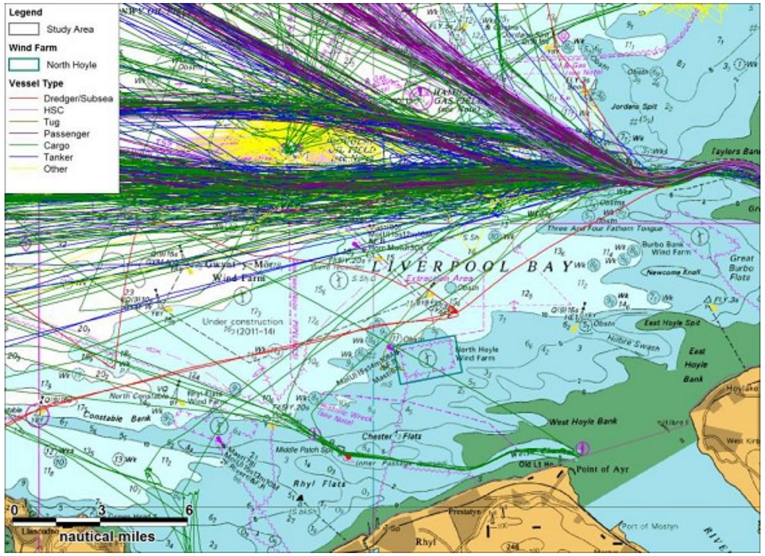
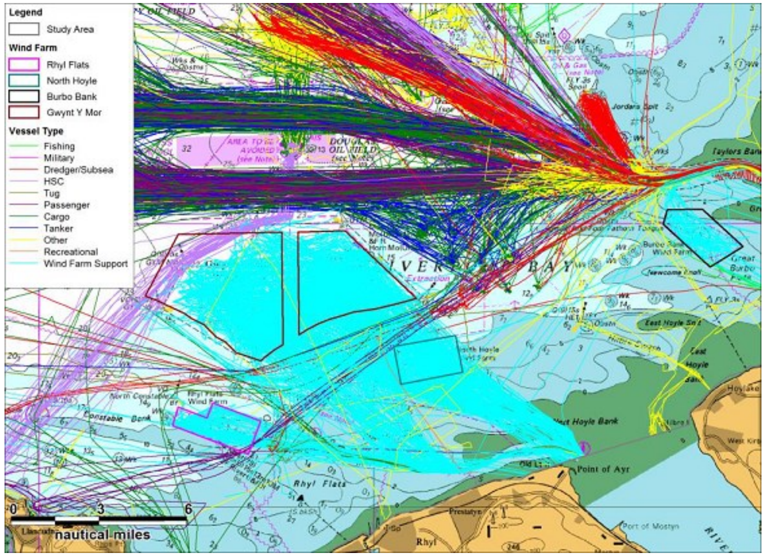


Figure 5.43: Vessel AIS track and route changes following OWF construction: East Irish Sea (south)

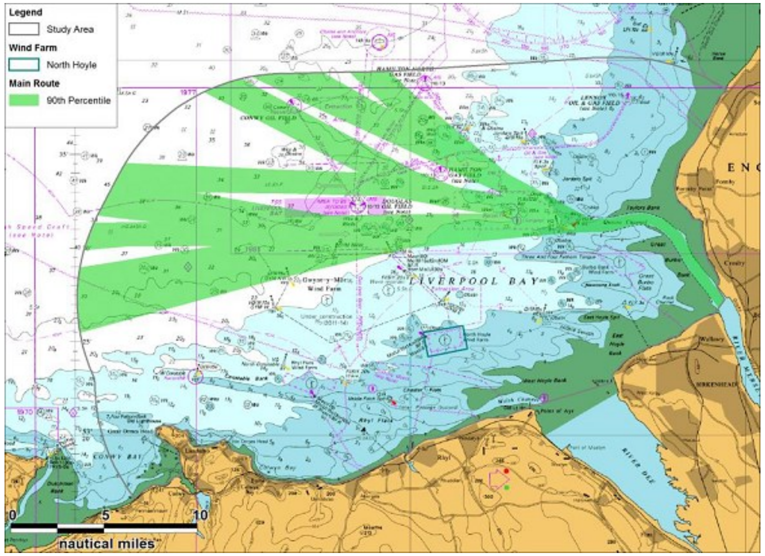
March 2006

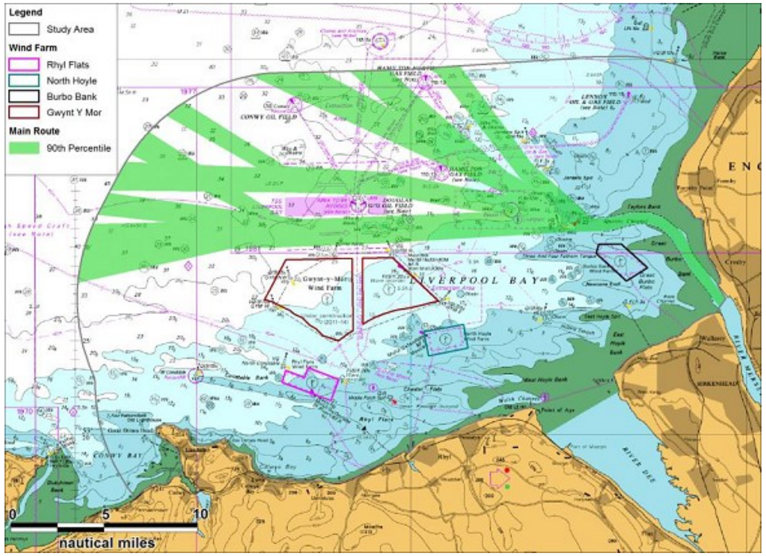


July 2015



90th percentile routes

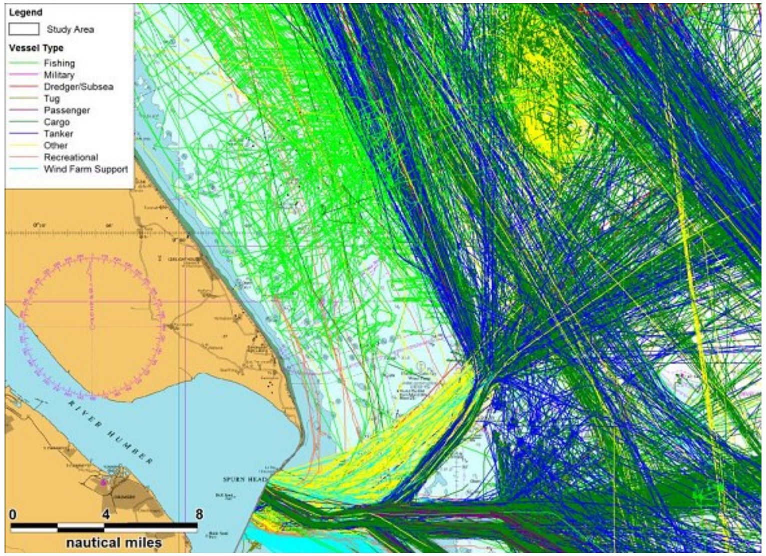




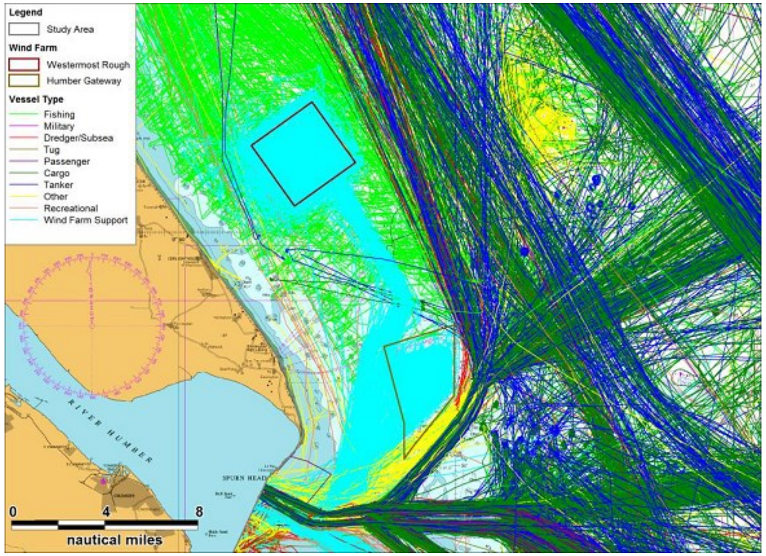
Source: Anatec (2016)

Figure 5.44: Vessel AIS track and route changes following OWF construction: Humber and Wash

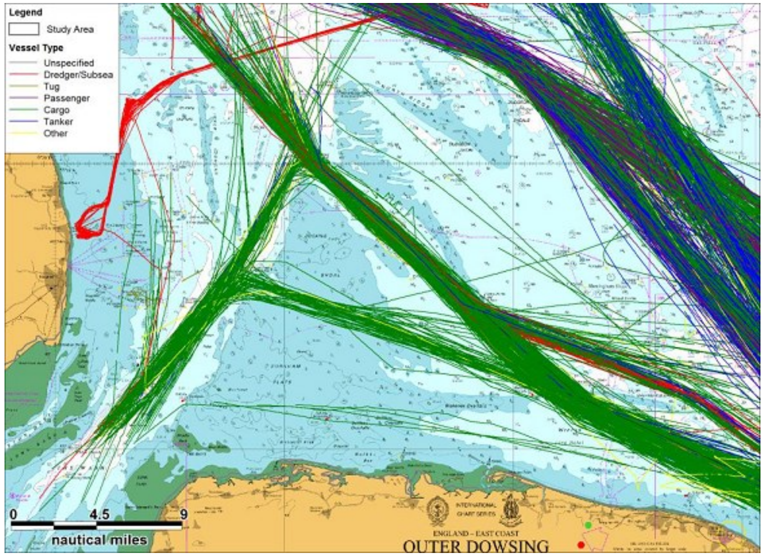
June 2013



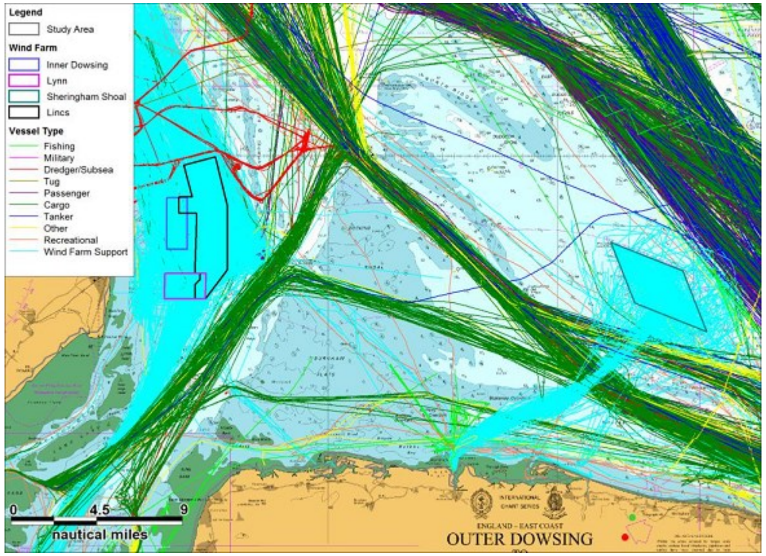
July 2015



April 2006



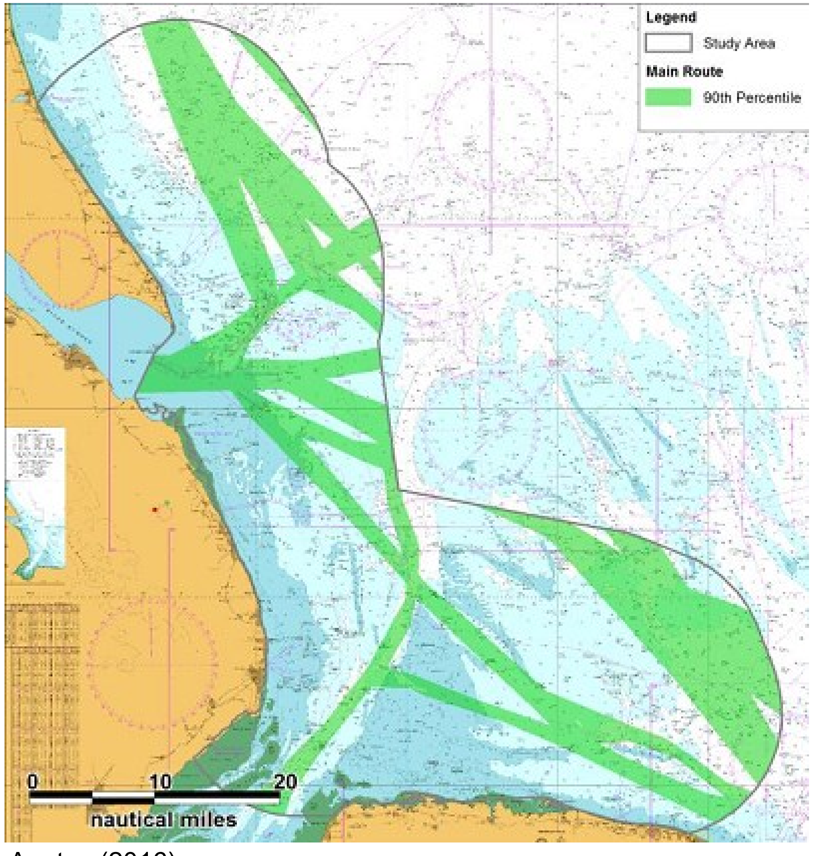
June 2013



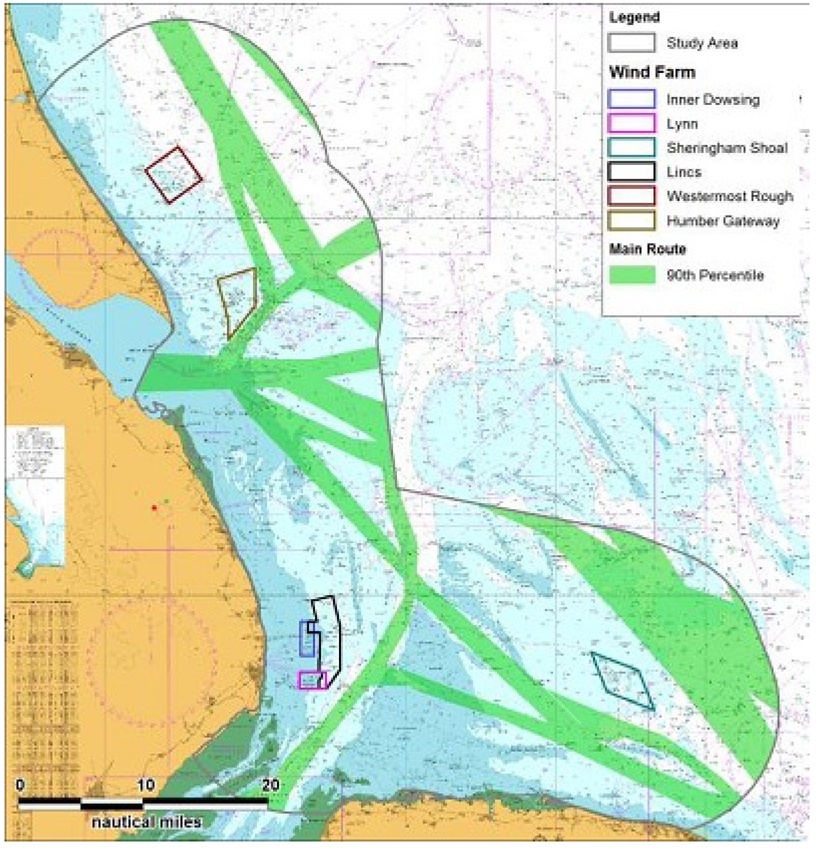
Source: Anatec (2016)

Figure 5.45: 90th percentile shipping routes: Humber and Wash

April 2006



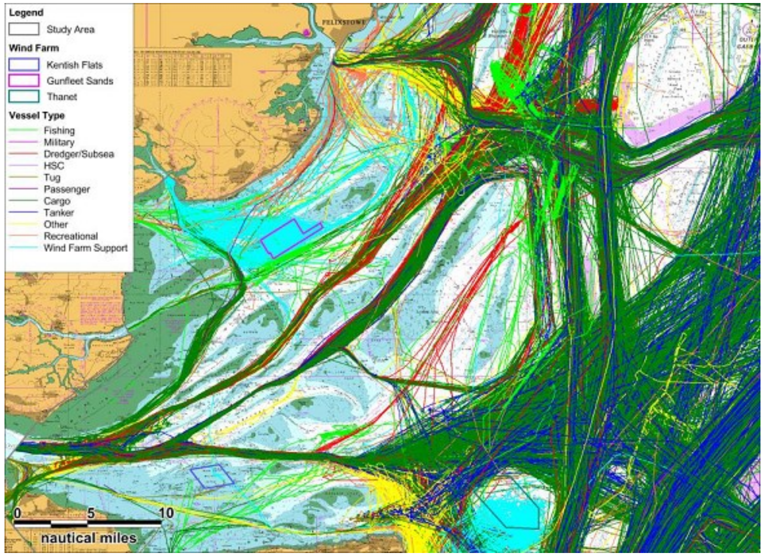
July 2015



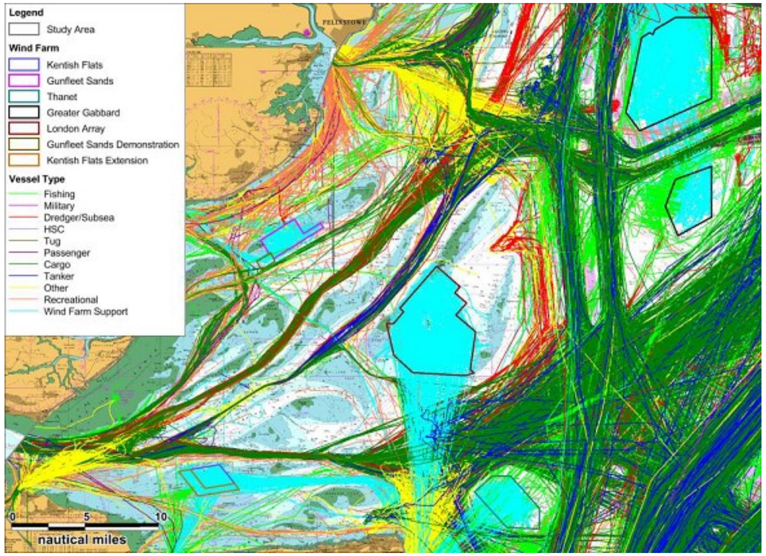
Source: Anatec (2016)

Figure 5.46: Vessel AIS track and route changes following OWF construction: Thames

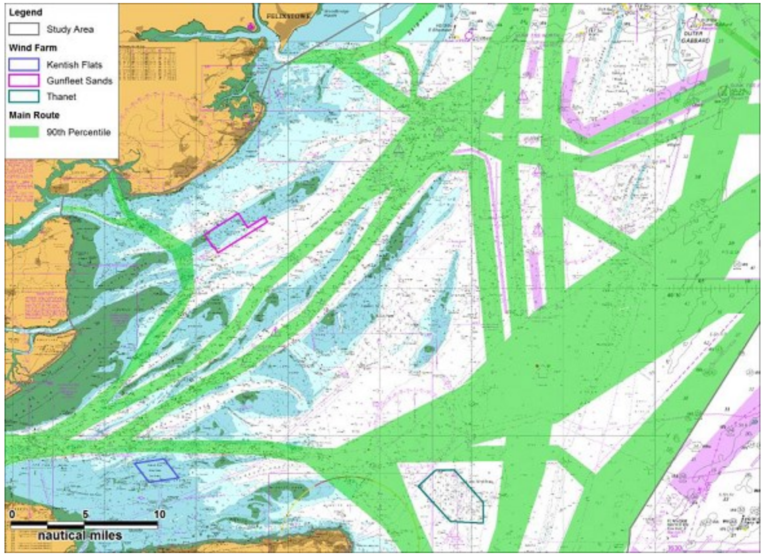
May 2009

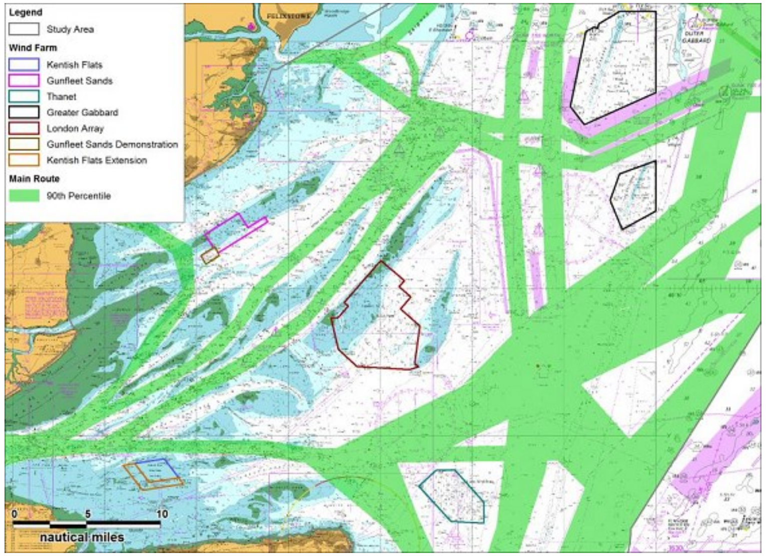


October 2015



90th percentile routes





Source: Anatec (2016)

The displacement of vessels around large arrays of devices during installation, operation and decommissioning phases, may increase journey times and distances. The location and size of the development, size of safety exclusion zone (if any) and type of journey will all determine how much disruption occurs, with increased journey distances resulting in increased fuel consumption, associated increased greenhouse gas emissions and costs to the shipping operator. There is the potential issue that an increase in the number of obstacles in the vicinity of approach routes to ports will have indirect effects on the ports themselves, through higher insurance premiums for vessels manoeuvring in these areas and therefore potential displacement of vessels to easier access and cheaper ports. A number of North Sea and Irish Sea ports experience high numbers of days where fog is an issue for navigation. The construction of OWF and other obstacles in the vicinity of port approach routes and associated constriction of vessels into set channels and routes would increase the collision risk and may deter some vessels from the ports. Long term reduced access to ports, potentially exacerbated during installation and decommissioning would affect trade opportunities. In view of the strategic importance of this sector, regional marine plans contain policies which seek to ensure that appropriate consideration and weight is given to the safeguarding of port approaches (e.g. PS1 policies in English marine plans and SAF_01a and b in the Welsh National Marine Plan).

Tidal range developments have the potential to significantly impact access to ports and therefore trade opportunities. The presence of a barrage would affect the environmental conditions of an estuary and potentially alter the water levels and sediment deposition patterns affecting the available water depth for navigation. Changes to tidal velocities and vessel size restrictions posed by lock dimensions are also likely to affect access to specific ports. The Severn barrage feasibility study (DECC 2010b) outlined potential impacts on Bristol, Cardiff, Newport and Sharpness ports of the construction of the Cardiff to Weston barrage, with for example a predicted reduction in employment of 2,100 people at Cardiff port alone and a reduction in GVA (gross value added) of £1.3bn over the 40 year evaluation period for all affected ports (DECC 2010b). Shipping channels should be maintained where they may be affected by tidal range projects.

A few primary navigation routes have been diverted as a result of offshore wind farm construction, the approach for the majority of these has been to take account of shipping traffic in their design and to avoid areas of high traffic (e.g. see Figure 5.46). Generic indications of risk tolerability given in MCA guidance and generic indications of the relative tolerability of wind farm distances from shipping lanes, recommend that offshore wind farm leases include a general prohibition on turbine location within a 1nm buffer of a primary navigation route (see Section 5.15); however, it is also understood that any such restriction would need to be compatible with relevant marine plan policies. Marine plan policies generally indicate that where proposals require static sea surface infrastructure that encroaches on "…high density navigation routes, strategically important navigation routes, or that pose a risk to the viability of passenger services, must not be authorised unless there are exceptional circumstance" (e.g. policy PS2 of the East Marine plans, and PS-3 of the others covering English waters). These types of routes are defined in the latest marine plans as those, "used by vessels of 300 gross tonnes or more" and "routes that are essential to regional, national and international trade." The routes used in the overall spatial consideration (Section 5.15) are modified from draft, unpublished MCA "OREI 1" primary navigation routes created for OESEA2 and Anatec (2013) using recently available AIS data. The original routes were based on 90th percentile of the AIS data available at the time they were made, which represents the definition of a primary navigation route within the meaning of the MCA guidance. The 1nm buffer is based on the "high" to "medium" risk threshold of the shipping route template[192]; and a larger buffer may be required where additional factors (such as traffic density and tidal set) increase the local risk. The identification of primary navigation routes is based primarily on AIS data which not all vessels carry; AIS-A is required for larger vessels (gross 300 tonnes or more on international voyages or 500 tonnes or more not on international voyages) and all passenger ships; AIS-B is targeted at the fisheries and recreation sectors.

There is no requirement for recreational vessels to carry AIS, but all fishing vessels >15m in length must carry AIS. Also see Section 5.7.2.2 and Appendix 1h for a discussion of fisheries Vessel Monitoring Systems (VMS) and Inshore Vessel Monitoring Systems (I-VMS). For small fishing vessels and most non-commercial vessels, including recreational craft, the navigational risk of offshore wind farm developments would be largely mitigated by new wind farms being largely outside of territorial waters, but it is realised that this will not be possible for some wave and tidal devices. In the case of wind farms, the bulk of current proposals are in offshore waters, and in view of the available space remaining for fixed wind farms of a commercial scale (see Section 5.15), it would seem unlikely that further leasing would result in large scale development in territorial waters.

Subject to the above considerations and recommendations, sufficient regulatory control and guidance exists at the consenting and operational stages to manage navigational safety risk effectively, and regional level marine policy relating to the importance of navigation, shipping and port activities, and identifying areas of particular interest to commercial and other navigation interests, will improve both the understanding of navigational use and also provides a consistent policy steer. Away from the primary navigation route network, there is no clear basis or requirement to spatially constrain offshore wind farm development on grounds of navigational safety. The consideration of smaller craft, primarily fishing and recreation, are starting to be covered by National and regional policy, though see below for a discussion on I-VMS data, and whether data privacy issues could curtail its use for certain marine planning functions. Potential consequences for recreational craft include displacement that could increase risk (e.g. by displacing recreational users into busier shipping lanes), and such displacement should be considered as part of any project specific assessment.

5.7.2.2 Fisheries

The distribution of fishing effort around the UKCS, described in Appendix A3h.13, is based on independent analyses of VMS and logbook data, and various published reports. Important fishing grounds to be considered when siting offshore installations are listed in Table 5.24. These areas exhibit high densities of fishing effort with high value of landings relative to all UK waters. Areas of deeper water and those of great local importance (which are more difficult to identify) are described in the text below. The information presented in Table 5.24 should be considered alongside the various maps presented in Appendix A1h, as these better illustrate the locations of the areas described.

Table 5.24: Important UK fishing grounds

Area	Primary gear type(s)
The south coast of the Moray Firth to approximately 12nm offshore, extending southeast to Peterhead (majority >60m water depth).	Primarily mobile gears, with most static effort closer to the coast.

[192] The MCA Template for assessing distances between wind farm boundaries and shipping routes (Annex 2, MCA Marine Guidance Note MGN 654 (M+F))

Area	Primary gear type(s)
Much of the Firths of Forth and Tay to approximately 12nm and particularly the areas of finer sediment off the coast of approximately Carnoustie to Montrose.	Mobile gears dominant in the Firth of Forth particularly for shellfish, primarily static gears to the north of Fife Ness.
Inshore waters off the coast of northeast England from approximately Hartlepool to Amble, extending northeast to the Farne Deeps (where water depth >60m). This area is fairly well defined by the extent of seabed sediments consisting of muddy sand.	Primarily mobile gears targeting shellfish, with most static effort closer to the coast.
To a lesser extent, inshore waters between Hartlepool and the Humber extending up to approximately 20nm offshore, although greatest effort within 12nm.	Mixed throughout the area, with mobile gears dominant north of Flamborough Head, and static gears dominating to the south.
Nearshore waters of the Wash and the Thames area.	Mixed, with mobile gears notably dominating within The Wash.
Outer Silver Pit, approximately defined by the extent of seabed sediments consisting of muddy sand.	Mobile otter trawling dominates the Outer Silver Pit, with a high density of static gear in the north.
The southeast coast of England (primarily Sussex) from approximately Dungeness to Portsmouth. Effort is greatest within 12nm, although remains high to the UK/France median line. High densities of non-UK fishing vessels operate throughout the area although decreasingly so closer to the UK coast.	Mixed; static gears dominating close to the coast and limited further offshore, with mobile gears widespread throughout the area and dominant further offshore.
Inshore waters between Portland and the Lizard, with effort generally greatest closer to shore (ca. <6nm) although very high effort extending to approximately 12nm offshore between Sidmouth and Plymouth. Effort remains high beyond 12nm, with considerable densities of non-UK fishing vessels present.	Mixed throughout the area, although static gear effort focussed close to the coast and selected sites offshore. Mobile gears (dredge, otter trawl) prevalent offshore between Start Bay and off the South West Peninsula.
The Bristol Channel and north coast of Cornwall.	Mobile gears offshore, with most static gear effort inshore.
Between the west coast of the Isle of Man[193] and the Northern Ireland coast, extending north to approximately Ballywalter and south into Republic of Ireland waters (considerable proportion >60m water depth).	Primarily mobile gears used with *Nephrops* targeted in the western Irish Sea mudbelt, greatest static effort close to the Northern Ireland coast.
Waters off the east Cumbrian coast extending south and west from approximately to Whitehaven to 12nm offshore.	Primarily mobile, targeting shellfish.
Inshore waters around the Isle of Arran, with high effort extending throughout much of the area between Kintyre and the Ayrshire coast (where water depth generally >60m).	Primarily mobile, targeting shellfish.
The Minch, particularly inshore waters between mainland Scotland and the Isle of Skye, between Gairloch and Ullapool, and off the northeast coast of Lewis (considerable proportion >60m water depth).	Mixed throughout the area, although static gears dominating around Skye and around the north coast of Lewis.

[193] The territorial waters of the Isle of Man support important fisheries particularly for shellfish. The waters to the east, south and west of the island are some of the most heavily fished in the region.

Area	Primary gear type(s)
Nearshore waters of Orkney and Shetland, particularly to the northeast of the islands (where majority water depth >60m).	Static gear dominant around Orkney, mixed around Shetland.

Outside of the areas of high effort and value from a UK context, many less intensively fished areas are of great local significance. Such areas are particularly sensitive to spatial conflicts; they are typically fished by small vessels operating within a limited range from port, and may serve communities with livelihoods dependent upon those fishing grounds. At a strategic level, it is not feasible to identify all such grounds; small, inshore vessels operate at almost every port throughout the UK and those in remote and rural areas are likely to be most sensitive. At region- and site-specific levels, early consultation with relevant Inshore Fisheries Conservation Authorities (IFCAs) (England and Wales), or Inshore Fisheries Groups (IFGs) (Scotland) and fishermen, will facilitate the identification of these locally important areas. In addition to those areas cited in Table 5.24, there are many areas in UK waters exceeding 60m water depth which are of very high fishing effort of considerable value. These include the Fladen Ground, approximately defined by the extent of seabed sediments consisting of muddy sand. Additionally, moderate-high levels of effort are present throughout much of the deeper waters of the northern North Sea and waters north of Scotland; these include numerous discrete areas of particularly high effort, notably along the continental shelf margin, where both mobile and static gears are heavily used. Extending from approximately 25km southwest of Pembrokeshire, the Celtic Deep is an area of very high fishing effort, approximately defined by the extent of seabed sediments consisting of muddy sand and sandy mud; the area also experiences considerable effort from non-UK vessels. The distribution of non-UK vessels is mainly in offshore waters, apart from in southern areas, where many foreign fleets (in particular French, Belgian, German and Dutch) hold historical rights to fish within 6-12nm of the shore[194].

During discussions with representatives of the fishing industry and fisheries management organisations, it was noted that extensive inshore fisheries take place throughout most UK waters to approximately 25nm offshore, and that through the activities of IFCAs the 0-6nm zone is generally quite well understood. The 6-12nm zone is however, an area of typically high fishing effort but less well understood and many foreign vessels operate in this area. Inshore vessels are quite restricted in areas which they fish by distance from home port, availability of sheltered waters and substrate type. Displacement from favoured grounds may have important economic implications resulting from increased steaming times (and fuel use) potentially required to reach alternative sites. Renewable installations, such as wave and tidal developments tend to be constructed in shallower, inshore waters, and therefore are more likely to be focal points for physical interactions with the fishing industry. Early OWFs have been sited in nearshore waters, but in recent years the nature and scale of such developments, and available space in suitable areas (e.g. of certain water depth, favourable shallow geology), is such that they are progressively being sited further offshore. This is consistent with experience in other European waters. The main risk posed to fishing vessels by wave and tidal devices is likely to be of collision, although snagging of gear on seabed-mounted devices is a potential risk which can be minimised by accurate marking of their locations on marine charts. Tidal barrages and lagoons may have significant barrier or habitat effects on inshore fish, particularly migratory, diadromous fish and juvenile or spawning fish that are found in bays and estuaries inshore. Impacts on fish species will have a direct effect on the fishing industry and the ecological effects are discussed further in Section 5.6.

[194] https://www.gov.uk/government/news/uk-government-announces-outcome-of-eu-fishing-licence-applications

However, development in inshore areas may restrict access for local, small-scale fisheries, including recreational sea angling, which will have regional economic and social impacts.

Potential spatial impacts of construction, operation and decommissioning of offshore renewables on fishing include, for example, the displacement from fishing grounds during the construction and decommissioning phases with the implementation of temporary safety zones of 500m and potentially permanent safety zones of 50m around the array area during operation. As well as excluding fishing from the development area there may also be added pressure of other vessel traffic being diverted and impacting on fishing operations (Halcrow 2006). It is also noted that new subsea cables may make areas less attractive for mobile fishing methods (i.e. beam trawls, bottom otter trawls), displacing vessels operating such gear.

These predicted effects have been reflected in a Crown Estate report examining changes to fishing activity following the construction of six OWFs in the eastern Irish Sea (Robin Rigg, Walney 1 & 2, Ormonde, Barrow and Burbo Bank), as reported by locally active fishermen (Gray *et al*. 2016). Vessel Monitoring System (VMS) data revealed significant reductions had occurred at sites since 2007, although this was associated with a decline in Irish Sea Total Allowable Catches (TACs) and a comparable decline in the wider region. However, fishermen consulted as part of the report all claimed to have reduced effort or stopped fishing altogether within the OWFs during the construction period, with only a small number returning post-construction. The majority of these fishermen claimed the OWFs had a greater impact on their fishing opportunities than quota management. Reasons given for a lack of confidence in fishing within turbine arrays included the risk of snagging cables or support structures and losing equipment, and the danger of engine failure while surrounded by turbines. Nevertheless, fishing activity was reported within OWFs, with some fishermen claiming to operate demersal trawls in cable-free corridors between turbines. Observations of fishing activity within the Barrow offshore wind farm, as described during stakeholder discussion, reveal trawling to be considered hazardous although potting activities are carried out safely.

Recent representations made by NFFO in relation to offshore wind farm applications in the southern North Sea note that project design parameters such as turbine spacing and cable routeing can significantly affect the potential for fisheries, and in particular mobile gears, to continue to fish inside offshore wind farm array areas[195]. A criticism raised has been that the worst case scenario approach under the Rochdale Envelope is such that it does not promote the cable design that minimises the potential for effect on fisheries. To be consistent with marine plan policies on co-existence (e.g. East Marine plan policy GOV2 and CO-1 policies of other marine plans covering English waters, SAF_01b of the WNMP) proposals should have to demonstrate they will avoid, mitigate or minimise effects that result in displacement of other activities, or else state the case for why a project should proceed despite displacement. Additionally, specific policies on fisheries displacement are included in the English (East Marine Plan policy FISH1 and FISH-2 of the other plans) and Welsh (FIS_01) marine plans. The proposed revisions to the National Policy Statement for Renewable Energy Infrastructure (EN-3) expands on the marine plan policy, specifically for offshore wind, noting that, "…The Secretary of State should be satisfied that the applicant has sought to design the proposal having consulted the MMO, Defra and representatives of the fishing industry with the intention of minimising the loss of fishing opportunity taking into account effects on other marine interests." Both of these policies need to be reconciled with the perceived or actual limitations on fishing from offshore wind farm construction and how the above policies promoting co-

[195] e.g. see the Statements of Common Ground between the NFFO and Hornsea Project Three, and Norfolk Vanguard.

location (see Schupp *et al.* 2021 for a OWF and fisheries stakeholder perspective), engagement and good design can be reconciled with other guidance. Marine Plan policies indicate all submarine cables should be buried to prevent interactions with other users, but despite this, such policy does not accord with the UK Hydrographic Office Mariners Handbook[196], guidance which advises vessels not to anchor or fish (trawl) within 0.25nm of a subsea cable. It can be envisaged how the above sets of policies could work together as wind farms deploy larger capacity turbines with correspondingly larger turbine spacing[197] that would allow fishing inside wind turbine arrays if coexistence optimised cable routeing is adopted. However, if the Mariners Handbook is strictly followed, bottom towed fishing practices are essentially precluded from many existing wind farms both due to cable arrangement and turbine spacing.

Floating offshore wind farms have varied foundation designs, some of which use catenary moorings that have the potential to extend some distance from the base of the foundation (e.g. the moorings of the Hywind project in Scotland were assessed on the basis of being 600-1,200m in length). Unlike fixed offshore structures, there is the potential that mooring lines compound the displacement of fisheries which could result from cabling, such that there is the potential to effectively exclude mobile fisheries in such arrays. To date such wind farms are only small-scale arrays but those assessed (e.g. Hywind, Kincardine, Erebus) have assumed that fishing is effectively precluded from the arrays through project life. Following an initial two day trial, Marine Scotland and Equinor are due to undertake trials using creels, fishtraps and jigging lines within the Hywind wind farm in the first half of 2022 in order to inform whether these fishing practices could take place safely within such projects. Effects from these projects have not been considered significant due to the comparatively small area occupied relative to wider fishing grounds, but based on the ScotWind round awards, the scale of floating wind farms in coming leasing rounds is likely to be comparable to that of fixed wind farms presently being installed, or certainly around 300MW in the first instance[198]. Such larger areas of potential impact for fisheries will require appropriate levels of mitigation through careful site selection and other measures to reduce the impacts on fishing interests.

Blyth-Skyrme (2010a) provides a summary of mitigation measures that might be considered for offshore wind which can be broadly divided into four categories which are described below. Note these are broadly applicable to fixed offshore wind farms, but are also largely relevant to floating wind farms other than where there is incompatibility with the continued operation of certain gear types.

Pre-construction options to limit impacts on commercial fishing

Pre-construction options may consider the siting or design of offshore developments to avoid, or reduce impact on, particular fishing grounds. The identification of important areas at an early stage, similar to the "core fishing grounds approach" as proposed by the MMO (MMO 2014d), and pre-emptive analysis of local fishing activity will allow and encourage early consultation and decision-making.

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196 https://www.gov.uk/government/publications/mgn-661-mf-navigation-safe-and-responsible-anchoring-and-fishing-practices/mgn-661-mf-navigation-safe-and-responsible-anchoring-and-fishing-practices
197 e.g. at a typical 7-8 multiple of rotor diameter spacing would be equal to ~1.5-1.7km for the 14MW Haliade-X turbine model assuming a rotor diameter of 220m.
198 https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/the-crown-estate-to-create-new-floating-wind-leasing-opportunity-in-the-celtic-sea/

Co-location of Marine Conservation Zones (MCZs) and OWFs would exclude certain types of activity, including fishing, from a single combined area rather than from two separate, potentially larger ones (see: Ashley *et al.* 2014, 2018). Blyth-Skyrme (2010b) identifies positive effects including minimizing social and economic impacts, supporting engagement efforts of developers with the industry and potentially supporting MCZ conservation objectives (with possible knock-on benefits for fishermen). The disadvantages are the limiting of grounds within OWFs that might otherwise be targeted, as well as the concern that fishermen could miss out on compensation for losing these opportunities. Clarity would also be needed over the responsibilities of developers to both co-location with MCZs and additional compensation related costs to the fishing industry. The availability of suitable sites may also be limited. Broadly, collaborative planning between developers and other stakeholders, including the fishing industry will allow pre-emptive mitigation of sources of potential concern.

Other design and procedural measures that could be taken to facilitate co-existence between industries included:

- Provision of seabed maps showing accurate and precise locations of hazards
- Identification of cable-free corridors within arrays that may be suitable for trawling
- The use of concrete mattresses to protect cables rather than rock dumping
- Clearing debris left on the seabed following construction operations

Supporting the existing fishery activity

Support for existing fisheries might include providing financial assistance to allow fishermen to operate within OWFs. This might include assistance to purchase new or modified gear, support for maintenance costs, provision of safety equipment or support for insurance for fishing within windfarms. Establishing fuel subsidy schemes for fishermen affected by displacement and promoting local fisheries and regulating access to fishing within developments are other ways in which the industry might be supported.

Enhancing stocks of targeted species and associated habitats

Promoting or enhancing stocks of commercial fish species, through direct seeding of wild or hatchery seed, or the release of large, broodstock animals (primarily shellfish), has been considered, although this may also happen naturally. The potential effects of offshore structures on fish assemblages have been the subject of numerous studies. It is generally expected that the exclusion of fishing (or at least intensive trawling) effort would be likely to have a local beneficial effect on fish stocks, and also on reducing seabed disturbance and associated ecological effects. However, exclusion in some areas is likely to result in negative effects on other fishing grounds through displacement of effort. A “reef effect” has been noted for oil platforms (Løkkeborg *et al*. 2002, Soldal *et al*. 2002, Coolen *et al.* 2020) and offshore wind farms (Linley *et al.* 2008, Reubens *et al*. 2014, Stenberg *et al*. 2015, Degraer *et al.* 2020). It is not fully understood to what extent reef effects might increase commercial fish stocks outside the vicinity of offshore structures. Reubens *et al*. (2014) noted that, while juvenile cod and whiting were attracted to turbines and OWFs, there was no evidence that this translates into a regional-scale increase in recruitment.

Developing new fisheries or non-fishing opportunities

Finally, options to develop new fisheries or other activities, would encourage and support the efforts of fishermen to adapt to new opportunities, perhaps by providing maintenance support (such as acting as safety patrol vessels at developments), or industrial (surveying, commercial diving) or recreational (angling, diving) support. Commercially valuable crustaceans such as edible crab and European lobster have been associated with the artificial reefs provided by man-made structures such as shipwrecks (Hiscock *et al*. 2010, Krone & Schröder 2011), oil and gas platforms (Southgate & Myers 1985, Pradella *et al*. 2014) and OWFs (Emu Ltd 2008, Leonhard & Pedersen 2006, Tonk & Rozemeijer 2019). As such, the opportunities for new targeted fisheries for these species may exist around and within OWFs, particularly if artificial reef effects can be enhanced through design and selection of materials (Hooper & Austen 2014). Syvret *et al*. (2013) describe the potential for shellfish cultivation, particularly of blue mussel, to co-locate with OWFs in Welsh waters. The potential for long-line or net bivalve or algal aquaculture within OWFs is also discussed by Blyth-Skyrme (2010a).

While the 25 Year Environment Plan and the *Environment Act 2021* do not apply the principles of environmental net gain to the marine environment, noting that there is legal provision in the Act to extend it to the marine environment through Regulation (see Appendix 2), some of the items noted above have the potential to provide both environmental benefits and the provision of services, though without site-specific assessment, it cannot be assumed that these would result in net gain, but may have the potential to result in adaptation by fisheries that would allow continued commercial exploitation, albeit with some diversification. This is consistent with marine plan policies including FISH-1 and FISH-2 of the English marine plans and FIS_01 of the Welsh National Marine Plan.

5.7.2.3 Military activity

Potential disruption to military activities may occur during the installation, decommissioning and operation of a renewable energy site. Current military practice and exercise areas (PEXAs) are mapped in Figure A1h.6 and are considered further in Section 5.15. Those areas which are considered to represent a significant constraint to offshore energy (and potentially other activities) are listed as danger areas (i.e. where live firing takes place); these may be used by the army, navy or air force. The latest UK Aeronautical Information Package (AIP)[199] indicates the vertical limits and types of activities which take place within specified air force danger areas. The majority involve supersonic flight and air combat training at altitude (e.g. 5,000ft-66,000ft), thus plan-related activities would not interact with such danger areas due to vertical separation. Some activities in a number of danger areas (in English and Welsh waters, danger areas D513/513B/513C, Druridge Bay; D412, Saxton; D207, Holbeach and D307, Donna Nook) involve live firing or bombing within a vertical range which meets the surface and so may present some exclusion. Other danger areas may also present potential development constraint to draft plan/programme activities and in some circumstances, activities may not be able to take place within such zones. Early consultation with the Ministry of Defence (MoD) may result in an acceptable solution to siting.

A number of other PEXAs are located along the coast and offshore where, with dialogue with the MoD, development may acceptably take place. For offshore oil and gas, CCS and gas storage subject to licensing under the *Petroleum Act 1998* or *Energy Act 2008*, licence conditions may be imposed which include informing the MoD of the timing and type of operations proposed, often significantly in advance of any work taking place (e.g. 12 months, see OGA 2019). In particular, OGA have informed prospective applicants in successive licensing rounds of which UKCS blocks may be subject to restrictions due to military interests. More recently, the MPS has amplified the above text, indicating that, "*Marine activities should not prejudice the interest of defence and national security and the MoD should be consulted*

[199] https://nats-uk.ead-it.com/cms-nats/opencms/en/Publications/AIP/

accordingly", and that*, "Marine plan authorities, decision makers and developers should consult the MoD in all circumstances to verify whether defence interests will be affected."*[200] The regional and national marine plans of devolved administrations further indicate that developments would not be authorised unless agreed with the MoD for activities to be undertaken (e.g. DEF-1 policies of the English Marine Plans) The Scottish National Marine Plan (for the purposes of this SEA is largely only relevant to oil and gas, CCS and gas storage), further emphasises that developments which interfere with radar (see below) and other national defence systems may be prohibited without mitigation (policy DEF 1).

OWFs have the potential to interfere with defence radar which facilitate the UK Air Surveillance and Control Systems (ASACS). Previously MoD policy did not allow any wind farm development take place within 74km of ASACS radar if it would be in the direct field of view. However, in June 2011 an agreement between the MoD and wind developers led to the procurement of a TPS77 radar that provided mitigation from the effects of wind farms located at Remote Radar Head (RRH) Trimingham. Subsequent concerns raised by the MoD and conclusions on the assessments made supporting recent offshore wind consent applications are noted, and additional mitigation for wind farms is still required. The Windfarm Mitigation for UK Air Defence programme[201], funded by BEIS and delivered by the MoD Defence and Security Accelerator, is presently in its second phase. Phase 1 of the programme awarded multiple contracts and identified various routes for wind farm mitigation, which included both radar signal processing and use of materials to control the radar signal of wind turbines, with a recommendation for a hybrid approach between these. Phase 2 of the programme seeks to understand the potential of such technologies further and has awarded contracts to develop some of the mitigation solutions from Phase 1. The solutions are applicable to both air defence radar and that used in air traffic control.

Marine planning has clarified the UK's position in relation to safeguarding military interests and this has been amplified through regional marine plans. Concerns remain regarding the potential effect of offshore energy on defence interests from all aspects of the plan, but well-established methods are in place to provide for mitigation. These include the identification of practice and exercise areas on charts, dialogue with the MoD and developers, including the MoD being a statutory consultee on planning applications and collaborative efforts such as on radar effects, and early identification by the licensing authority of where there are MoD interests and potential constraints.

5.7.2.4 Aviation

The potential impacts of wind farms (onshore and offshore) on aviation have been documented by the DTI (2002), CAA (2013), DECC (2015), RenewableUK (2019). Offshore energy installations may affect aviation activity principally in two ways; through interference with primary surveillance radar (PSR) used in air traffic control and military air defence radar, and/or through creating an en route obstacle. OWFs are the most likely aspect of the draft plan to be the source of such potential effects as they can cause unwanted returns on surveillance radar at some distance from radar locations and/or shadow objects; they can be relatively large

[200] MPS Section 3.2.
[201] https://www.gov.uk/government/publications/air-defence-and-offshore-wind-working-together-towards-net-zero/air-defence-and-offshore-wind-working-together-towards-net-zero, https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2021-government-and-industry-led-taskforce-unlocks-new-opportunities-for-offshore-wind/

obstacles in terms of height (e.g. the latest GE Haliade-X 14MW turbine has a blade tip height of 248m) and are also likely to occur in relatively high numbers.

The Aviation Investment Fund Company Limited (AIFMCL) was set up under the plan, led by RenewableUK, to bring together wind energy developers to develop mitigation for radar issues. Despite a number of mitigation measures developed for military radar (e.g. TPS77 radar standard, see above[202]) and PSR (Project RM), there is presently no single technical solution to radar issues, and the work noted above taking place under the Air Defence and Offshore Wind Windfarm Mitigation Taskforce seeks to identify, test and improve mitigation techniques.

Wind farms have the potential to cause physical obstruction to low flying aircraft, and guidelines relating to aviation issues and wind farms are detailed in CAA policy document CAP764. Other than for military purposes, as discussed above, low flying aircraft could include helicopter traffic to/from offshore oil and gas installations and in their final approaches. Helicopters typically travel at an altitude above wind turbines, for example in the southern North Sea outwards flights tend to be in the altitude range 2,000-3,000ft and inbound flights in the range 1,500-2500ft to ensure safe vertical separation between helicopter traffic, but traffic must also keep a safe distance (at least 500ft) from any structure, including wind turbines. Maintaining this distance may be problematic where the icing level (0˚ isotherm) and low cloud is at an altitude which prevents aircraft travelling at heights which maintain a safe vertical separation from a wind farm. A number of Helicopter Main Route Indicators (HMRIs) have been defined over UK waters, largely relating to the oil and gas service sector and are detailed in the latest UK AIP[203] (see Figure 5.47 – note the mapped area relates only to English and Welsh waters which are within remit of the draft plan/programme for renewable energy). HMRIs are therefore concentrated over areas within the major hydrocarbon basins of the UK, namely the southern, central and northern North Sea, and in the East Irish Sea (Morecambe Bay). With the exception of much of the northern North Sea, water depths in these areas are relatively shallow and are prospective for offshore wind energy; this means that helicopter traffic is already a consideration of wind farm applications and assessment. Whilst the HMRIs do not have any statutory basis, the CAA has indicated that there should be a 2nm obstacle free buffer (i.e. 4nm corridor) for these routes, which could be increased if there was the potential for a reduced air traffic service.

Consultation zones with a radius of 9nm are established around offshore installations. These are not development exclusion zones but a space around each installation within which consultation with helicopter and installation operators should take place. This area allows for space within which low visibility approaches and missed approaches can be safely made, and encompasses 360˚ around an installation. Approach procedures typically commence at 8nm distance, with final approach starting at 5-6nm distance and a minimum flight height of 200-300ft is reached within 2nm of the helideck; any obstacle within 9nm of a helideck may therefore affect operations, particularly where low visibility flight operations are routine.

Consultation with helicopter and installation operators provides the opportunity to mitigate potential effects of wind farm obstructions should they fall within part of those areas (HMRs,

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[202] Installed through agreements reached between the MoD and wind developers, the TPS-77 allows for the creation of a three dimensional Non Automatic Initiation Zone (NAIZ) to prevents false returns and allow continued tracking of aircraft over the NAIZ. The Aviation Plan (DECC 2015) indicated that trials were ongoing to optimise the performance of these radars against specific wind farms. The latest updates may be found in the minutes of the Aviation Management Board: https://www.gov.uk/government/groups/aviation-management-board-aviation-advisory-panel-and-fund-management-board

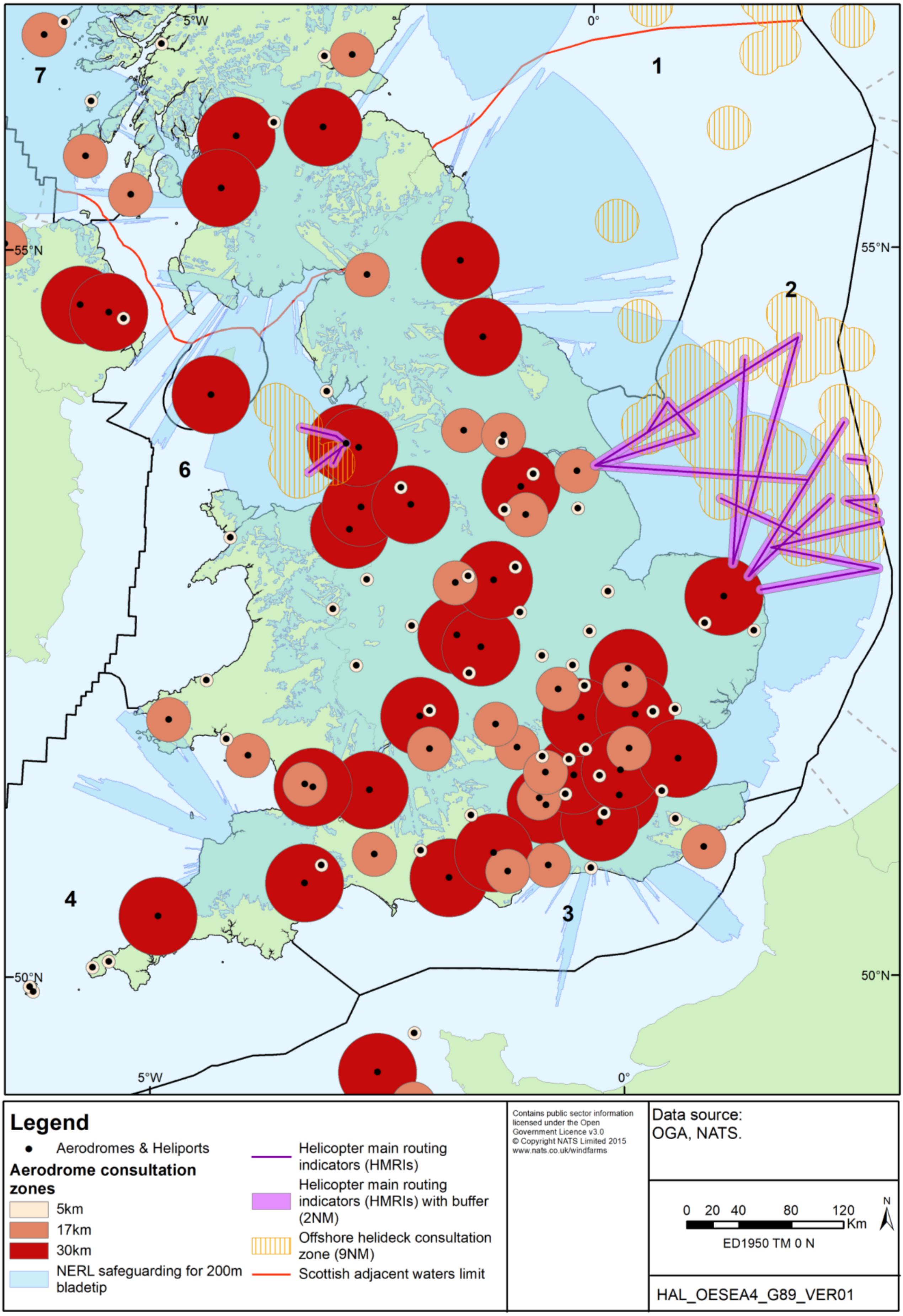
[203] https://nats-uk.ead-it.com/cms-nats/opencms/en/Publications/AIP/

consultation zones) described above. For example, consultation during the Hornsea Zone 1 and 2 planning process allowed for acceptance that a deviated route around the wind farm would be taken during periods where helicopters could not overfly the area due to meteorological conditions (see Smart Wind 2013), and that taking place with oil and gas operators as part of the Hornsea Three consenting process resulted in a 2.8nm exclusion zone for turbines around the Chiswick platform to enable a greater degree of flexibility for take off and approach (Ørsted 2019).

In order to identify wind turbines as potential obstructions to aviation interests (particularly low flying), guidance on markings and lightings is provided in a range of policy and guidance documents (e.g. CAA CAP764, and MGN543 in relation to Search and Rescue (SAR) operations), and also in legislation (e.g. the *Air Navigation Order 2016* (as amended), also refer to CAA document, CAP393). There is a statutory requirement for lighting of any wind turbine located in territorial waters and greater than 60m in height above highest astronomical tides (HAT). The CAA may specify additional lighting, and the Regulations recommend at least one medium intensity light visible in all directions, with only peripheral turbines having the requirement in larger farms. Analogous to shipping navigation interests (above), OWFs are typically charted in the UK AIP, this allows for the issuing of Notices to Airmen (NOTAM) in the event that turbine lighting has failed. The MoD (2020) guidance on OWF lighting includes both visible and infra-red lighting. The guidance also includes a lighting standard developed through a multi-lateral air-sea trial to satisfy both navigational and aviation requirements, which exceeds that of other CAA, MCA and Trinity House requirements. Each wind farm also has its own Emergency Response Co-operation Plan (ERCoP) in relation to helicopter based SAR, which details project specific requirements including lighting and markings of wind turbines, operations within the wind farm and rescue facilities.

The potential for interference with aviation operations remains a concern as the number and size of turbines in UK waters continues to rise. However, work is ongoing to ensure that effects of wind turbines on aviation interests can be successfully mitigated and experience has indicated that, to date, large wind farms can be compatible with aviation interests. Future offshore wind farms using fixed foundations are likely to continue using the shallow southern North Sea and East Irish Sea areas, with the possibility of existing wind farms also being extended, however, available space for wind turbines in these fixed wind resource areas beyond existing proposals is likely to be extremely limited (see Section 5.15). Conversely, the deployment of turbines at greater distance from the shore through the expansion of floating offshore wind has the potential to avoid a range of other user interests, including of aviation – see Section 5.15 for a discussion.

Figure 5.47: Areas identified by the CAA within which there may be potential constraints for wind deployment



5.7.2.5 Dredging and aggregates

Dredging and aggregate extraction have the potential to be affected by the construction of offshore energy infrastructure through exclusion from prospective areas. The depths at which certain technologies covered by the draft plan/programme are likely to be deployed in the near to medium term are technically and economically limited (see Section 5.15), and for wind farms in particular, siting has concentrated on shallow areas and sand banks which are also favoured for aggregates extraction (particularly in Regional Sea 2). The potential area of suitable aggregate resource is large (e.g. see Appendix 1b and 1h), but licensed areas or those defined as exploration or option areas are more geographically restricted (see Figure A1h.21), and the actual area of seabed dredged is small[204]. Both the licensed area and area dredged has declined significantly in the last 15 years (see Appendix 1h).

Aggregate supply, which is concentrated in the south and south east, with smaller areas in the Irish Sea and Bristol Channel/Severn, is strategically important to the UK, and a level of safeguarding of these resources to provide a consistent supply is indicated in the MPS and relevant Marine Plans (e.g. policies AGG1-2 those for English waters, and SAF_01a of the Welsh National Marine Plan). These policies indicate that proposals, which would include activities associated with the draft plan, are unlikely to be permitted in licensed, application, exploration and option areas unless they demonstrate compatibility, or in the case of the East Marine Plans, where there are exceptional circumstances[205]. Additionally, assessments for new developments in English waters must consider the potential impact on wider prime aggregates resources (policy AGG3), also see (MMO 2013a and Appendix 1b).

The above “safeguarding” marine plan policies should prevent impacts on the aggregates industry from elements of the draft plan/programme by appropriate consideration of the potential for co-location. To date, offshore wind farms have avoided interaction with these areas both in the location of array areas and export cable routeing. In view of the relatively small area of aggregates extracted from the UKCS annually and likely advancement of floating offshore wind in future leasing rounds which will allow for wind farm siting away from shallower waters where aggregate extraction is most prevalent, interactions between these two sectors should be avoidable, or at least minimised. There is an overlap in the tidal stream resource area (Sections 2.5.2 and 5.15) and the aggregates areas covered by East Marine Plan policies AGG1-3, though part of the resource remains outside of presently licensed areas or those subject to applications and exploration and option agreements. While there has been no commercial interest in tidal stream development in the southern North Sea to date in this resource area, should any tidal stream proposals be made the potential spatial conflict with aggregates (amongst other sectors) would need to be resolved through the planning process. Aggregates areas are considered further in Section 5.15 as part of an overall spatial appraisal of constraints on plan related activities.

5.7.2.6 Tourism and recreation

The potential for conflict between recreational users of the marine environment and offshore energy installations is predominantly derived from exclusion, the potential for collision risks (e.g. to recreational sailing) and visual intrusion. The tourism industry is socially and

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[204] See: The Crown Estate and the British Marine Aggregate Producers Association (2021) The area involved 23rd annual report Marine aggregate extraction 2020, and, The Crown Estate and the British Marine Aggregate Producers Association (2018) Marine aggregate dredging 1998-2017 a twenty-year review.

[205] Note that such circumstances can include the licensing of an area by the OGA for oil & gas activities, subject to agreement with the leaseholder, however, at present this policy wording is only applicable to the East Marine Plan areas.

economically important to the UK and the coast in particular has been a popular destination for British holidaymakers of all age groups (see Appendix 1h). Its importance is recognised in the MPS (Section 3.11), including its sensitivity to seasonality, which has been regionally defined in a number of plan policies (TR1-TR3) for the East Inshore and Offshore Marine Plans. In addition to potentially transient effects from construction including noise and visual intrusion (largely from nearshore pipe or cable installation and landfall), longer term effects may be derived from physical obstruction to recreational sailing activities and changes in landscape or seascape character – the latter is discussed in Section 5.8.

The Royal Yachting Association (RYA) has developed an atlas of cruising routes, general sailing and racing areas around the UK (described in Appendix 1h). The atlas identifies areas of use, indicative routes and intensity of use, however confidence in actual use is generally low (see Anatec 2012). The RYA is in the process of updating the atlas and augmenting it through the use of AIS data to examine the passages of recreational craft, while recognising the limitations of this system for small vessels which may not have AIS installed – local knowledge is therefore important at the development level. An RYA (2015) position paper identifies the concerns of recreational craft users, which include displacement (e.g. physical exclusion through loss of recreational routes, interference with racing areas and potential loss of and access to sheltered harbours and anchorages) and enhanced collision risk derived from wind turbine blades and subsea infrastructure such as tidal stream devices and cable protection materials. Note that for offshore wind, RYA (2015) indicate a minimum rotor tip sea surface gap of 22m above mean high water springs would minimise potential collision risks[206] with rotors, guidance which has been taken into account in current UK offshore wind farm design.

The potential effects of tidal range devices differ from offshore wind, wave and tidal stream devices, in that they will be shore connected, and potentially in close proximity to harbour approaches, or in the case of barrages, introduce changes to how certain areas are navigated. Additionally, changes in water levels, speeds and morphological changes due to alterations in sedimentary process (see Sections 5.4 and 5.5) have the potential to affect navigation generally (as above) including recreational users (e.g. as identified by DECC 2010b,d).

Many of these issues are reflected elsewhere in navigation guidelines (e.g. in relation to lighting and charting) and also in national policy including the MPS, Energy NPS EN-3 and regionally in the East Marine Plans with regards to the requirement for proposals to consider the effects of developments on recreational craft and their activities, and to minimise and mitigate against any effect. The RYA cruising routes and sailing areas are considered further in Section 5.15 in relation to wider potential spatial interactions and constraints to future renewables deployment in UK waters.

5.7.3 Potential inter-plan conflicts

There are spatial overlaps with certain resource areas for each aspect of the plan (see Section 2.6). Most of the resource areas are large and historically spatial conflict has been avoided as the footprints of individual developments has been comparatively small at the scale of the UKCS. Certain resource areas are becoming increasingly constrained, and in particular for fixed offshore wind, although the decommissioning of certain offshore oil and gas installations has the potential to free-up space. Some of the key potential resource areas for carbon dioxide storage are in the southern North Sea and east Irish Sea and include both saline

[206] Also note that RYA (2015) indicate that to date there have been no recorded life threatening incidents involving recreational craft reported to HM Coastguard. Also see: https://www.rya.org.uk/knowledge/planning-licensing/offshore-renewables/wind-energy

aquifers and depleted natural gas reservoirs (see Appendix 1b and 1h); there is some overlap between the extent of these geological structures and proposed wind farms and remaining potential fixed wind resource areas. The primary issue of co-location between these technologies relates to the ability to undertake monitoring which is a statutory requirement of any carbon storage permit. The monitoring methodology would usually include repeat seismic survey which would be challenging to undertake should a wind farm be constructed over the storage site. However, this is not the only available monitoring method, and though uncertainty remains, there may be the potential for co-location, with the development of new and acceptable monitoring methods (Robertson & McAreavey 2021).

5.7.4 Controls and mitigation

The range of controls and potential mitigation options to avoid significant effects from plan/programme activities on other users of the sea and coasts are described above and in Appendix 3. These encompass legislation, assessments required as part of the consenting processes, guidance, best practice liaison and stakeholder engagement, and also relevant marine plan policies and those of the Energy National Policy Statements. It is acknowledged that there are several areas of research on the minimisation of the effects of OWFs in particular, which include effects on military and civilian radar, and that solutions are being delivered through initiatives including the Air Defence and Offshore Wind Windfarm Mitigation Taskforce. As a consequence it is considered that with appropriate siting and liaison, significant effects on other users from plan/programme activities can be avoided.

5.7.5 Summary of findings and recommendations

The primary issues for other users of the marine environment relate to navigation risk and the interactions of fishing activities with marine devices, although it is recognised that poorly sited developments can have significant effects on other users, including coastal tourism and recreation (also see Section 5.8).

Exclusion and displacement as a result of offshore development reduces the remaining area available for other users to operate in. If offshore development proceeds in a way that displaces navigation routes, and grounds for fishing, aggregate extraction and other activities, other areas may come under increasing pressure from multiple potential users and competition between users will be concentrated in the smaller space available. While each individual offshore development may only result in a relatively minor route adjustment or displacement, the cumulative effect of several such developments can lead to significant displacement and barrier effects. For industry, and particularly small-scale activity such as inshore fisheries, the combination of an enforced route adjustment, coupled with exclusion from all or part of a favoured fishing ground, could have a significant and damaging economic impact.

UK waters contain important navigational routes for international shipping. The English Channel and the southern North Sea in particular, and the Irish Sea, support high levels of vessel traffic between the UK, the continent and internationally, and there are strategically important routes outside of these areas. Offshore developments in UK waters may affect vessels travelling to or from the UK across administrative boundaries. Any resulting route alterations may have effects on ports currently supporting vessels traversing these routes.

Monitoring data of existing OWFs suggest that regular users of the area adapt to altered routes and in busy areas the introduction of a traffic separation scheme can significantly reduce any risk of accidental collision, noting that wind farms are typically sited away from major shipping routes as part of site selection at the leasing stage and in project design. Whilst individual risk assessments have concluded that, in keeping with guidance, the effects of individual developments, and cumulative/transboundary effects are acceptable, for some areas such as the southern North Sea and east Irish Sea, the imposition of further large wind farms has the potential to lead to significant changes in shipping activity and a requirement for some form of additional routeing. Ideally, project site selection and the planning process associated with development consent would minimise impacts on shipping, but at a more strategic level, the MMO has a duty to keep the marine plans under review, acknowledging that policies may need to reflect the changing environment and activity taking place in each area. It is recommended that a key part of each review should be to further analyse AIS and other shipping data, and to consider whether stronger policy (i.e. the creation of "clearways") where further development cannot take place is required, or at the least, updates to the location and nature of strategically important shipping routes should be mapped against relevant policies. Further routeing measures can be referred to the IMO for adoption by individual Governments. Any such routeing would require engagement and agreement for all waters of the British Isles as well as international coordination for transboundary routes since there are wind farm and other development proposals in the waters of adjacent states.

As wave and tidal developments are currently at demonstrator scale, the spatial extent of commercial scale arrays of these developments and the implications for navigation are difficult to ascertain, although there are regulations on charting, lighting and navigational aids for such devices. While submerged tidal arrays have the potential to avoid all interactions with surface users, there is relatively little experience of the potential for displacement of such activities in wave farms or tidal arrays closely associated with the sea surface, and certainly those of a commercial scale. The displacement of shipping and subsequent impact on the cost of shipping and port revenues is potentially significant, and should be taken into account when siting arrays of wet renewable devices.

Safety zones are either automatically applied, or may be applied for, in the offshore oil and gas sector (and by extension for CCS and gas storage) to ensure the safety of installations and subsea infrastructure. *The Electricity (Offshore Generating Stations)(Safety Zones)(Application Procedures and Control of Access) Regulations 2007* (as amended) defines "standard safety zones" allowable under the Act as 500m during installation, major maintenance, "extension" and decommissioning, and 50m under operation, though the latter have seldom been applied. In Part 2 regulation 3 (c)(ii), there seems some flexibility, "*in relation to the proposed safety zone… whether the applicant seeks the declaration of a standard safety zone, or if not, what dimensions are sought for that zone*.", however, a maximum of 500m is permitted in Article 60 of UNCLOS. It is noted that in reference to wave and tidal devices, the Regulations (regulation 3(b)(iii)) indicates applications for safety zones must include "*… a description of the extent and location (or proposed extent and location) of anchors, moorings and cables used (or to be used) in relation to the installation*." Related guidance[207] for safety zones notes that, for wave and tidal devices, "*…the relevant regulatory authority and MCA will need to consider, in consultation with the developer, whether the standard dimensions for safety zones as set out above are appropriate and, if so, what part of the device's structure they should be measured from. This is to ensure that the movement of such a device, or part thereof, through the water and any moorings or cables will be adequately covered*." The need for these should be further explored in the context of the potential for multiple anchors to be located at some distance from floating wind turbines and the difference in how moorings and safety zones are treated in the Regulations and guidance,

[207] https://www.gov.uk/government/publications/offshore-renewables-energy-installations-applying-for-safety-zones

which do not appear to have kept pace with floating offshore wind farm development. The potential future use of subsea sub-stations may also benefit from safety zones.

The effects of offshore developments on fishing activities depend on the scale of fishing interests in the area, the ability and willingness to fish within the areas, the space available for displacement of fishing into other suitable areas and the management regime of fisheries in that area. To date, there has been relatively little experience of fisheries adaptation and co-location with offshore wind farms. At a strategic level, caution is required with regard to the siting of a major expansion of offshore infrastructure to ensure fishing activities and skills of local cultural and economic importance are not inadvertently lost, through the prevention or significant hindrance of fishing activity for a generation or more during the lifetime of the developments. Applicants for consent and relevant decision makers should ensure that they reflect the relevant policies including *inter alia* those in marine plans and the Energy National Policy Statements highlighted above, as these mechanisms, along with experience to date on wind farm consenting and operation, are key checks for the planning process to ensure that the activities of the fishing industry are appropriately considered, and unacceptable effects mitigated. While planning policy indicates that developers and decision makers must consider displacement issues, including of fisheries, the cumulative and incremental effect on the fisheries sector from increasing offshore development is not well understood and is challenging to assess.

5.8 Landscape/seascape

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Potential effects of development on seascape including change to character (interactions between people (and their activities) and places (and the natural and cultural processes that shape them))	x	x	x	x	x	x	x	x

5.8.1 Introduction

There are three principal considerations for an assessment of the likely impacts of offshore energy activity on the seascape/landscape of UK waters and coastlines:

- the limit of visual perception from the coast (i.e. are the devices or installations visible and what influences their visibility)
- the individual characteristics of the coast which affect its capacity to contain a given development
- how people perceive and interact with the seascape, and what changes in character may be introduced by certain developments, including in a non-visual way

Prior to the development of offshore renewables, offshore energy developments in UK waters have primarily been oil and gas installations where the only representation of such developments at the coast or on land was in the form of cable and pipe landfall and associated infrastructure (e.g. former fabrication and maintenance yards such as that at Nigg and Ardersier), shipping and helicopter movements, and terminals such as those at St Fergus, Easington and Bacton. Drilling activity and production platforms have in the most part been too far from shore to be visible, notable exceptions being Beatrice in the Moray Firth, exploration wells sites off Dorset and Cardigan Bay (though temporary), structures in the east Irish Sea and those associated with the rig support industry, such as in the Cromarty Firth and Firth of Tay.

The more recent development of offshore renewables, and specifically offshore wind farms (OWFs), has led to a greater consideration of landscape/seascape issues as they are relatively large (recent turbines of 14MW capacity have blade tip heights of 260m, with proposals for larger units in the future), and numerous (for example Gwynt y Môr contains 160 turbines), and until recently technically limited to shallow water depths that favoured nearshore sites. More recent developments, Rampion excepted, are largely located further offshore. The Round 4 preferred projects are at least 29km (15.5nm) from land in the Irish Sea and 53.5km (29nm) from shore in the southern North Sea, and the early commercial floating projects in the Bristol Channel are 35km (19.5nm) from land. Significant cost reduction in fixed and floating foundations makes sites further from shore more desirable in terms of wind resource, and there are typically fewer constraints in these areas (see Section 5.15). With the exception of demonstration scale wind farms, similar to those recently deployed in Scotland (Aberdeen, Kincardine, Hywind), it is not anticipated that further large-scale commercial wind farms will be in close proximity to the shore.

Tidal stream and wave developments remain at demonstration scale to date. The technical resource, and therefore locations where such devices may influence landscape, is spatially restricted (see Sections 2.5 and 5.15). Tidal range developments will interact with any landscape they are set within, both directly as they are coastally connected, and indirectly through any other potential changes they may generate (e.g. shipping pattern and type and for larger barrage projects, intertidal extent).

Offshore hydrogen production facilities are likely to be similar in scale to small offshore platforms of the kind used for southern North Sea gas developments or CCS projects, which could also involve regular shipping traffic. They are also likely to be situated in proximity to offshore wind farms, or potentially in proximity to potential geological stores, which are generally some distance from the coast.

For some developments, particularly offshore wind, there is the potential to mitigate coastal effects through siting further offshore, whereas tidal technologies are shore connected or have a largely nearshore resource, and therefore are inherently visible within the landscape/seascape. Offshore oil and gas, gas storage and CCS installations will typically be small, isolated, distant from shore, and perhaps, entirely subsea.

The following sections therefore concentrate primarily on potential effects from offshore wind deployment, but also consider the potential location of other renewables deployment.

5.8.1.1 Planning policy context

The planning policy and wider context of landscape/seascape is set out in Appendix 2. Key areas of UK policy are outlined below.

The Marine Policy Statement (MPS) arising from the *Marine and Coastal Access Act 2009* states that all coastal landscapes should be considered in the preparation of marine plans, not just those which are protected through designations, which is broadly complementary to the tenets of the European Landscape Convention (see Appendix 1c). Note this has been taken forward into regional marine planning including policy SOC3 in the East Inshore and Offshore marine plans, the SCP-1 policies of the other English Inshore and Offshore Marine plans, SOC_07 of the Welsh National Marine Plan, and GEN1 of Scotland's National Marine Plan.

The East Inshore and Offshore marine planning process involved the commissioning of a methodological pilot study for seascape assessment, which was developed by Natural England and formalised in, *An approach to Seascape Character Assessment*, published in 2012, which was applied across the marine plan areas of England and Wales consistently to produce a set of Marine Character Areas (MCAs, see Appendix 1c, Figure A1c.3). The publication *An Approach to Seascape Sensitivity Assessment* (MMO 2019), complementing that of Natural England (2019), is intended to be used in the assessment of sensitivity of MCAs at a national level, or Seascape Character Areas (SCAs) at a regional/local level, for strategic purposes in relation to potential development types.

Planning policies, for instance the National Planning Policy Framework and the Energy National Policy Statements (e.g. EN-1 and EN-3), exact the highest degree of protection to designated sites (i.e. statutory designated areas such as Ares of Outstanding Natural Beauty (AONBs)), but do not propose that development should be precluded within them where project design would not conflict with the interests and features for which the sites are designated. These planning policy documents are presently subject to review[208]. As with previous NPSs, where an offshore wind farm is within the sight of the coast consent should not be refused solely on the grounds of an adverse effect on seascape and amenity unless:

- it considers that an alternative layout within the identified site could be reasonably proposed which would minimise any harm, taking into account other constraints that the applicant has faced such as ecological effects, while maintaining safety or economic viability of the application
- taking account of the sensitivity of the receptor(s) and impacts on the statutory purposes of designated landscapes as set out in Section 5.10 of EN-1, the harmful effects are considered to outweigh the benefits of the proposed scheme

Linked to this topic is that of the historic environment (e.g. listed buildings, UNESCO world heritage sites (WHS), scheduled monuments), where their setting is considered to be relevant to their designation or appreciation[209] or their intrinsic value[210].

5.8.2 Consideration of the evidence

The following considers the limit of visual perception of offshore energy installations from the coast which primarily relates to offshore wind but is applicable to other offshore structures. The potential sources of effect from submerged or partially submerged devices are also considered. The visibility of structures at distance from the coast is dependent upon a series of compounding factors including atmospheric/meteorological conditions (haze, precipitation, fog), the chromatic contrast of structures at sea and their surroundings (i.e. sea and sky), the arrangement/complexity of offshore activities, and also the structure height (dipping height) of offshore objects which may be above the level of a given horizon. Beyond the limitations imposed by viewable distance due to the curvature of the earth, the effects of haze, meteorological and other conditions that limit the distance at which activities could be seen, or at the least the duration at which visibility would be limited, should be taken as context only. Project level assessments are required to take a precautionary approach, and therefore base conclusions on the maximum possibly visibility.

5.8.2.1 Curvature of the earth and theoretical visibility

The curvature of the earth influences the visibility of offshore structures but is negligible except at very long distances – for instance an observer of height 1.5m would still see the top of a structure 160m in height, at 25-30km from the coast at sea-level, and would observe a similar scene (albeit at a reduced scale) at 45-50km from the coast at 100m above sea-level. The basic formula for calculating the distance over which an object is visible, taking account of the curvature of the earth and atmospheric refraction is (after Scott *et al*. 2005):

$$d = \sqrt{2rh1} + \sqrt{2rh2}$$

[208] https://www.gov.uk/government/consultations/planning-for-new-energy-infrastructure-review-of-energy-national-policy-statements
[209] For instance, “essential setting” and “”significant views” are identified in Wales in relation to registered Historic Parks and Gardens.
[210] https://historicengland.org.uk/images-books/publications/gpa3-setting-of-heritage-assets/ and https://historicengland.org.uk/images-books/publications/commercial-renewable-energy-development-historic-environment-advice-note-15/

(Where: d=visible distance, r=radius of the earth (7,430km accounting for atmospheric refraction), h1=height of observer, h2= height to top of structure).

For example, the sum of the height of an observer at 50m (+1.72m for an average height person) in addition to the height of a structure (260m). The resulting maximum theoretical viewable distance would be 89.9km – note that this value is based on the maximum blade tip at 260m, and at a point when the entire structure has just disappeared over the horizon, i.e. the distance of 89.9km represents that when all visible aspects of the structure would have disappeared. DTI (2005) guidance in relation to wind farms considers that effects are likely to arise when the nacelle becomes visible at the horizon, as it is debatable as to whether blade tips can be distinguished by the human eye at such long distances. For the most recently installed turbines (e.g. a representative 8MW turbine) a typical hub height is 120m (theoretical visibility 70km), with larger proposed units with a blade tip of 260m as considered above having hub heights at the order of 180m (79km).

Other factors are locally important, including screening by embankments, vegetation, buildings, and increased elevation can also allow for a greater view of the horizon which can diminish the scale of the view that includes offshore structures, however this reduction may still cause an effect, for instance, if in a designated landscape.

Table 5.25 indicates the "worst case scenario" of theoretical visibility for wind and marine renewable devices from a range of viewer heights which are available at the coast, or within 10km of the coast, around the UK.

Table 5.25: Theoretical maximum viewable distance due to curvature of the earth

Viewer height (m)	Viewable Distance (km)			
	Wind turbine nacelle (180m ASL)	Wind turbine nacelle (120m ASL)	Tidal stream structure (10m ASL)	Surface wave device (3m ASL)
1.7 (sea level)	59	49	17	12
6	62	53	23	17
22	71	61	31	25
100	91	81	51	46
150	99	90	60	54
250	113	103	73	66
500	138	129	99	93

Note: based on a turbine of 160m to blade tip with a rotor diameter of 90m (i.e. central nacelle height of ~115m). Lower values of 6, 22 and 100m are based on typical viewing heights stated in White Consultants (2020a) relating to promenades, low-lying hills and cliffs and coastal hills respectively.

At a project specific scale, seascape studies consider the zone of theoretical visual influence (ZTVI) around a development, which is the extent of the potential visibility of a development. Digital terrain models and GIS tools are used to perform this calculation which takes into account, amongst other things, aspect, height and intervisibility. Such visibility is theoretical in the sense that it assumes no surface cover (e.g. trees and other tall vegetation, buildings, sea defences etc. – though field survey can be used to inform the process) and so has a tendency to overestimate the potential area impacted – a result of this being that if it predicts no visibility then there is no interaction and visual effects are unlikely (DTI 2005).

As part of evidence gathering for the first marine plans, viewshed analysis (Figure 5.48) was undertaken for the coast of England and Wales indicating land with sea views and sea visibility from land, based on the methods outlined in MMO (2014b). This work can inform strategic level considerations of visual effects, but is limited as a more detailed understanding of the visual influence of individual developments can only be gained through a Seascape and Visual Impact Assessment (SVIA). As part of Round 4 leasing, The Crown Estate undertook work to produce a graphic representation of areas of sea with higher visibility from landscape designations, highlighting the potential for interaction between offshore projects which may be visible outside of these sites. The work involved a viewshed analysis assuming an offshore structure height of 250m, and so is somewhat limited by these parameters, but nonetheless provides a good indication of areas where projects are most likely to be visible taking account of a number of other factors discussed below.

5.8.2.2 Contrast, lighting and navigational markings

The atmosphere is thickest at the horizon and appears lighter there, darkening overhead. Structures which are white and light grey (typical of wind farms) will contrast least, though certain devices requiring high contrast navigational markings will contrast more. Tall structures may be silhouetted by sunset or sunrise, and clear views are more likely at sunset (Scott *et al.* 2005), and therefore certain viewing aspects are more greatly affected than others.

Lighting of renewables devices and other offshore installations must meet both Trinity House and CAA standards for marine navigation and aviation respectively, in addition to other requirements, for instance in relation to military activity. Navigation lighting requirements, as set out in IALA Recommendation O-139 notes that lights must have a nominal range of 10nm (18.5km), though it may be surmised that these lights could be viewable from a greater distance. These lights are located at a level on turbines (not more than 30m) which means they are less likely to be visible over longer distances due to the curvature of the earth (White Consultants 2020a).

Navigational lighting requirements for gas storage, including for carbon dioxide, will be analogous to those for oil and gas installations. It is possible that marine navigation lighting may be visible at the coast in clear night conditions, particularly where other light pollution is absent, and may therefore have greatest influence in rural areas, but as for wind turbines, navigational lighting is limited in its visibility by the curvature of the earth. Those devices (typically tidal, though potentially also wave) which are completely submerged may still require identification buoys depending on their position in the water column. The level of marking will be decided after risk assessment. Appropriate navigation buoys (with lighting visible for 5nm) would be required at the corners of arrays and above sub-surface devices. With regard to wind farms, aviation lighting on the nacelle may appear to flash as turbine blades pass over them. Guidance on markings and lighting is provided in a range of policy and guidance documents (e.g. CAA CAP764, and also MGN654 in relation to Search and Rescue (SAR) operations), and also in legislation (e.g. the *Air Navigation Order 2016*, also refer to CAA document, CAP393). There is a statutory requirement for lighting of any wind turbine in territorial waters greater than 60m in height above highest astronomical tides (HAT), and though the CAA may specify other lighting, the Regulations require at least one medium intensity light visible in all directions, with only peripheral turbines having the requirement in larger farms. As the pace of rotational movement in each turbine may differ in any given farm, and the orientation of the blades for each turbine will be different, this may generate a sequence of irregular light flashes as the blades pass in front of the lights.

The MCA Marine Guidance Note (MGN) 654 outlines considerations which need be taken with regard to operational safety and emergency response in areas used by offshore renewable energy infrastructure (OREI), which is augmented by CAA CAP764, MoD (2020) and guidance relevant to Emergency Response Co-operation Plans (ERCoPs) – see Appendix 1h and Section 5.7 for more information). MGN654 contains a number of recommendations, including for design requirements. Issues outlined in this paper which may influence the appearance of devices from the shore and at sea include: wind turbines should be individually marked with characters which can be identified at 150m from the turbine, turbines and substations should have distinct markings, and, identification characters should be illuminated but baffled to prevent excess light pollution.

5.8.2.3 Haze and meteorological factors affecting visual range

The above methods of determining viewable distance and visibility do not take into account haze and meteorological conditions which might further limit visual range. Visibility affected by haze is the barrier to visual acuity brought about by atmospheric aerosols (Husar & Husar 1998). In this case, the viewable distance can be taken to mean, “the maximum distance at which an observer can discern the outline of an object”. Husar & Husar (1998) present the following formula for calculating such distances (shown here as modified in Scott *et al.* 2005):

$$v = c \div e$$

(Where: v=visual range, c=constant determined by the threshold sensitivity of the human eye and the assumed contrast of visible objects against their background, e=extinction coefficient – a measure of how much haze is in the air).

Table 5.26 lists the maximum likely viewable distance at which the outline of an object can be made out given a range of UK specific coefficients. Scott *et al.* (2005) point out that this visual range is not the same as visual significance, though it will influence significance. The acuity of an individual’s eye and the number, form and lighting of viewable objects will vary this distance (Husar & Husar 1998).

Figure 5.48: Land with sea views and sea visibility from land, England and Wales

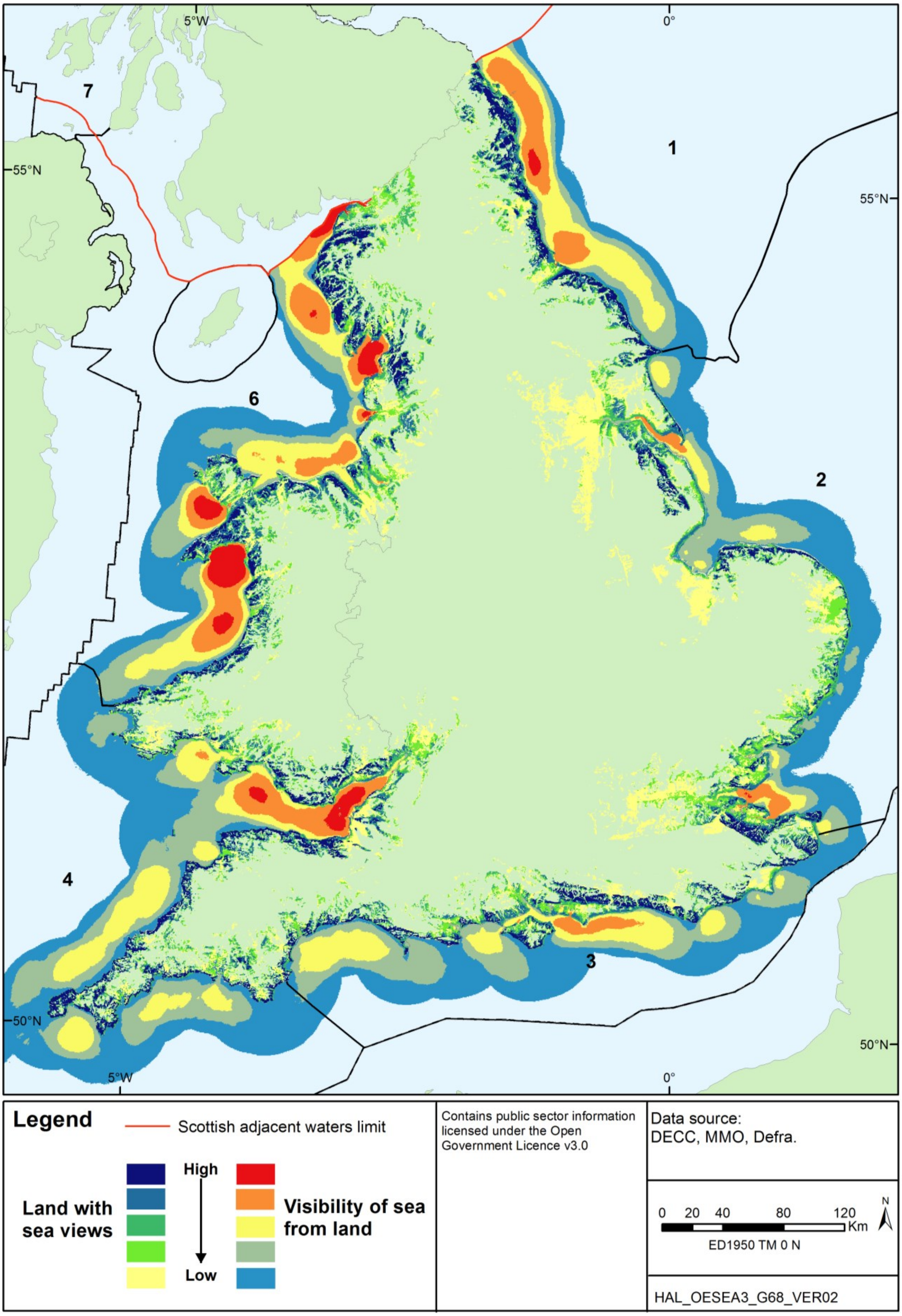


Figure 5.49: Landscape related designations and the visibility of the sea from these

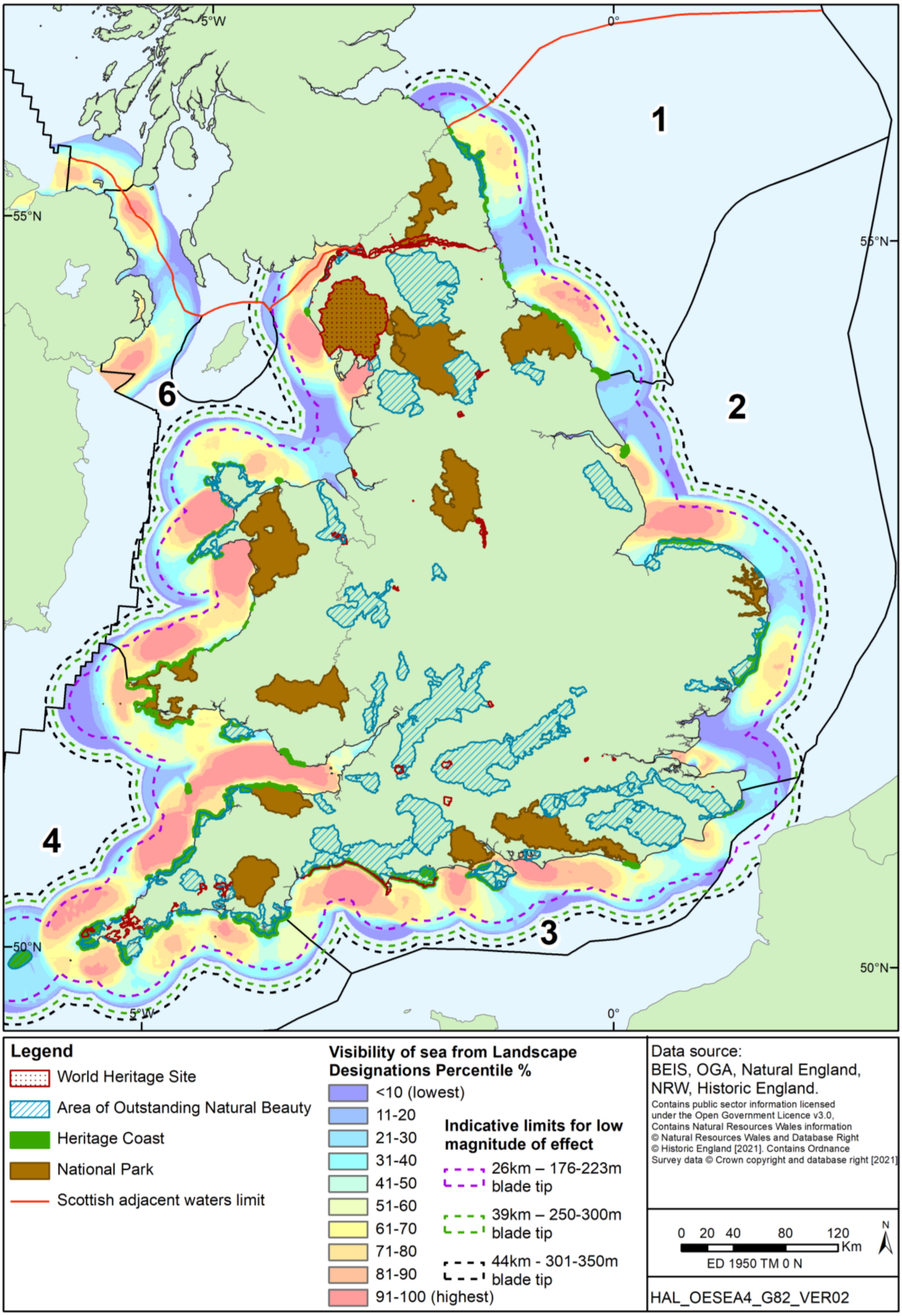


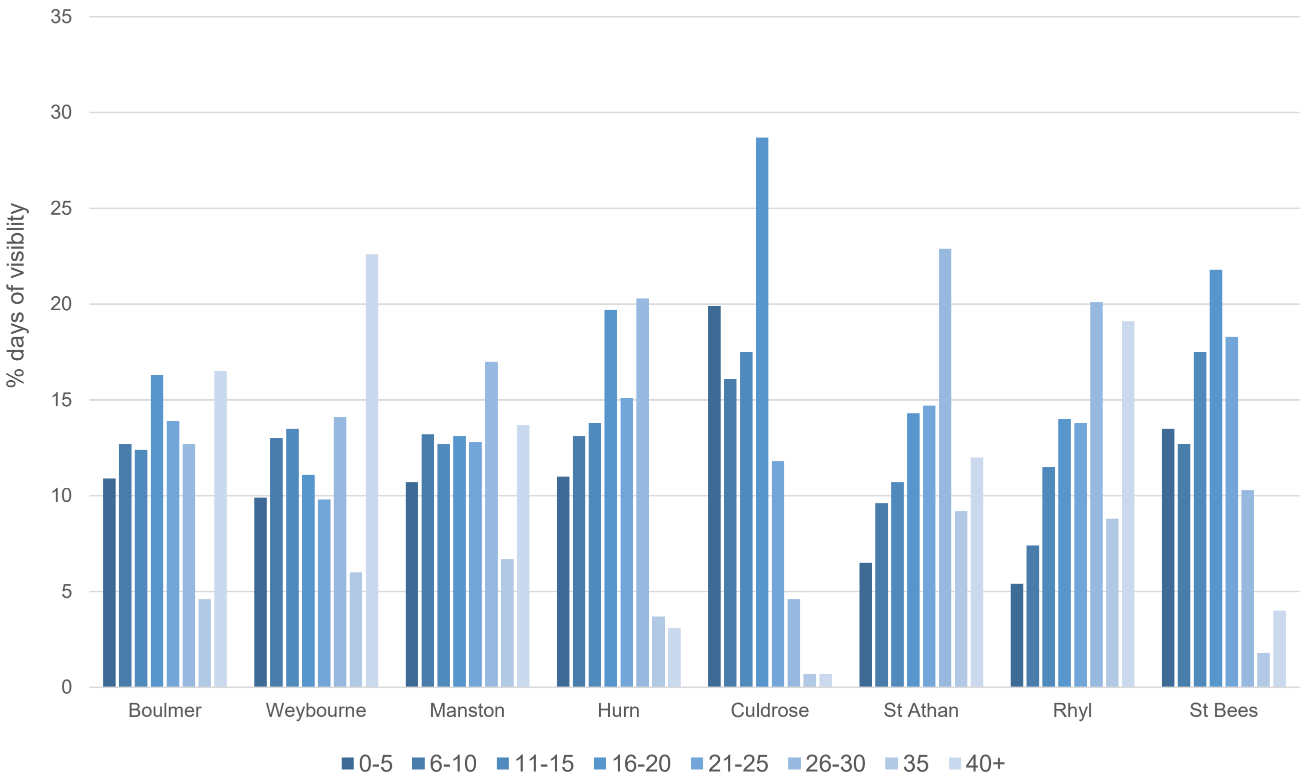
Table 5.26: The influence of haze on viewable distance

Applicable area and season	Haze coefficient (e)	Visual range (v)
Northern Scotland	0.1	39km
Wales (spring and summer). Central and southern Scotland (summer to winter)	0.15	26km
Central and southern England (spring). Central England, north and south Wales (winter). Parts of south- and north-east England (summer)	0.2	19.5km
Southern England (winter)	0.25	15.6km

Source: after Husar & Husar (1998). Assumes a 'c' value of 3.9 as recommended in Scott *et al.* (2005).

The above calculation of haze filters out any meteorological phenomenon which might also affect visibility (e.g. rainfall, fog) and therefore represents clear visibility. DTI (2005) recommend the use of Met Office visibility data to assess trends in conditions over a 10 year period for stations located landward of proposed wind farm sites. Figure 5.50 indicates the percentage of days where visibility falls within a range of distances over a 10 year period. The majority indicate visibility is primarily 30km or below. The percentage average of days for all locations where visibility is within each of ranges is given in Table 5.26. White Consultants (2016) note that the methods used to collect this data may not provide an accurate view of visibility, as it does not take account of the varying conditions that may exist at certain distances offshore.

Figure 5.50: Percentage of days visibility for distances 0-40+ km, 2008-2017



Source: after White Consultants (2020a)

Table 5.27: Distribution of cumulative percentage days visibility for coastal weather stations, 2008-2017

Station	Visibility distance (km)							
	0-5	6-10	11-15	16-20	21-25	26-30	35	40+
St Athan	100	93.5	83.8	73.1	58.8	44.1	21.2	12
Rhyl	100	94.6	87.2	75.7	61.7	47.9	27.9	19.1
Manston	100	89.3	76.1	63.3	50.2	37.4	20.5	13.7
Weybourne	100	90.1	77.1	63.6	52.5	42.7	28.6	22.6
Hurn	100	89	75.8	62.1	42.3	27.2	6.8	3.1
% Average cumulative totals	100	89	76.8	63.1	45.7	31.9	16.7	11.5

Source: White Consultants (2020a)

Rainfall incidence, sunshine hours and propensity for fog provide additional meteorological factors in determining relative visibility of offshore structures (see Appendix 1f for a consideration of these).

5.8.2.4 Activity specific considerations

Offshore wind

Considered in the context of 28 SVIAs undertaken for various Round 1, 2, 3 and Scottish territorial waters wind farm projects, the distance where a low magnitude of effect was found to occur is a maximum of 48.2km for turbines with a blade tip of 300m, reducing to 26.1km for smaller turbines of up to 145m in height (White Consultants 2020a). Average values were 30.6km and 19.2km for these sizes of turbine respectively. Medium magnitudes of effect are noted at much closer distances, with a maximum of 33.3km and 15km, and an average of 29.7km and 14km for turbines of 300m and 145m blade tip respectively. These estimates do not reflect SVIAs undertaken for wind farm extensions due to the potential impact of the baseline (i.e. existing turbines) on the magnitude of effect from such project proposals. The exclusion of these projects made a minor difference to the distances at which low and magnitude effects could be experienced by increasing these by ~1km for the 250-300m wind farm scenario.

It has been previously noted that fewer larger turbines were considered more acceptable than many smaller ones (White Consultants 2016), but this is not necessarily reflected in the recent analysis of SVIAs. White Consultants (2020a) noted that there appeared to be no strong relationship with the number of turbines in an array and the expected magnitude of effect, noting some variation in the conclusions of the magnitude of potential effect for wind farms, their distance from shore and number of turbines. Variation in the approach of assessors and the presence of other wind farms as part of the baseline (noting the exclusion made above in relation to thresholds of effect magnitude) being assessed may be factors in explaining this.

White Consultants (2020a) considered the thresholds of average low magnitude of effect detailed above to indicators for minimum thresholds as it is considered that effects could still be significant at around these distances for high sensitivity receptors. It is noted that the difference in these thresholds of effect compared to the similar exercise undertaken for Wales

(NRW 2019)[211] are due to fewer wind farms being considered and a slightly different basis for the assessment. For the purposes of OESEA4, it is considered that those values in NRW (2019) are relevant to Welsh waters and that those presented in White Consultants (2020a) are relevant to English waters. While the analysis in White Consultants (2020a) included wind farms in Scottish waters, this area is not covered by the draft plan/programme.

Based on a series of wireline scenario analysis, indicative thresholds of no significance based on distance from the shore for a range of turbine sizes for a representative 500MW wind farm are shown in Table 5.28. Significance is concluded for high sensitivity receptors where the potential magnitude of effect is small or greater, for example, for a small 3.7MW (137m) turbine of the kind installed in early offshore wind farms the threshold of no significance is beyond 24km, whereas the threshold of no significance for 20MW (350m) turbine is well beyond 24km but less than 35km (White Consultants 2020a). For medium sensitivity receptors, significance is judged at moderate magnitudes of effect (see Table 5.28). A separate large wind farm scenario of around 80 turbines of 350m and 400m (20MW+) height was also analysed which concluded that for highly sensitive receptors the threshold of no significance was well beyond 35km (35-44km), and for medium sensitivity receptors was well beyond 24km (24-35km).

In practice development scenarios will vary for each individual wind farm and also the variables determining visibility for individual wind farms. The visibility of structures from the coast, or their intrusion on sites designated for their visual qualities, does not necessarily preclude development in planning (see: NPS (EN-1) and the MPS), and any consideration of coastal "buffers" is too generalised an approach to take into consideration the many anthropogenic and natural variations along the coast and the variety of development scenarios which might take place (e.g. installation number, type, design and orientation).

Table 5.28: View of potential magnitude of effects for 500MW offshore wind farm scenarios viewed at 22m AOD

Turbine height/ capacity (MW)	Distance from shore/viewpoint			
	13km	18km	24km	35km
137 (3.6)	Moderate and moderate/large	Small and small/ moderate	Small	n/a
175 (5)	Moderate and Large	Moderate and moderate/large	Small and small/moderate	n/a
190 (7/8)	Moderate and Large	Moderate and Large	Small	Very small
220 (10)	Large	Moderate and Large	Small and small/moderate	Very small
250 (15)	Large	Moderate/ large and large	Moderate	Very small
350 (20)	Large and Very Large	Large	Moderate	Small

[211] For Wales, NRW (2019) indicated a maximum distance of 52.7km and average of 41.6km for turbines of 226-300m for a low magnitude of effect, and a maximum of 31.4km and average of 27.9km for a low magnitude of effect.

Turbine height/ capacity (MW)	Distance from shore/viewpoint			
	13km	18km	24km	35km
400 (20+)	Large and Very Large	Large and Very Large	Moderate and Large	Small and moderate

Source: White Consultants (2020a)

Early wind farm siting in the UK was relatively close to the coast (e.g. the average, referred to in OESEA3, was 9.4km). Since then, the average has increased to 22km for operational projects, 66km for consented projects and 37km for those in the planning process (see Appendix 1c) – note that the average for those in planning is lower than those consented as many of these relate to extensions to wind farms built closer to shore (e.g. Dudgeon, Sheringham Shoal, Awel y Môr). Turbine capacities of operating farms generally range from 2-3.6MW, with a height to blade tip in the order of ~160m, but the capacity of turbines has increased substantially in recent years (see Figure 2.2), and the most recent applications for consent are indicating potential parameters of up to 350m blade tip heights. In English waters, the bulk of wind farm projects either developed, consented or planned to date are in the southern North Sea (Regional Sea 2). These wind farms are generally too distant to be perceived from coastal locations (e.g. the Dogger Bank projects, Hornsea Projects One and Two, East Anglia One), but have the potential to alter the character of areas further offshore.

The Round 2 SEA (BMT Cordah 2003) considered that seascape issues became significant within a distance of 8-13km, but that the distance from the coast at which development was acceptable varied due to differences in the quality of the seascapes being considered. That SEA considered that wind turbine blade tip heights would be in the order of 150-160m. Similarly, though made as part of a wider range of considerations relating to the possible impacts from offshore wind (also see Section 5.15), it was recommended in previous OESEAs (DECC 2009, 2011, 2016) that developments should generally take place out with 12nm (~22km) from the coast (i.e. in offshore waters). This recommendation was indicative, not spatially prescriptive, and subject to site specific consideration of potential effects (including on seascape) which may result in developments being more acceptable either closer to the coast, or further away. Landscape and seascape issues were considered as significant for those projects taken forward in former Round 3 zones which are within viewable distance of the coast (Rampion, Navitus Bay, Atlantic Array). Whilst effects on landscape were identified for Rampion, the Secretary of State indicated that with agreed mitigation their effects were not significant enough to refuse the application (also note the wording of the NPS EN-3 in relation to the grounds on which a project should be refused on the basis of landscape/seascape issues, also see Appendix 2). A greater number of landscape issues associated with Navitus Bay was the principal reason for the refusal of planning consent[212], and a number of significant seascape effects were identified for the Atlantic Array, though this was withdrawn for reasons other than landscape effect (White Consultants 2016, 2020a).

Siting offshore wind farms within 12.5km of the coast has been subject to local opposition in Belgium, which has led to the adoption of a wind farm zone beyond 12nm (some 22km) from the coast – a similar approach has been adopted by the Netherlands and its operational schemes are around 23-57km from shore other than demonstration schemes and Egmond aan

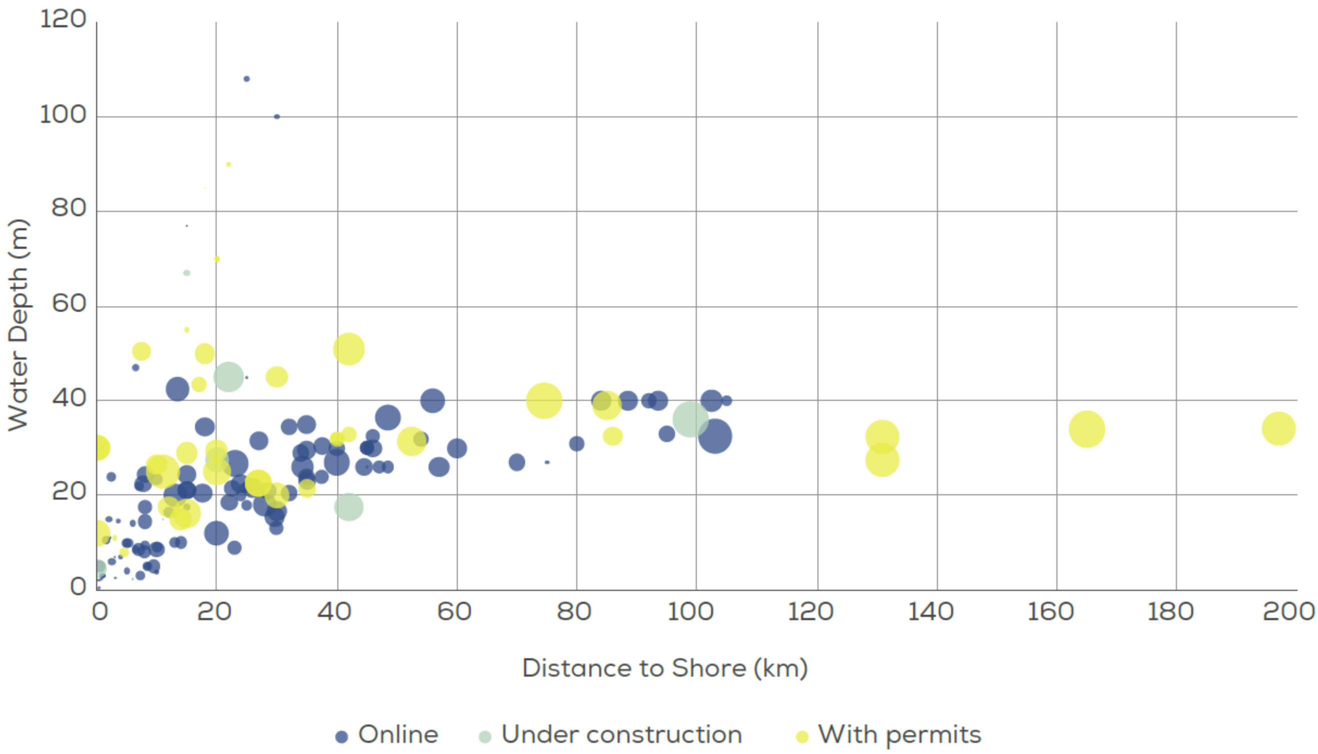
[212] http://infrastructure.planninginspectorate.gov.uk/projects/south-east/navitus-bay-wind-park/ and https://webarchive.nationalarchives.gov.uk/ukgwa/20210101024134/https://infrastructure.planninginspectorate.gov.uk/projects/south-east/navitus-bay-wind-park/

Zee (10km). Denmark has sited wind farms of limited size up to 32km from the coast, though more emphasis is given to public perception of turbine arrays rather than visibility. Some sizeable wind farms have been erected within viewable distance from the coast, for instance the Horns Rev 1 site which has 80 2MW turbines located just less than 20km from the Jutland coast. To the east, the Lillgrund wind farm lies between Denmark and Sweden and is highly intervisible between the coasts of both countries, and more recently Horns Rev 3 is located 30km from the shore and uses 49 8.3MW turbines.

The deployment of offshore wind energy in Germany has increased considerably in recent years. The first operational wind farm in German waters was the Alpha Ventus, a testing site 45km from Borkum Island. The site originally consisted of 6 5MW turbines, though was upgraded to 12. Germany has 27 operational wind farm schemes, with a further five under construction or planned; the average distance from shore for these projects in 55km and the majority of new schemes are at least 115km from shore (White Consultants 2020a). Projects at such a distance from shore should all but eliminate visual disamenities of turbines for shore based receptors, though will obviously change the character of the North Sea and Baltic Sea from passenger ferries, recreational craft and other commercial ships.

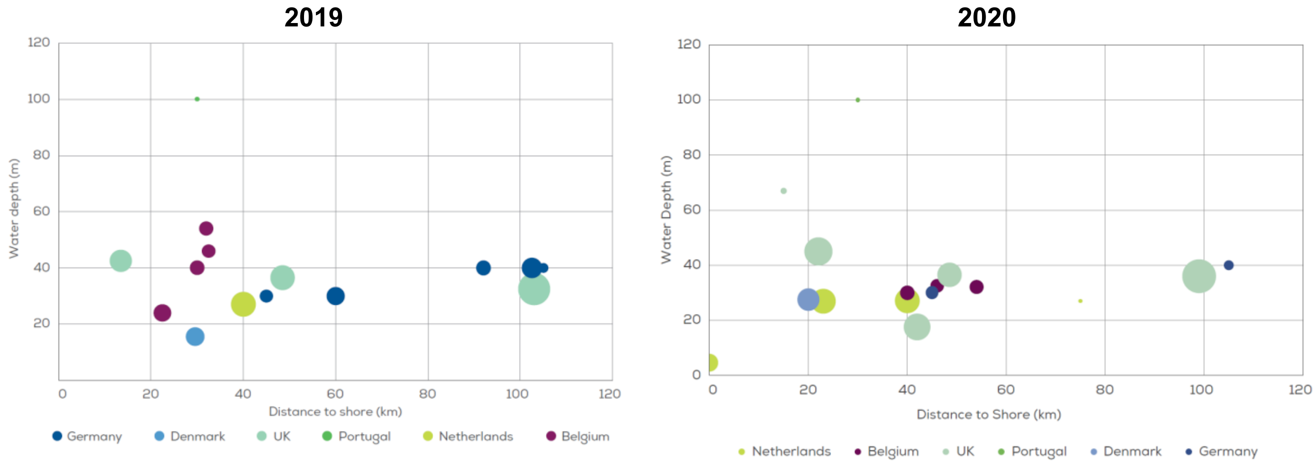
Considering all European countries, the average distance of offshore wind farms from the coast has been steadily increasing. Those farms installed in 2008 were on average 10.5km from the coast, rising to 12.8km in 2009, 29km in 2012, 32.9km in 2014, 43.3km in 2014 (EWEA 2016) and 52km in 2020 (WindEurope 2021) (Figure 5.51). The average water depths that wind farms are deployed in has generally increased over time as foundation technology and experience has grown, in particular for the UK. The relationship between water depths and distance from shore for projects constructed in 2019 and 2020 is shown in Figure 5.52.

Figure 5.51: Average European wind farm distance to shore in km



Source: WindEurope (2021)

Figure 5.52: Average water depth and distance to shore of offshore wind farms under construction



Source: WindEurope (2021)

The lifetime of a wind farm may be in the order of 25-30 years, after which repowering may be an option. This could involve fewer, larger turbines as opposed to just the upgrading of turbine generators, blades etc. and so any OWF may be considered to have a long-term effect on landscape/seascape, and in time may come to be a significant component of landscape and seascape character.

Wave and tidal stream

The draft plan/programme considered in this SEA would allow for further leasing/licensing of areas of the seabed for wave, tidal stream and tidal range technologies that will introduce a number of new visual components into seascapes. Seascape studies currently available for such technologies include those within the SEAs for marine renewables in Scotland (Faber Maunsell & Metoc 2007) and Northern Ireland (AECOM & Metoc 2009) and some development level assessment, for example LUC (2019) in relation to the Billia Croo wave test site.

Very little work has yet been completed studying the impacts that wave and tidal devices may have on seascape. The present demonstration phase of wave and tidal devices has led to a wide range of contrasting designs, the impacts of which will become more apparent as they progress towards commercial viability and are deployed in larger arrays. In an attempt to anticipate the level of impact, a number of national scale studies (for Wales, Scotland and Northern Ireland) have conducted assessments based on a few generic structure types. The same assessment criteria for landscapes and seascapes as used previously for offshore wind will apply to these devices, and as such, site specific and device specific impacts will need to be considered at the individual development level. The smaller vertical component of open water wave and tidal devices will make them less obtrusive at a closer distance to the shore compared with offshore wind, and certainly for tidal stream, it is likely than any project will be relatively close to the shore given the area of technical resource in waters relevant to the draft plan/programme and this SEA (Figure 5.55).

The Wales regional seascape study (CCW 2008b) considered the possible impacts from tidal current and wave devices of a scale and form thought probable in the next 10 years, with tidal stream represented by vertical columns projecting from the sea surface (10x3m), and wave by broad, flat objects (3x400m) – e.g. similar in form to the former SeaGen tidal and Pelamis wave devices. Seascapes generally displayed less sensitivity to the wave scenario than to the tidal one, though in both cases headlands and areas with restricted or focussed views (e.g.

along estuaries) recorded high sensitivities. It should be noted that this exercise only looked at a single scenario for each technology (which were not well defined) and seascape unit, and the impacts of particular wave and tidal designs may differ significantly from these. Similar scenarios for wave and tidal devices were considered by the Scottish Government in its marine SEA (Faber Maunsell & Metoc 2007) and in the Northern Ireland offshore energy SEA (AECOM & Metoc 2009), though recognising that surface point structures may also be wave devices, (e.g. point absorber-type devices).

The Scottish study defined ten seascape types which could be attributed to specific study areas, for which a sensitivity score was then attached for linear, point and shore connected structures. The study outlined that the least sensitive seascapes were those that offered open and expansive views, while those with a large vertical component were of moderate sensitivity. In keeping with CCW (2008b), Faber Maunsell & Metoc (2007) and AECOM & Metoc (2009) regarded linear wave devices to have less of an effect on broad, open seascapes compared with point structures, primarily as linear structures may follow the natural movement of the sea and be partially hidden by wave motion. The more enclosed and complex seascapes found in the sounds and fjords of Scotland's west coast were regarded as having the highest sensitivity to wave and tidal devices, for example, see LUC (2019). Some tidal devices such are designed so that they have no surface component, and therefore visual impacts would be largely restricted to those occurring during deployment, monitoring and maintenance, and subsequent decommissioning, though any local substation would constitute surface infrastructure if it is required. Depending on the position of the device in the water column (i.e. whether it is at sufficient depth to be avoided by the draft of most vessels), these may be marked with buoys and navigational lighting (Faber Maunsell & Metoc 2007).

The SeaGen tidal stream device in Strangford Lough, Northern Ireland, was an individual demonstrator project which is visible as a point surface structure, reaching 10m above sea-level. The Environmental Report for this development (Royal Haskoning 2005) indicated that the device would be visually obvious at all stages of development, which would affect views from land, particularly Portaferry, and the open seascape offered during ferry crossings. The requirements to use paints providing suitable contrast and lighting for navigation were highlighted as restrictions in making the device less visible, and that mitigation options were minimal. Visual impacts were considered most significant during maintenance as the turbine blades would be exposed above the water surface, though this is a temporary, but intermittent activity. Similar tidal stream devices are therefore likely to pose a transient visual impact proportional to the amount of time required for maintenance. Visual impacts present for the life of many submerged developments are therefore likely to be restricted to any local substation that may be required above water and associated landfall. Similarly for wave devices, and though location specific, LUC (2019) noted mitigation include the extent of the wave site, limits on device size including height above sea level, and the reversibility of effects, however, there was limited scope for additional mitigation beyond the arrangement of devices to create a more coherent appearance. It was noted that the sense of wildness could be locally affected, and adverse, with the site experienced by high sensitivity receptors. It should be noted that this study is highly site specific, however, the conclusions in relation to similar seascape character types may be indicative of the nature of effects on high sensitivity seascapes (noting that Billa Croo is located within the Hoy and West Mainland NSA) for a range of wave device designs.

The operational lifetime of individual wave and tidal stream devices is uncertain, but individual farms may be in the order of 25 years, after which repowering may be an option. In addition to the effect of devices, operation and maintenance vessel traffic will also generate sources of effect on the landscape/seascape. Any wave or tidal stream farm may be considered to have a long-term effect on landscape/seascape.

Tidal range

A seascape study was undertaken as part of the SEA for the Severn Tidal Feasibility Study (DECC 2008b, 2010c) in addition to that already completed for a hypothetical inner barrage between Lavernock Point and Brean Down by Land Use Consultants (2007). Specific impacts (e.g. on individual AONBs, National Character Areas and viewing locations) for the Severn are presented in these reports, though only generic impacts are considered here as these may be more widely applicable to other estuaries considered for tidal range technologies in the UK. Barrages would alter the character of a given estuary due to land-use change associated with new infrastructure, for instance power cables and onshore development associated with the barrage (access roads and buildings), with significant effects predicted during construction and decommissioning (DECC 2010c). Any tidal barrage would be visible at all points in the tidal cycle and would block views in both directions on its landward sides. Secondary effects include the potential loss of intertidal habitat (and also associated fauna and flora), a reduction in the extent of intertidal areas at low tide, changes to water clarity and also shipping routes.

DECC (2010c) indicated that for the Severn tidal barrage, uncertainty surrounded what form intertidal areas would take following a change in sedimentation regime of the estuary, and how long it would take for such a new regime to become established. Therefore the consideration of landscape/seascape impacts of such structures is more complex than the more simplistic consideration given to other forms of offshore activity, and the Severn Tidal SEA recommended that local level, design stage visual assessment would be required to minimise impacts. Similar effects may be generated by lagoons, though some of these may be exacerbated at low tide as, depending on specifics of development design, more of the embankment structure would be exposed. Barrages may also be multi-use structures, incorporating a road crossing which could have its own street lighting that would be visible at night, in addition to the movement and lights of vehicles.

For any tidal range device, the installation of a lagoon or barrage wall(s) represents a long-term change. The lifetime for most tidal range proposals exceeds 100 years, and after this period repowering may be possible, or else the bulk of the structure may be left *in situ*.

Offshore oil & gas, gas storage, carbon dioxide storage and offshore hydrogen production

Carbon dioxide transport and storage facilities may have few visual components in the marine environment visible from coastal locations, and any associated structures may be restricted to the temporary works related to landfall of pipelines or increased, or new, port facilities at the coast and any associated tanker traffic. Gas storage operations may have similar impacts, having both onshore and offshore facilities. The Gateway Gas Storage project was the first proposal in UK waters to suggest for the use artificial salt cavern construction to provide gas storage capacity. The proposal included offshore facilities 24km from the coast and 20 wells, each with a monopod topside facility of dimensions 14x14m, reaching 50m above the seabed. It is uncertain whether this will be typical of the size, design and orientation of any future developments of this type, and the results of the seascape study for this development (see Gateway Gas Storage 2007) may not generally be applicable to other locations, though provides an indication of how such facilities and offshore wind farms visually interact. The prospectivity for carbon dioxide storage and natural gas storage largely coincides with areas which are the same or similar to the major hydrocarbon basins of the UK (see Section 2.5 and Appendix 1b), and in particular the southern North Sea and east Irish Sea, for example, the wider Bunter Sandstone group. The potential, therefore, is that offshore surface facilities associated with these types of projects that could result from future licensing and leasing will be some distance offshore, be relatively small (e.g. comparable to southern North Sea gas installations, which may not be manned), and isolated. These facilities would have navigational lighting and marking equivalent to that for oil and gas installations.

Many new oil and gas activities require only temporary surface infrastructure, as on completion many wells are tied-back to existing facilities. When this is not the case, longer term visual impacts may come in the form of jacket-type installations or FPSOs (which may be ship-shaped), and transient support vessel and aviation traffic. At night, any flaring and lighting from support vessels and rigs may also be visible from shore.

The operational lifetime of individual oil and gas developments will vary widely depending on the size of the resource discovered, production rates, and at what point economic recovery is no longer possible. Historically, large fields have had significant life spans (e.g. the Forties Field started production in 1975 and continues to produce oil), whereas smaller fields using tie-backs may have a lifespan of 10-25 years, or sometimes less. Installations can be considered to have a medium- to long-term effect on landscape/seascape. Gas storage sites may have a long service life as they maintain both inject and withdraw gas depending on demand. Carbon dioxide storage sites will have a life limited to the storage capacity of the formation and injectivity rate – the reverse of that for oil and gas production. Therefore, the life of such installations will be similarly variable.

5.8.2.5 Seascape sensitivity

Assuming that a development is visible from the coast, a number of factors can be considered to determine the overall significance of the effect, including the sensitivity of the receptor or seascape and the magnitude of change. Aspects of landscape/seascape "value" are also of relevance which can be informed by the location of designated areas (landscapes such as Areas of Outstanding Natural Beauty (AONB), National Scenic Areas (NSA), National Parks, or other conservation features such as World Heritage Sites (WHS), scheduled monuments or landscapes of historic interest – see Figure 5.49 and Appendix 1c for an overview of these), but a wider range of sites may help identify valued landscapes, including recreation value and conservation interests. Value is also locally variable, with stakeholders having differing views on what may be valued (LI & IEMA 2013), for example see Devine-Wright & Howes (2010).

There are a number of ways set out by DTI (2005), adopted from previous guidance, and used in regional scale studies such as Scott *et al.* (2005), which attempt to identify through objective (and partly quantitative) means the sensitivity of a particular coast or defined seascape unit. More recently, MMO (2019) define how seascape sensitivity may be assessed, informed by Natural England (2019) and the LI & IEMA (2013). In relation to the seascape character areas defined for UK waters, including those in English and Welsh waters, MMO (2019) define sensitivity to be the combination of the susceptibility of a defined marine character area to a defined type of change and the value of the seascape (e.g. due to its, "…special qualities including perceptual aspects such as scenic beauty, tranquillity and wildness, natural or historic attributes or features, cultural associations, or its relationship with designated or valued landscapes and coasts"). MMO (2019) includes a list of factors affecting sensitivity and examples come under the headings of, natural, cultural/social, quality/condition, aesthetic and perceptual, visual characteristics, relationship between seascape and coast (if not covered under other headings), potential for cumulative effects, and also value criteria (e.g. designations for landscape, nature conservation, heritage, and other attributes, for example, strength of character and sense of place.

The degree to which a given landscape/seascape may accommodate an offshore development, is largely determined by sensitivity. Key considerations including how the form and scale of the development interacts with coastal morphology and the level of development already experienced from coastal positions within viewable distance of the development. These characteristics are highly variable at the regional and local scale and are difficult to account for in a comprehensive manner at a strategic level, particularly without any spatially explicit consideration of where future leasing will take place.

The horizontal and vertical scale of the coast can influence the sensitivity of a seascape. Where the principal viewing platforms are across bays, inlets, sea lochs and inner firths, developments may take up more of the horizon and be framed by headlands, whereas more open, expansive views have the opposite effect (Scott *et al.* 2005). Aspect influences structure visibility during sunset and sunrise, as they appear silhouetted against the sky. Outside of scale, form, aspect and exposure, seascape sensitivity is greatly influenced by the level of coastal development, and this can be highly variable within regional scale seascape units. Urban and industrial settings, areas where other forms of mechanical movement are present (e.g. ships, cars), where artificial light is prominent, and where the observation points are from busy roads or beaches, may be considered less susceptible to development than rural areas. Where there is already considerable urban or industrial development, including existing offshore energy development, cumulative impacts are important (DTI 2005).

Sensitivity is not just a measure of the compatibility of development with coastal landscape, but also the users of that landscape. Examples of a range of sea and land based activities along a scale of sensitivity (for instance recreational boating to extractive oil and gas, and tourists/visitors to military and industrial users) are provided in DTI (2005). The use of the coast for such activities may be relatively easy to define and measure, though the sensitivity of individuals is more complex. Income losses from tourism and recreation activity were a common source of potentially significant effect related to the landscape effects of the Rampion and Navitus Bay developments, and this is also recognised in the overarching NPS for energy (EN-1), the MPS, the TR1 policies of the English marine plans, and the SAF_01 policy of the Welsh National Marine Plan.

Many of the factors influencing perceived aesthetic (landscape/seascape) quality are relative and subjective concepts which are bound by any given individual's attitude, perceptions, and *a priori* or *a posteriori* knowledge about offshore energy developments or indeed environmental/energy issues more generally. Prior knowledge or experience of offshore wind farms may take a variety of forms however, and Ladenburg (2009) found that those people with experience of wind farms sited far from the shore were generally more positive about the visual impacts of future developments than those with experience of nearshore wind farms, and that demographic and use of areas which would be visually altered by wind farms affected attitudes to offshore wind (Ladenburg 2010). The level of acceptable change for particular types of projects can be variable for individuals and communities, and can strongly affect the appreciation of an area and even threaten identity for those with strong place attachment (Devine-Wright & Howes 2010).

Landscape preservation (and change), like many environmental issues, is an emotive topic. Attitudes range from romantic views of nature as unspoilt "wilderness" to be preserved for its inherent landscape value, less anthropocentric "deep ecology" ideas of humans as part of the natural ecosystem, or "wise use" ideas falling within the umbrella of sustainable development. In each case, the inherent quality or naturalness of some landscapes are valued more than others, as recognised in statutory designations and the use of "value" in landscape/seascape studies. Naturalness and wilderness may often rely on perception more than any ecological understanding (e.g. see Carver *et al*. 2002, Colley & Craig 2019). In Scotland, a map of wild land areas was published in 2014[213], developed following consultation on previously defined "core areas of wild land". Four physical attributes were considered to define wild land: perceived naturalness of the land cover, ruggedness of the terrain, remoteness from public roads, ferries or railway stations and visible lack of buildings, roads, pylons and other modern artefacts (see Appendix 1c).

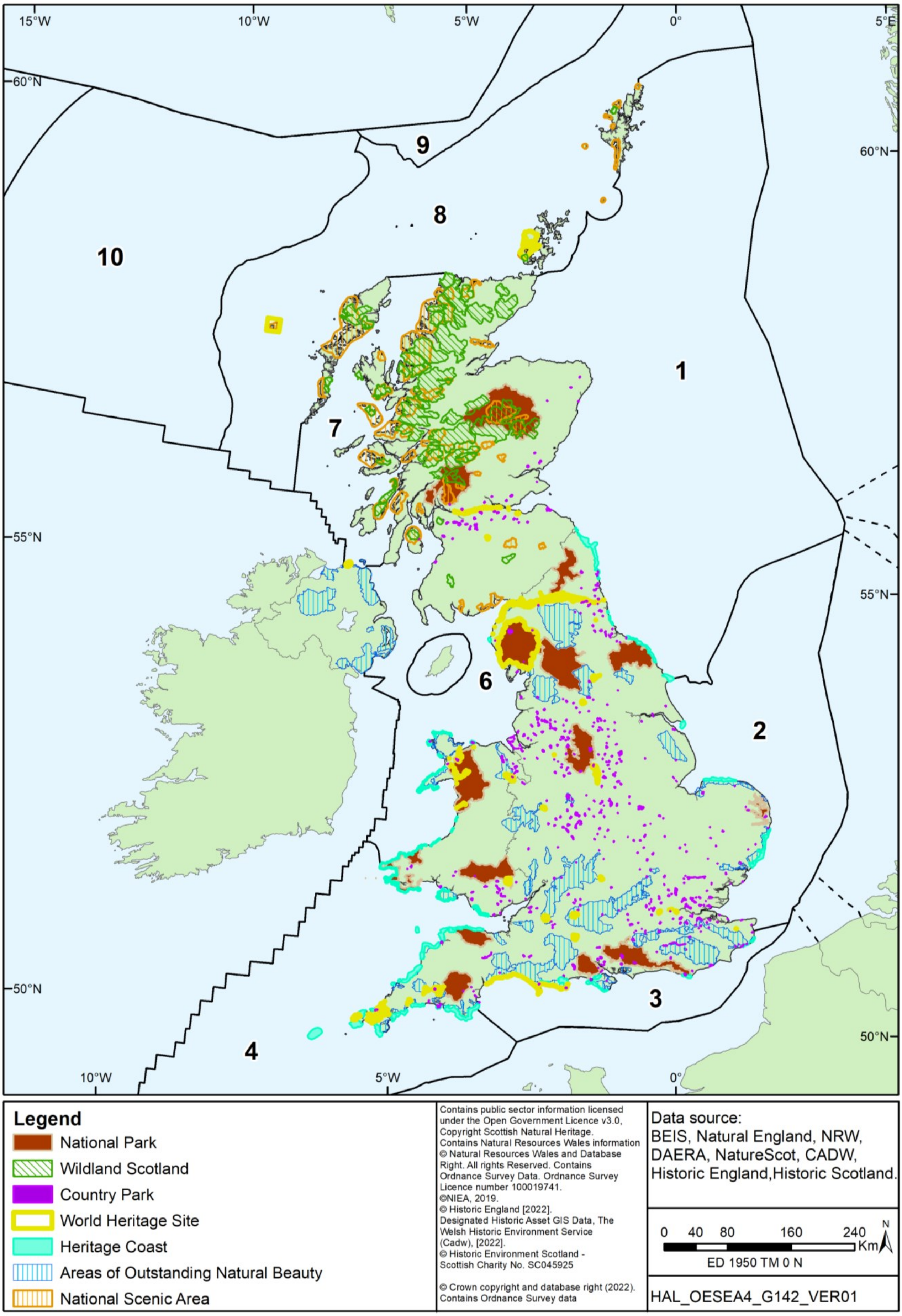
It is not just "wild" places where visual intrusion is regarded as deleterious, for the countryside or cultural aesthetic may be regarded to be as important, for instance the recent attention given to "Character Areas" which are assessed in the context of their natural (though more semi-natural) and cultural heritage qualities, and indeed for more recent urban qualities. Urban areas as distinct landscapes is highlighted in the European Landscape Convention, and by association with certain cultural World Heritage Sites (e.g. the Cornwall and West Devon Mining Landscape).

A Countryside Commission (1993) report, though now dated, indicated that over 60% of the UK public regarded the countryside as a vital component to their quality of life as opposed to the perceived "stress and pollution" of cities (Macnaghten & Urry 1998), and given that in 2019 82.9% of the population in England were urban dwellers, it may be presumed that for many people experience of the countryside, and in particular the coast, is an important occasional relief. Surveys of awareness and attitudes to renewable energy, specifically onshore wind, indicate that people are generally in favour of the use of renewables, including wind power, and that the general population perceives advances in renewables as necessary (possibly linked with perceptions and knowledge relating to the effects of climate change, and the role of renewables in cutting greenhouse gas emissions).

The BEIS (2021j) public attitudes tracker recently indicated an 81% support for offshore wind. This is not a proxy for the potential acceptability of such projects in terms of landscape and seascape effects, however, it does demonstrate a high level of support amongst the UK public for this technology. Similarly, the tracker noted an 80% support for wave and tidal. In answer to the question which could be regarded as most pertinent to landscape/seascape, "*I would be happy to have a large scale renewable energy development in my area*", less positive support was attracted (63% agreed, 13% disagreed, and remainder did not know or showed indifference). The difference between high support and lower acceptance has been previously considered by Bell *et al.* (2005, 2013).

[213] https://www.nature.scot/doc/wild-land-areas-map-and-descriptions-2014

Figure 5.53: Principal landscape or landscape related designations in the UK (also see Appendix 1c)



5.8.3 Spatial consideration

Section 2.5 provides an indication of the prospectivity for each element of the draft plan/programme which gives an outline view of where activities could potentially take place on adoption of the plan/programme – see Table 2.1. An overall spatial consideration for each of the major plan elements where the technical resource can be defined is provided in Section 5.15. The following section makes use of the prospectivity of draft plan/programme activities to help frame the discussion (also refer to Figure 5.55 to Figure 5.58), and is also informed by a range of information including landscape designations and the content of various character area descriptions as referenced in Appendix 1c.

In the absence of any further assessment of landscape and seascape sensitivity to offshore development, it can be seen from Figure 5.49 that those areas least likely to generate significant visual intrusion are those to fall outside of the visible range of designated landscapes which may be surmised to have a high landscape/seascape "value", and more widely for OWFs, areas greater than 44km from the coast (i.e. the average distance where the magnitude of effect of turbines of blade tip height of 350m is considered to be low for higher sensitivity seascapes; see above and White Consultants 2020a). Note that this scale of turbine incorporated into a large scale deployment scenario is significantly greater than even the largest models presently available (e.g. Vestas V236-15MW at 280m, scheduled for production in 2024), and that for much of the time, visibility will not reach such distances (Figure 5.50).

In relation to some planned and now operational large-scale offshore wind farms, those on the Dogger Bank and the former Hornsea and East Anglia Round 3 zones, are well beyond limits of low magnitude of effect (Figure 5.49). It is identified in Section 5.15 that some technical resource of fixed wind farms remains within a distance that effects could be significant, however, other constraints in these areas may make their development challenging, and further wind leasing is more likely to take place further offshore, particularly in view of cost reductions and increasing experience of deploying floating offshore wind farms.

The following section covers all Regional Seas other than those at extreme distance from the coast (Regional Sea 5 and Regional Seas 9, 10 and 11). As noted in Section 2.3, each aspect of the draft plan/programme is applicable to only some areas of the UKCS depending on various devolved arrangements. For clarity, unless there are transboundary considerations, the following discussion covers oil and gas and gas storage for the whole UKCS, carbon dioxide storage for the EEZ other than the territorial waters of Scotland, and renewables in the inshore and offshore waters of England and Wales. The prospectivity of each area is also considered, and this section should also be read in conjunction with Sections 2.5 and 5.15 in order to put in the context the potential scale of further leasing and licensing, and also the other range of constraints that might limit the deployment of certain technologies in some area.

Figure 5.54: Designated landscapes in the UK and areas of technical and theoretical resource in relevant UK waters

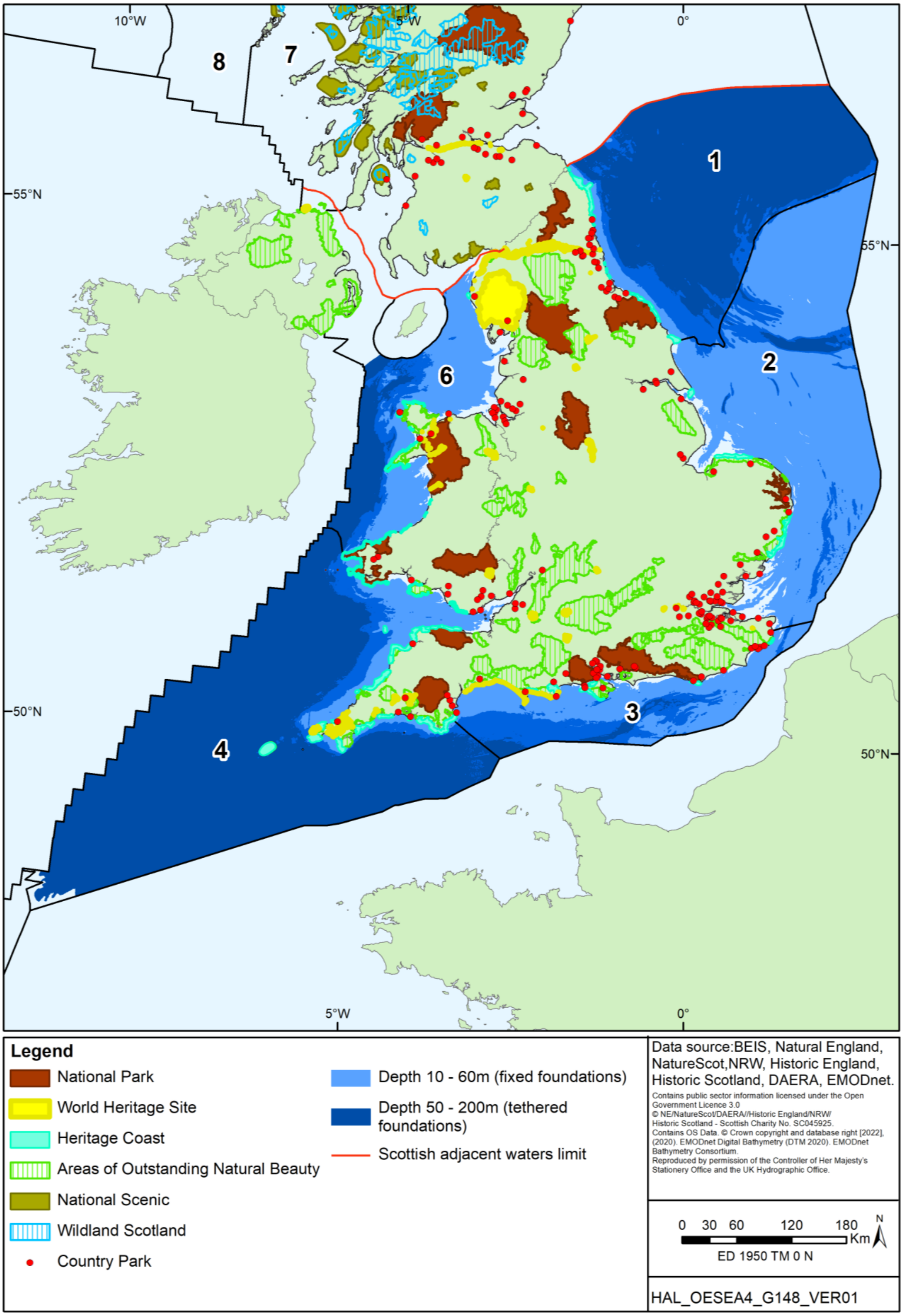


Figure 5.55: Designated landscapes in the UK in relation areas of technical and theoretical tidal stream resource in relevant UK waters

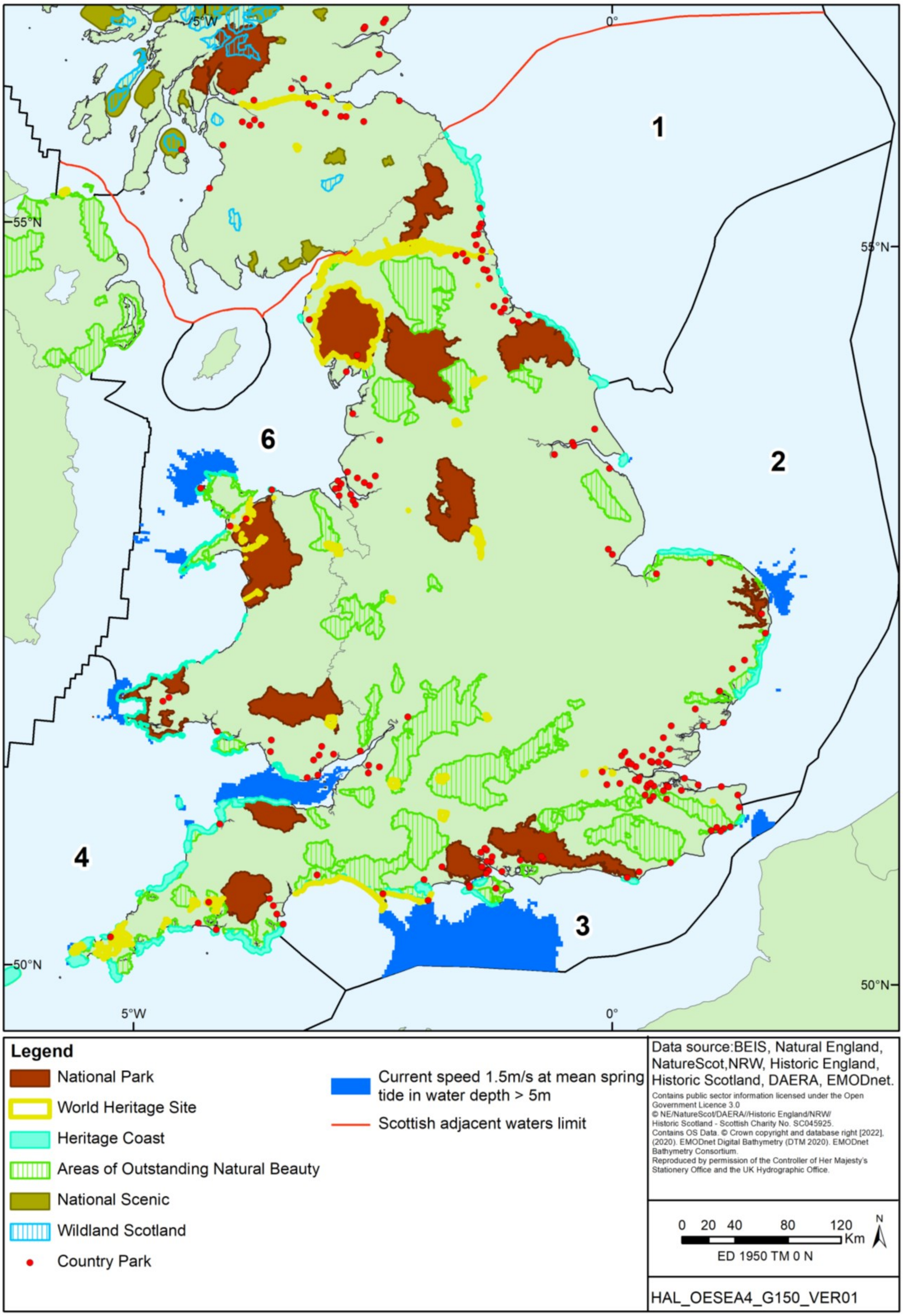


Figure 5.56: Designated landscapes in the UK in relation areas of technical and theoretical wave resource in relevant UK waters

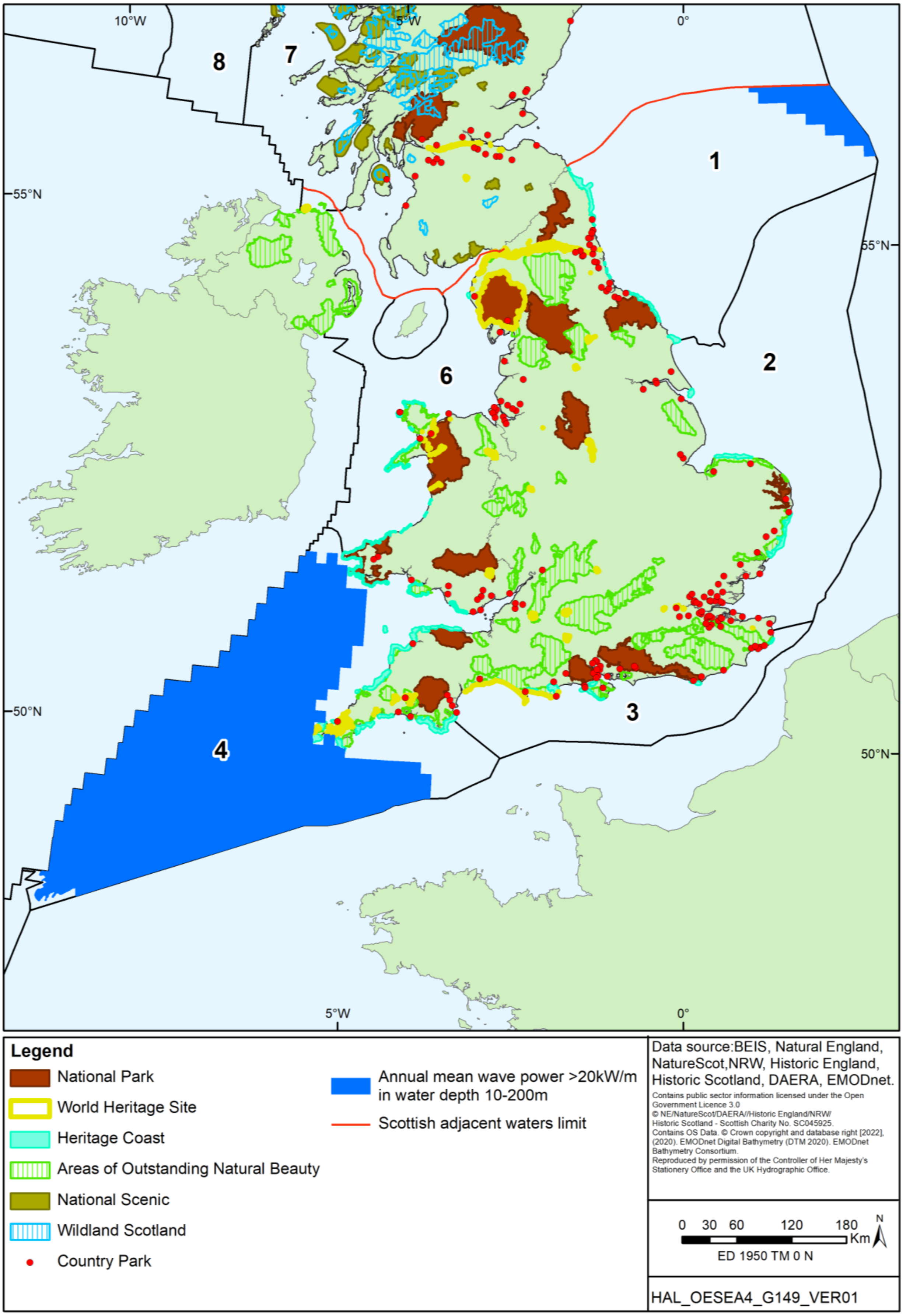


Figure 5.57: Designated landscapes in the UK and areas of technical and theoretical resource for tidal range in relevant UK waters

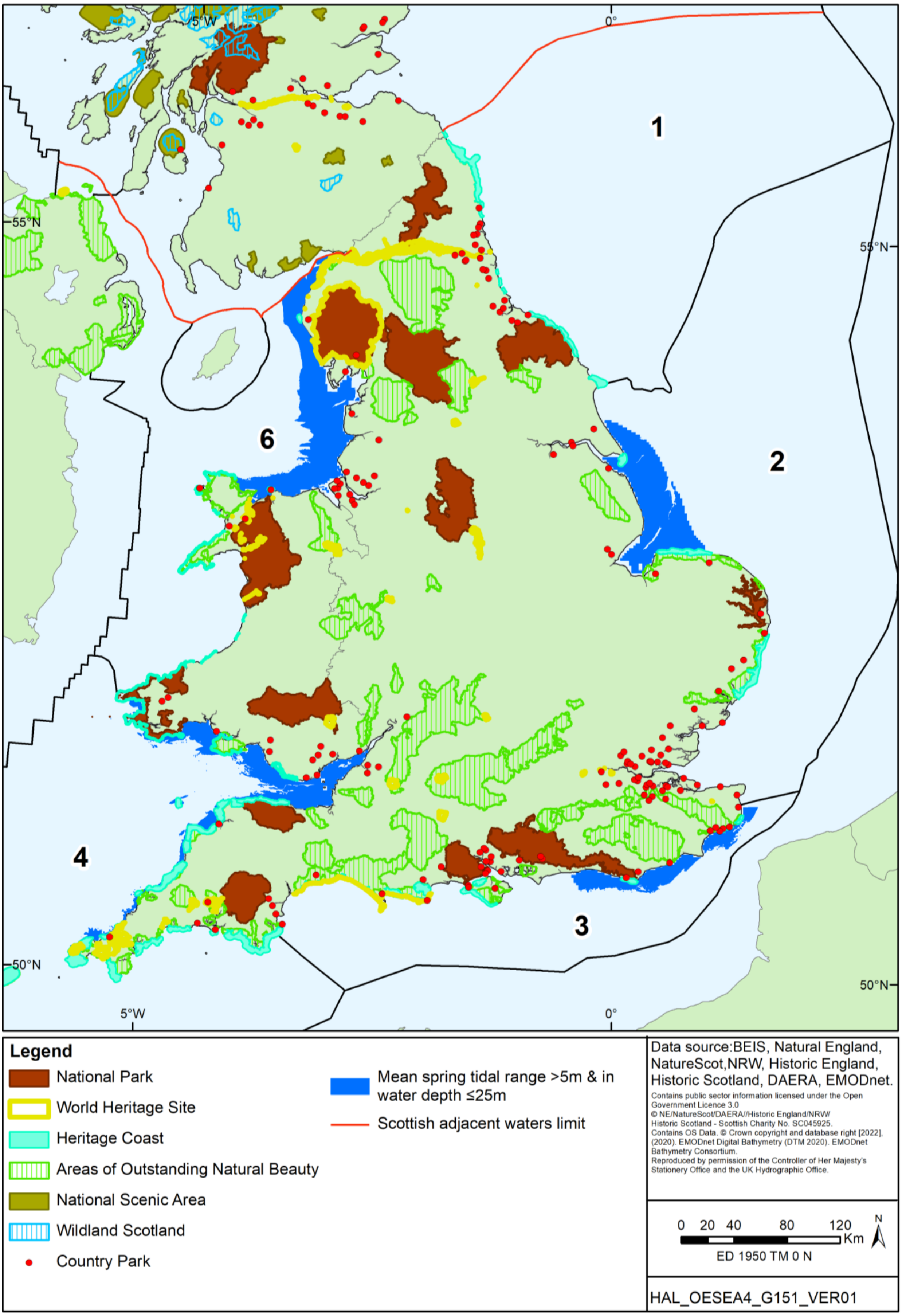
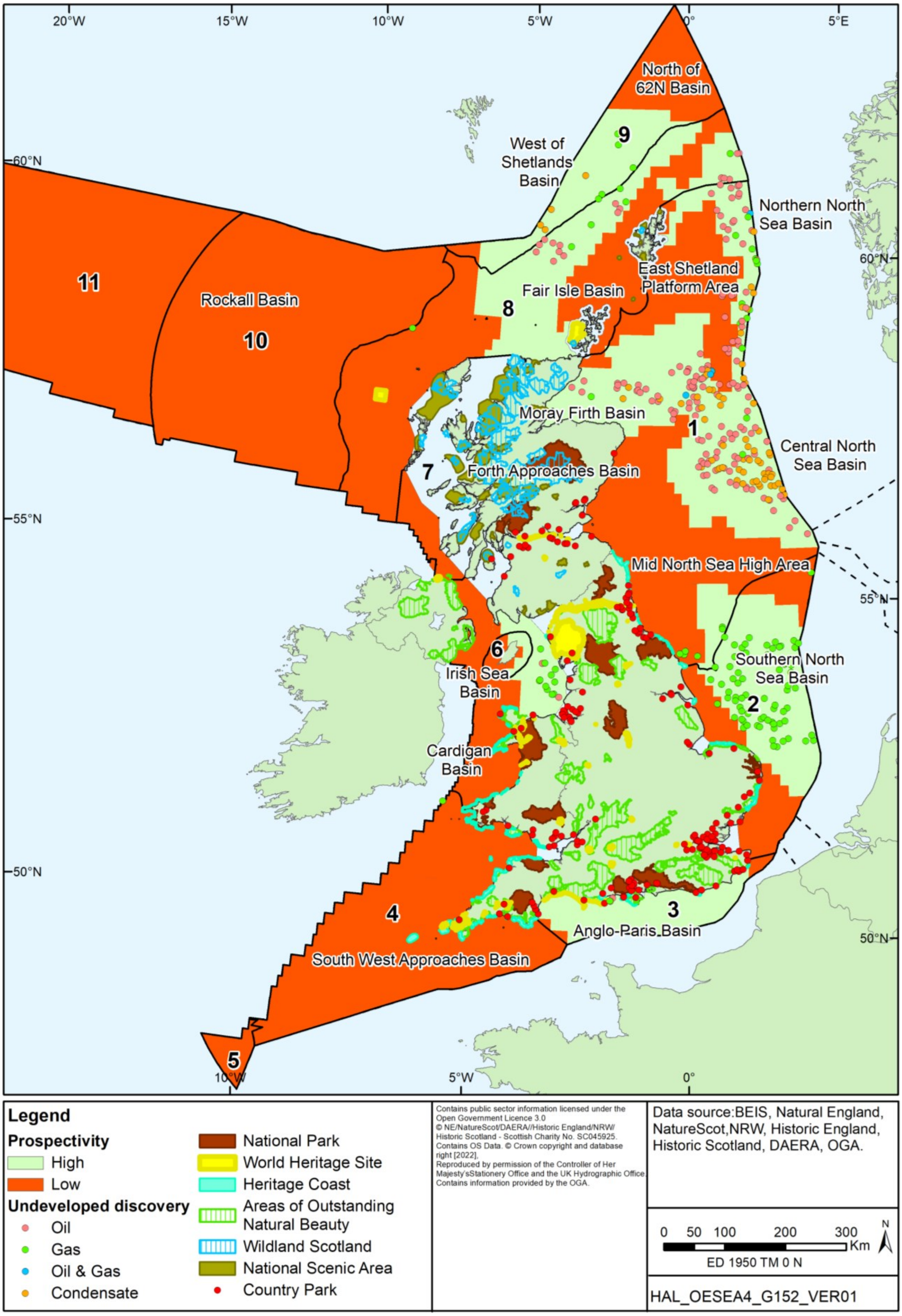


Figure 5.58: Designated landscapes in the UK in relation to the major oil and gas basins of the UKCS, their high level prospectivity and the location and type of significant* discoveries



Note: * "significant" generally refers to the flow rates that were achieved (or would have been reached) in well tests (15 mmcfgd or 1,000 BOPD). It does not indicate the commercial potential of the discovery.

Regional Sea 1

Wind turbines are the most likely renewables devices to be deployed in the area of Regional Sea 1 covered by this draft plan/programme. Deeper waters to the east of the UK in this Regional Sea have prospectivity for tethered turbines, particularly given the relative quiescent wave climate compared to other major prospective areas in English and Welsh waters, namely the South West Approaches. A relatively small coastal strip therefore provides potential for fixed foundation offshore wind, and any such wind farm would be visible from the coast. Outside of the potential for demonstration scale projects, there seems low prospect of large scale commercial wind (fixed or floating) being deployed in the nearshore for a variety of reasons (also see Section 5.15), in relation to seascape, the higher visibility of the nearshore areas off Northumberland Coast AONB, the North York Moors National Park, and related Heritage Coasts. There is the potential that future floating wind farms could be located at a distance from the coast where they would be visible, however, in view of the wider constraints within the resource area for floating wind in Regional Sea 1, it is more likely that floating wind will be sited towards the indicative limits of low magnitudes of effect (see Section 5.15).

There is limited prospectivity for wave devices to the north east of Regional Sea 1, however this area is a minimum of 210km from the coast and infrastructure at this location would be too far from the coast to see, so any effect is discounted.

Oil & gas structures are typically located too far from shore to be perceptible, though a number of blocks were awarded in recent offshore oil and gas licensing rounds which abut or are in close proximity to the coast, (e.g. North Yorkshire – Block 41/18, Buchan coast – including Blocks 18/1-18/5 and Caithness Coast – Block 12/16, see Section 2.5.3). This demonstrates continued interest in such areas for exploration activities. Such exploration, if involving drilling, typically requires the temporary presence of a mobile drilling rig for, on average, up to 10 weeks as well as support vessels and helicopters for supply and crew changes. Exploration activities may also involve the use of vessels for seismic survey which may take in the order of several days or up to several weeks to complete. Based on historical trends, typically less than half of the wells drilled reveal hydrocarbons, and of that, less than half will have a potential to progress to development. Additionally, installations can be more permanent (i.e. for field life), but are increasingly subsea in nature and tied back to existing host facilities. All such facilities are well beyond the distance at which they would be visible from the coast in Regional Sea 1.

Landfall associated with any gas storage, unloading or carbon dioxide transport and storage or hydrogen transport projects may locally affect certain areas. Pipeline and cable landfalls can both create effects on the landscape and visual resource, however they tend to be temporary in nature (perhaps 6 months). Teesside and Tyneside are centres of high carbon dioxide emissions, and may therefore be prime locations for CCS demonstration. The proximity of these regions to the North Sea is also advantageous, as extensive existing oil and gas infrastructure exists which could be used for carbon dioxide transport and storage on depletion of hydrocarbon reserves. While this SEA only considers future offshore leasing and licensing, it is noted that there is also potential for carbon dioxide storage in Scottish waters, exemplified by the Acorn Project.

The open and expansive seascapes viewable from Shetland's coast may be compatible with the scale of any development, though they may affect the intricate land/sea relationship and views of outlying islands including Fair Isle and the appreciation of the vertical scale of high cliffs where these are present. The perception of remoteness and "wildland" qualities of some coastal areas and the highly natural character of the outlying islands may also be affected by development. To date, no oil and gas licensing blocks have been awarded in close proximity to Shetland, however the terminal located at Sullom Voe provides for an association with the oil and gas sector in this area. Increased use of the seas around Shetland for aquaculture may visually conflict or generate in-combination effects with offshore energy developments.

In the Moray Firth, the Beatrice platforms can be seen from land by day and night, though are at some distance from any viewable location. The Jacky development was removed in 2021 and Beatrice is subject to decommissioning and is likely to be removed in the coming years. Any further development of oil and gas infrastructure in this area is likely to be in a similar location, or else associated with a small area off the Caithness coast, however operations for the latter could be based onshore. The seascape study for the Beatrice demonstrator wind turbines concluded that the average distance at which low magnitude effects occurred was 30.3km from the coast, extending to a maximum of 41km, which provides an indication of the high degree of visibility in this area. Any further development would extend the visual effect of offshore oil and gas infrastructure in the Moray Firth, and may act cumulatively with further offshore wind projects, such as Moray East and Moray West. This may further affect the perception of this area as being remote and "undeveloped" (e.g. see areas of wildland identified for Caithness in Figure 5.49), however, it should be noted that there continues to be an association with the oil and gas industry in this area, for example the rig servicing yard at Nigg provides for regular views of transiting mobile drilling rigs in the Moray Firth and Cromarty Firth, and more recently, shipping and the barge transport of infrastructure related to the offshore wind farm developments in the Moray Firth.

With regard to carbon dioxide transport and storage, the Captain Sandstone in the Moray Firth has the potential for CO_2 storage. Any infrastructure that could be developed here (note that only offshore waters are of relevance to this draft plan/programme for CCS), would not be appreciably different than surface infrastructure associated with oil and gas exploration and development.

The east coast of Scotland has few statutory landscape designations, just two – the Dornoch Firth and Fair Isle NSAs. There are Local Landscape Designations which stretch around Fraserburgh Head from Peterhead to Cullen, in the outer Dornoch Firth and parts of the Caithness and Ross-shire coast though these are not regarded with the same weight as NSAs, and the area does not contain the same "wild" perception as Scottish landscapes to the north and west. Within the context of the draft plan/programme, significant effects are not considered likely. To date no blocks off the east coast of Scotland have been licensed within ~40km of the coast (see Appendix 1h). The terminals at St Fergus and Cruden Bay have an association with the industry which will continue for the foreseeable future (and may continue through re-use associated with carbon dioxide transport and storage), and major ports in the area including Peterhead, Aberdeen and Dundee are characterised by offshore oil and gas activity, with Dundee also servicing mobile drilling rigs.

For some areas such as the Firth of Forth and Firth of Tay, urban expansion is unlikely to significantly alter the sensitivity of the landscape, which contains landmark road and rail bridges, and great coastal variety. The firths have some industrial elements including power stations and petrochemical plants which may reduce their sensitivity to development, however, it is considered unlikely that activities related to the draft plan/programme could be situated such that they are visible from coastlines within the firths. For example, the area is not considered to be particularly prospective for either oil and gas projects, or gas storage, including carbon dioxide storage, and this draft plan/programme only covers carbon dioxide storage when it is located beyond 12nm from the Scottish coast. The coast from the Firth of Forth to the English border affords wide open views to the sea from a generally linear coastline. Existing development and transport infrastructure already give a developed character in places and busy shipping lanes are present in the sea. The coastal is dramatic in places, and includes views to Bass Rock and the Isle of May.

Further south to Flamborough Head, the coast has a high number of designated landscapes including Heritage Coasts (e.g. North Yorkshire and Cleveland, Flamborough Head, and North Northumberland), a National Park (North York Moors), AONB (Northumberland Coast) and World Heritage Site (Hadrian's Wall). A number of national trails traverse the area including the Cleveland Way and Yorkshire Wolds Way on which people would be primarily expecting wild and natural views across the land and sea. These paths are now being augmented with access (paths and recreation areas) created under the *Marine and Coastal Access Act 2009*, with the sections of path from South Bents to Filey Brigg presently open (see Appendix 1h), with the remaining sections in Regional Sea 1 approved but not yet open. The establishment of such a coastal path has the potential to raise access to the coast and enhance the number of receptors who could experience any changes or effects resulting from projects related to the draft plan/programme. As noted above, the siting of large commercial fixed or floating wind farms close to the shore in this area is considered unlikely, and additionally, the following consideration is only relevant to offshore wind and oil and gas exploration and production, as the resource areas for wave and tidal elements of the draft plan/programme are either not present in Regional Sea 1 or are too distant to be significant (Figure 5.55 to Figure 5.57).

The Northumberland coastal plain is sparsely populated and rural, and the coast affords wide open views to the east from both elevated hard-rocked cliffs in the north and soft low-lying coasts to the south. Views include those out to the Farnes, Coquet and Holy Island and undeveloped coastal views over open horizons. The waters are not intensively used and are characterised by smaller inshore fishing boats and recreational craft. This area, which incorporates NCA1 and MCA 23 (see Appendix 1c), coincides with a number of landscape related designations (e.g. Northumberland Coast AONB, North Northumberland Heritage Coast), as well as being a popular amenity area both on the coast and offshore (e.g. surfers, kayakers, boat trips). There are a number of conservation designations for important bird colonies and reef habitats both relevant to the mainland coast and islands, as well as strong cultural and religious associations associated with Lindisfarne. These aspects, taken together with the undeveloped, exposed and, relative, remoteness of the area and high levels of visibility of the sea suggest a higher level of sensitivity to offshore wind and other energy development in this area. The western extent of MCA 26, Berwick Bank, will have a similar visual sensitivity to those areas noted above as it provides part of the maritime setting to, for example, highly valued landscape designations. The offshore area to the east of MCA 26, and all of MCA 28, will be less sensitive to purely visual effects due the distance from large numbers of coastal. Both these areas are associated with productive fishing grounds and contain relatively busy shipping routes, suggesting lower sensitivity to energy-related activity.

This coastal area to the south of this is contrasting, with waters towards the Tyne, Tees and Wear Estuaries (MCA 22) including extensively developed lowland coast with industrial elements at Middlesbrough, large shipping vessels associated with Tyne and Teesport and demonstration scale offshore wind farms of Teesside and Blythe. Notable distinctions from the largely urban character include Hadrian's Wall WHS which meets the coast at Wallsend and the undeveloped Durham Heritage Coast, which has good coastal access with increasing opportunities for recreational activity. In this area, to the north of the Tees lowlands, Magnesian Limestone has formed a varied line of bays and headlands – erosion has generated features such as caves and stacks, increasing the complexity of the coast. Highly visible offshore structures may detract from the complexity and the unique, incised gorge-like coastal denes, particularly where views are focussed down enclosed denes. For much of this area, its generally exposed nature and industrial elements suggest a lower sensitivity to offshore development that may make it more compatible with such activity, and though this is broken up by locally important undeveloped coastal areas, a relatively high level of shipping traffic offshore lessens the sense of remoteness. Similar to the above, further offshore the Farne Deeps (MCA 25) has views of the settled coast and in the west with prevalence of fishing and shipping activity, but is more remote in the east (though military activity and shipping characterise the area), going beyond the limits of visual significance for any development.

Cliffs along the coast between Saltburn-by-the-Sea and Flamborough Head (including parts of NCA 25-27 and MCA 21) include Jurassic and Cretaceous exposures, and reach between 100 and 150m, affording views over a wide open seascape. Although possibly viewed by few from these elevated locations, which includes the Cleveland Way, sunrises would silhouette turbines or other structures against the sky and make them more visible at this time of day. The coast includes parts of the North York Moors National Park and has undeveloped stretches with dark skies and high levels of tranquillity. Important bird colonies are present at Bempton Cliffs and Flamborough Head which also includes a complex coastline of cliffs, caves, arches and platforms, which are distinctive and draw visitors to the area. There are strong historic associations with fishing including whaling at Whitby and the 19th and early 20th century herring fleets, with major historic fishing ports including Scarborough, Whitby, Filey, Flamborough, Straithes and Robin Hood’s Bay. The rugged coastal form, small coves, bays and coastal towns and fishing villages of the North York Moors area and the lightly settled area of the Yorkshire Wolds may not be compatible with the developed character of wind turbines, rigs (though temporary) or other surface installations in close proximity to the shore. The inshore area contains a large number of wrecks with relatively fewer wrecks offshore (MCA 24) the area was historically important as part of the East Coast War Channels (see Appendix 1i) which were vital for transporting coal and other goods from the Tyne to the Thames and France during WWI and WWII. While the offshore areas associated with this in Regional Sea 1, which include MCA 24 and 27 are partly or entirely beyond any limits of visual significance related to offshore energy development, these areas (amongst others) spanning the wider southern North Sea contain the palaeolandscape, Doggerland (now the Dogger Bank), an area which may have remained habitable for part of the early Holocene (see Appendix 1i), and while of historical importance, these offshore areas contain significant vessel movements and also some oil and gas activity, reducing their sensitivity to further development.

Regional Sea 2

The most likely renewables devices to be deployed in the area of Regional Sea 2 are wind offshore turbines. A small area off Spurn Head and a larger area off the east Norfolk coast also fall within the technical range for tidal stream devices. No proposals have been made for such devices in these areas to date, and while demonstration or possibly small commercial deployments projects are possible, a range of potential constraints on these areas (see Section 5.15) may reduce the scope for deployment there. The design of tidal stream devices also mean they tend not to be surface piercing, or have a substantial surface component and are arguably less likely to generate significant effects. Large commercial deployments with surface elements (as exemplified at Strangford Lough) could introduce visual components in the form of low structures and lighting. Even if these devices do not meet the surface, they may require illumination in the form of buoys where water depths are limited and devices reduce the under-keel clearance of vessels.

The area between Holderness and the North Norfolk coast has the largest tidal range resource on the east coast of the UK. A number of proposals have historically been made for schemes at the Humber and Wash, however, these have not been realised, and focus to demonstrate the technology has tended to be on the Severn. Additionally, there are a number of potentially significant constraints on tidal range development in this area (see Section 5.15) that make large areas within Regional Sea 2 very unlikely to be suitable for such projects.

Oil & gas structures are typically located too far from shore to be perceptible, the prospectivity for gas finds is generally too far from shore for any project to be visible, and the array of existing infrastructure in the area makes the potential for subsea tie-back to host facilities more likely, negating and longer term impacts from surface infrastructure. Seaward licences for oil and gas exploration have been in the past been awarded close to the coast, for example the East Riding of Yorkshire, but to date few wells have been drilled in proximity to shore, and licences have been relinquished without development, with prospectivity generally lower closer to coast both to the north and south of Norfolk. As indicated above, exploration activities are temporary in nature and development stage proposals are increasingly subsea in nature. The southern North Sea has a long history of hydrocarbon (principally gas) exploration and production, with gas terminals constructed at Easington, Theddlethorpe (now subject to decommissioning) and Bacton, and a high concentration of surface infrastructure offshore (e.g. as recognised in the East Marine Plans seascape character area 3, the East Midlands Offshore Gas Fields).

The Yorkshire and Humber area has significant carbon dioxide point sources, with previous proposed projects to capture and store CO_2 from power stations including Drax and as part of the Don Valley Power Project. More recently, the Humber along with Teesside have been selected as part of the UK Government's CCUS cluster sequencing, which aim to store a significant volume of the UK's industrial CO_2 emissions in an offshore storage site, with deployment potentially in the mid-2020s. The proximity of this region to the southern North Sea is also advantageous, as extensive existing oil and gas infrastructure exists which could be used for carbon dioxide transport and storage on depletion of hydrocarbon reserves, proven storage and sealing structures in the form of former gas fields, and the largest and most prospective saline aquifer on the UKCS (see Appendix 1b, and also refer to East Marine Plans Policies CCS1 and 2 and related policy maps).

The most northern section of coast in Regional Sea 2 contains a number of Heritage Coasts include Flamborough Head, Spurn Head, and the Norfolk and Suffolk Coasts. In Norfolk and Suffolk these coincide with the Norfolk and Suffolk Coasts and Heaths AONBs and the Broads National Park, signifying the importance that is attached to the landscapes, and associated seascapes, of these areas. Like other areas of the English coast, coastal paths and related amenity land are being developed in Regional Sea 2, with parts already open (e.g. Skegness to Mablethorpe, Sea Paling to Weybourne) and others which are at various stages of completion (see Appendix 1h).

Higher cliffs are present at Flamborough Head, with those along the coast of Holderness and Lincolnshire to The Wash being lower. The Holderness coast is characterised by extensive WWI and WWII coastal defences and the composition of the coast (extensive glacial tills) are soft and erodible, leading to some of the highest rates of coastal retreat in the UK. The general absence of coastal vegetation and low lying nature of the coast create an exposed character and provide wide, expansive views of the North Sea, but the flat topography also limits views of the sea inland. Inshore fishing, and in particular potting, is locally important. Holderness is generally rural and contains a number of areas seasonally popular with tourists including caravan parks, and the seaside towns of Bridlington, Withernsea and Hornsea. Offshore wind farms are already a feature of part of this coast, with the Westermost Rough wind farm visible from Withernsea, and Humber Gateway visible from Spurn Head. Views from the coast will be large scale and open, with the exception of the Humber, though the industrial nature of much of this area may be compatible with offshore structures. Open, eastern facing views may mean that there is a strong contrast between structures and the sky during sunrise.

The variation in local cliff height will alter the viewable distance of the observer, though if infrastructure is sited sufficiently offshore this should not significantly influence the impact of a development, though at night navigation and aviation lights may be more visible from higher ground. Where there are a number of offshore wind farms, the movement of blades passing aviation lighting on the nacelle could result in the appearance of irregular flashing of lights. Water depths of <60m extend well offshore from the Holderness coast so wind farm development is possible where any visual impacts are likely to be only experienced by people on passenger ferries, recreational craft and commercial and fishing vessels. The creation of large wind farms offshore, such as at Dogger Bank, has the potential to change the character of how these seascapes are experienced, or perceived. The East Marine Plans character area 1, Dogger Bank, emphasises the extensive and remote nature of the area, and the expansive open water character of the seascape which has few surface features. Both the existing proposals for this area, and any future proposals given the large technical area of opportunity for fixed offshore wind, or tethered turbines just to the north, would introduce surface components and likely affect the remote nature of Dogger Bank. Elsewhere, such as in proximity to the Hornsea offshore wind farms or, once constructed, Norfolk Vanguard and Boreas, gas installations have been a feature of these seascapes for some time though in low densities, or else high shipping densities result in a seascape for which industrial activity is well established, making these less sensitive to further development.

Extensive areas of saltmarsh are present in the Humber and Wash Estuaries, which provide low, open and simple landforms which may be incompatible with vertical turbine structures. Numerous smaller examples occur in estuaries draining the outer Thames in Suffolk, Essex and Kent (e.g. Medway, River Stour), and views may be focussed down some more enclosed estuaries. Any tidal range schemes which incorporate a barrage will alter such focussed views by generating a visual barrier to the open sea, having associated access roads, surface infrastructure, lighting, and the light and movement of vehicles. This may amount to a substantial change in the character of such areas. Loss of intertidal area and related changes to habitat and species in the estuary, for which climate change and any tidal scheme could act cumulatively, would also introduce a significant change to the landscape of the estuary.

Individual tidal stream devices would be less of a visual intrusion, though may still require navigational marking and lighting, and as indicated above, are highly restricted in terms of viable location (Figure 5.55). The low lying nature of the Broads and also North East Norfolk and Flegg, and screening of the sea by sea walls and dunes may restrict views of any tidal devices in this area, however at the coast views are expansive and so devices or their markers could be visible. The low-lying Broads back onto the coast near Great Yarmouth and are also a visually intricate landform which will increase the sensitivity of this section of coast to vertical offshore structures, including nearshore wind turbines. The number of potential constraints on development close to the shore in this area (see Section 5.15), and certainly within territorial waters (see Section 5.6), are such that future siting of large commercial arrays in proximity to the shore is considered unlikely.

The vast open views of the North Sea afforded from Norfolk, Suffolk, Essex and Kent coasts has the potential to reduce the perceived visual intrusion of any wind farm or other offshore development as it would only change visual aspects of a part of the seascape, however in view of the multiple activities taking place in the southern North Sea, and those extant and planned wind farms, any impact would need to be considered with regard to the potential for cumulative effects to be generated. The coastline is made up of a combination of cliffs and low-lying shingle, sand and saltmarsh, and where these views are simple and horizontal; they may be undesirably interrupted by the vertical form of certain offshore structures. Cliffs also tend not to be high, and their scale may be further diminished by large turbines in proximity to the coast (however, see above in relation to the multiple levels of constraint in this area which could limit deployment here). The development in this area is largely rural and existing developments (e.g. Sizewell and Bradwell nuclear power stations) are extremely visible in this very flat and open landscape. White Consultants (2020b) applied the seascape sensitivity methods outlined in MMO (2019), amongst following other guidance, to the inshore and offshore waters off the Suffolk coast. The type and scale of development assessed included wind farms with a bade tip up to 400m, with sensitivity assessed for a number of defined seascape character areas. It was found that the seascape of Suffolk is sensitive to offshore wind farm development due to its relationship with the Suffolk Coast and Heaths AONB and Suffolk Heritage Coast. Seascape character areas closest to the AONB and Heritage Coast were considered to generally have a High visual sensitivity, such they would be unable to accommodate offshore wind farm development without significant character change or adverse effects (also NRW 2019, Regional Sea 4 and Regional Sea 6). To the south of the Suffolk Heritage Coast and inshore, sensitivity reduces to High/medium with some visibility of existing wind farms for which cumulative effects are currently avoided due to distance from the coast and separation, though further development towards the shore was considered to cause harm to the qualities and natural beauty of the AONB and Heritage Coast. Medium/low levels of sensitivity where adverse effects are not considered likely, and for large wind turbines of up to 226-400m, were considered to be beyond 40km from the coast. In addition to offshore wind farms the contrast of Sizewell A and B was considered to make the AONB and Heritage Coast more vulnerable to change by other energy infrastructure, with these and also Sizewell C likely to act cumulatively.

There are numerous coastal urban areas along the coast though many are small or holiday resorts (e.g. Great Yarmouth, Cromer, Skegness) rather than industrial towns, noting that some (Skegness in particular) already have seascapes in which offshore wind is a significant component. The largest and most developed areas are Hull and Greater London which include gas terminals, oil refineries, chemical engineering industries and various coal and nuclear power stations (e.g. Sizewell, noting the context provided above). Holiday resorts may have less capacity to absorb the visual intrusion of offshore structures than these more industrial areas. The Thames has area has high carbon dioxide emissions, and as a result may be an area supporting CCS in the future. Onshore developments may include those used for gas compression, or increased port activity and gas offloading – uses which are broadly comparable and compatible with activities already taking place in Regional Sea 2. Any offshore infrastructure associated with CCS has the potential to generate cumulative or incremental effects in a region which is already extensively used for other marine activities, however as noted elsewhere, their form and location are likely to be similar to that of existing gas field infrastructure which forms an established part of the offshore seascape (e.g. MCA 3 of the East Marine Plans) (see Appendix 1c and also Section 5.15).

Pressures on existing use of the landscape come in the form of further industrial and urban development around Hull and the Thames, and there is limited pressure from caravan, theme park, golf course and water sport development. There is a continuing spread of holiday resorts and homes (e.g. around Cleethorpes, between Mablethorpe and Skegness). Beach nourishment and historical coastal defence, its maintenance and other engineering is altering the physical form at a number of locations along the coast which may continue in the future (e.g. in relation to the implementation of shoreline management plan policies). Coastal squeeze leading to beach steepening and mudflat areas is likely to be exacerbated by any sea-level rise (see Appendix 1b, 1f and Section 5.12). In some other places, cliff erosion (e.g. Holderness, North Norfolk, Suffolk Coast) will continue to change the form of the coast and is a distinctive characteristic of these areas with strong historical associations (e.g. relating to lost villages). Onshore wind is also a feature of the coast, and these, and any subsequent developments within viewable distance of the coast, could generate cumulative impacts if there is sufficient intervisibility of onshore and offshore structures within seascapes.

Regional Sea 3

Prospectivity for plan activities in Regional Sea 3 is primarily for offshore wind and tidal stream, with an area in the eastern Channel between Sandwich Bay and Worthing having prospectivity for tidal range development. The lack of large natural embayments makes this area more likely to be targeted for lagoon-type developments rather than barrages. Issues raised on visibility for previous wind farm proposals in this area, and the occurrence of multiple uses (particularly major shipping lanes) in a relatively confined area of sea, suggests a highly constrained resource for offshore wind, with the resource area having higher levels of constraint (see Section 5.15). Tidal stream resources are located off the Kent coast and in the central English Channel, south of Portland, St Alban's Head, Durlston Head and the Isle of Wight. In view of multiple users of this area, and its sensitivity for other reasons also related to landscape/seascape (see below), the potential resource for tidal range may be very limited.

Limited offshore oil and gas potential exists in the area, which is generally regarded to have low levels of prospectivity, however, seaward blocks were awarded in recent (28th) licensing rounds for blocks which abutted or were in close proximity to the coast, but these have subsequently been relinquished. The licence associated with the Wytch Farm field, Dorset, while a seaward production licence is produced onshore via extended reach drilling. The hydrocarbon basins which have been exploited in this area have the potential to act as carbon dioxide storage in the future, however potential connectivity to large emitters is more restricted (i.e. Fawley refinery) than in other areas of the UK.

The coast of Regional Sea 3 has progressively more designated landscapes or features of natural and cultural importance to the west, however large, linear designations track the coast such as the Dorset and East Devon AONB, Dorset and East Devon Coast World Heritage Site, East Devon Heritage Coast, and Isle of Wight AONB and Tennyson Heritage Coast. The South Downs National Park extends in a general east-west trend and includes a number of notable seascapes with elevated views, for example from Beachy Head and the Seven Sisters (see LUC 2015 for an overview of views within this National Park). Between Dover and Beachy Head, the coast includes elements of the Kent Downs and High Weald AONBs and the South Foreland, Dover-Folkstone and Sussex Heritage Coasts in addition to numerous country parks within 10km of the coast. These designations afford the landscape a high value where they meet the coast, and the North and South Downs Ways provide access to coastal cliffs at Beachy Head and between Dover and Folkestone, frequented by people seeking the views of the accompanying AONBs. Camber to Folkstone, Folkstone to Ramsgate and Rufus Castle to Lulworth Cove, are the only sections of the English coastal path to be completed and opened to date, with other stages wholly or partly approved, with some yet to be approved but for which proposals have been published (see Appendix 1h). Maritime use is a strong characteristic of most of the seascape character areas identified for the South Marine Plan areas, including the large commercial traffic associated with the Dover Strait and shipping lanes of the central Channel, and smaller fishing and recreational craft which more strongly characterise the inshore areas of Selsey Bill, south Wight and the Solent. The area has a long and established maritime history attested to by the number of historic shipwrecks and other losses in this Regional Sea (see Appendix 1i). In addition to views from the various coastal designated and other locations in Regional Sea 3, these areas also define aspects of these seascape character areas as they are experienced, for example, from recreational sailing. The area contains numerous RYA cruising routes and clubs/marinas and therefore views from sea to some of these major landforms may be altered by offshore development.

Dover and Folkestone are urban areas which may be more compatible with offshore structures, though the elevation of the landscape around the towns, which includes cliffs and high ground in excess of 150m, will increase the viewable distance and may diminish the scale of the cliffs if they are intervisible with developments; it should also be noted that the nature and scale of shipping and related IMO measures in the region make the area less prospective for large commercial energy development (see Section 5.15). Throughout much of the east of Regional Sea 3, the potential impact of wind turbine lights and movement may be reduced due to the lights of the French coast and busy shipping traffic, though development here is probably not likely given that UK waters only extend to ~13km from the coast, and have the highest shipping density in UK waters.

Dungeness Foreland and Romney Marshes are low lying, with coasts affording expansive views across the English Channel. The coastal strip has numerous 20th century developments, and includes industrial elements such as the Dungeness nuclear power stations which may make the coast less sensitive to additional components with an industrial character. To the west of the Foreland, the Saxon Shore Way travels along a rugged, cliffed coast towards the town of Hastings which has low lying, open views out to sea. Hastings, Bexhill and Eastbourne are large urban centres, but are also tourist destinations and retain a largely non-industrial character which may be compromised by offshore structures.

The area off Hastings is likely to interact with two contrasting landscapes. There are a number of designated areas including the South Downs National Park and the Sussex Heritage Coast. Beachy Head has an extensive chalk cliffed area reaching heights in excess of 100m, and includes the distinctive Seven Sisters landform. The “stunning, panoramic views to the sea” is a key characteristic and special quality of the National Park, and the area provides a break in urban development (see below) providing a sense of space and visual connection with the sea. The elevation of the cliffs will not only increase viewable distance, but may not be compatible with the scale of some large developments. In addition, the relatively rural nature of the area around Beachy Head and the presence of the South Downs Way mean that people wishing to perceive a “wild” part of the countryside may be impacted. This area contrasts markedly with lower and more developed urban areas along the coast including Brighton, Littlehampton and Bognor Regis, with some visibility of the Rampion wind farm from Brighton. The effects of Rampion on the stretch of coast covering the South Downs National Park and Brighton were considered significant, but were not sufficiently so that the project was refused consent. The eastern half of the coastline in Regional Sea 3 is highly accessible to London and the south-east and towns including Brighton are popular seaside resorts. Historically the area was important for trade and defence, with 19th century forts and Martello towers characteristic of the area.

Further west, designations include the Tennyson and Purbeck Heritage Coasts, the Isle of Wight and Dorset AONB sites, the New Forest National Park and the Dorset and East Devon World Heritage Site – these extend from the Isle of Portland to the Isle of Wight. People on the relatively rural stretch of coast from Weymouth to Bournemouth, which includes the South West Coastal Path, are likely to be impacted by offshore developments. Some of the coast along the same route reaches elevations of up to 150m, increasing the viewable distance. Larger developments may diminish the scale of these cliffs though any potential project is likely to be sufficiently offshore for this to be negligible as nearshore technical resource is highly constrained (see Section 5.15) in views from land to sea, but not sea to land or on certain cruising routes. This area of coast is quite complex, with enclosed views through The Solent and out from Weymouth Bay. The urban settlements of Weymouth, Bournemouth, and Portland Island and Harbour may be less sensitive to offshore infrastructure due to the level of development in these areas. As indicated above, landscape/seascape effects have proved to be a source of potentially significant effect for offshore wind farm developments in this area. Whilst future proposals may differ in scale or turbine design than those previous proposals, there is limited scope to mitigate the visibility of larger wind turbines within this enclosed area, and therefore significant effects may be expected for OWFs unless they are sites well outside a distance at which effects could be significant, which depending on the scale of any proposal could be equal to or more than 40km.

Submerged or partly submerged tidal stream devices could be acceptable should any deployment occur, with visibility determined by their design and requirements for navigational markings. Should such devices have a surface component, it will be relatively small (e.g. at the most 10m as suggested in Faber Maunsell & Metoc 2007) compared to offshore wind, though it is likely that these devices will be in close proximity to the shore, and these may not be incompatible with the wider strong maritime use of the area. Should wind, tidal and oil and gas developments take place in the west of Regional Sea 3, there is the potential for cumulative visual impacts to develop from plan related activities, however this is considered unlikely in view of prospectivity for energy development in this area.

The technical resource for tidal range approximately extends between Sandwich Bay and Worthing on the south east coast. As indicated above, the potential for any device here would be limited to lagoon-type developments. Any imposition of large, shore connected structures would interact with the contrasting coastal forms in this area, including coastal exposures of chalk in the form of cliffs including the Seven Sisters and Beachy Head which includes a chalk foreshore and subtidal chalk ridges, and the shingle ridges to the east culminating in the Dungeness Foreland – these areas also have strongly contrasting elevations. Any development would alter views of these major landforms, the sensitivity of which may make this type of development incompatible with the character of the area.

Regional Sea 4

The waters of Regional Sea 4 (see Figure 5.54) have generally proven to be too deep for fixed offshore wind foundations however the area, and in particular the offshore area, is highly prospective for tethered foundation-type technology. Shallower areas, including the Bristol Channel, have formerly been considered for offshore wind but did not prove viable (e.g. the Atlantic Array referred to above). This area has some of the most prospective waters for offshore wave energy in the UK and contains the only wave demonstration site in English and Welsh waters. Tidal stream energy is prospective in a very small area off western Cornwall, within the Severn Estuary and off Pembrokeshire (Figure 5.55), with demonstration sites being located off Pembrokeshire. There has been historically very strong interest in the Severn as a potential source of tidal range energy. Several lagoon development proposals have previously been considered without commercial success to date, and there is a wider technical resource along the coasts of the Bristol Channel.

To date, the majority of seaward oil and gas blocks have not been licensed in Regional Sea 4, and there are presently no licensed areas in Regional Sea 4. A single significant gas discovery has been made in the area however this has not been commercially exploited to date; there is generally considered to be a low prospectivity for hydrocarbons in this area (Figure 5.58, Section 2.6, Appendix 1b). A relative paucity of geological understanding compared to areas subject to intensive exploration (e.g. southern North Sea, east Irish Sea) makes Regional Sea 4 a less likely candidate for gas storage or carbon dioxide storage.

The Regional Sea 4 coastline contains a dense array of landscape designations including the Dorset, East Devon, South Devon, Cornwall, Isles of Scilly, North Devon, Quantock Hills and Gower AONBs, Exmoor, Dartmoor and the Pembrokeshire Coast National Parks, and the Cornwall and West Devon Mining Landscape World Heritage Site. Numerous Heritage Coasts are also present in both England and Wales, and the South West Coast Path and Pembrokeshire Coast Path, along with the wider Wales Coast Path (completed in 2012), make the coast easily accessible to the public as regular visitors or tourists (see Appendix 1h). These elements provides an indication that the seascapes of this Regional Sea are likely to have a high landscape/seascape value, and also likely sensitivity to industrial development.

Low and high cliffs dominate the coastline all around the South West Peninsula to the inner Severn to around Burnham-on-Sea, where the elevation of the land near the coast diminishes. Much of this cliffed coastline is rural and sparsely populated, and the South West in general is considered to be one of the most tranquil areas in the country away from the main towns and transport links, though is much reduced since the 1960s. The high coastline affords wide and expansive views out to sea from the coast including between Falmouth and Bigbury bays, and out from Mount’s Bay, but the area has had a number of recent additions in the form of onshore renewable energy structures including wind and solar farms. Any development between the Isles of Scilly and the South West Peninsula would interfere with views to and from the islands and would be incompatible with the rural and complex form of the isles, and their strong historical associations (see Appendix 1i).

Urban population centres include Plymouth and Falmouth, and though such areas are generally considered more compatible with offshore developments than rural coasts, the natural complexity of their setting may be disrupted by offshore structures. Indeed views may be focussed down The Sound, Plymouth, and Carrick Roads into Falmouth Bay. Other Urban areas include Cardiff and Bristol in the inner Severn. Towns such as Lyme Regis, Seaton, Beer and Bude are traditional and rural in nature which may not be compatible with the scale and form of large offshore structures. The northern Cornish coast also includes numerous dramatically sited ruins from 19th century mining buildings to Tintagel Castle, and the coast here in general has a visually complex geomorphology, with the underlying geology (“killas”) being a key influence in the character of the area. Tourist centres such as Torbay, Torquay and Newquay have a distinctive character, and high surrounding cliffs and some small islets, the scale of which may be diminished by offshore developments. Views may be filtered down the Axe, Exe and Teign, and make turbines or other offshore structures a focus of attention on the horizon, however wave devices may be less visible by day due to their low profile, but would require navigational lighting which could influence how views are experienced by night.

The Bristol Channel has surrounding coasts in England and Wales. Landscape value here is recognised in the Hartland, Lundy, North Devon, Exmoor, Glamorgan, Gower and South Pembrokeshire Heritage Coasts; North Devon and Gower AONBs and the Exmoor and Pembrokeshire coast National Parks (see Figure 5.49, Appendix 1c). Unlike most other areas, the Bristol Channel is viewable from almost all sides from high cliffed coasts, and there are also considerable stretches of flat low lying ground abutting the Severn such as the Gwent and Somerset Levels. Large developments may interfere with views across the Bristol Channel and down the Severn, where offshore wind turbines would be silhouetted against sunsets. Views from Devon and Cornwall to Lundy Island may be compromised by developments in the offshore parts of this area, and the rural undeveloped and often secluded nature of much of the coast in this region may be incompatible with the industrial character of offshore structures.

The Severn has previously been subject to SEA for a feasibility of tidal range options including two possible barrage structures and a number of tidal lagoons, and the visual impacts of these may be found in DECC (2010c). Any changes imposed by the technologies covered by the draft plan/programme are further complicated by the longer term evolution of the baseline in this area, namely sea-level rise which unmitigated will lead to a reduction in intertidal area and related habitats and species which are characteristic to certain areas of the estuary. Mitigation in the form of compensatory measures is already being undertaken (e.g. at Steart, also see the Wales National Habitat Creation Programme, Oaten *et al.* 2018). Such measures would require coastal change in the form of managed or unmanaged retreat which will itself be a force for change in certain areas. Additionally, beach steepening and loss and flood defence maintenance may also begin to alter the character locally, but this is likely to be in areas of existing sea defence.

The construction of any tidal range device must therefore be considered in this context, particularly large estuary scale barrages which have the potential to exacerbate intertidal loss, in addition to changing the aspect of certain views, for example changes in water clarity and the form and type of shipping. Any such large device would significantly affect the character of the area, including changes to strong regional associations such as the Severn Bore, and maritime associations with trade and now recreational sailing and cruising. Whilst crossings in the Severn include two bridges, these are in the inner part of the estuary and so have less of an effect on diminishing the range and type of view that a large barrage might impose at day and night due to the requirement for navigational lighting and any associated road network. Barrages may not affect views down the estuary, but depending on their location could generate locally significant effects. Using Figure 5.57, it can be concluded that devices in the inner Severn (i.e. around Cardiff and Newport, or on the English side of the Severn) will be highly visible, and there is strong intervisibility with the Welsh and Somerset coast here leading to the potential for a large number of affected receptors. The area has centres of urban development, including major ports at Cardiff, Barry and Newport, and associated industrial infrastructure (e.g. the Llanwern Steelworks, Usk Mouth Power Station), however this is juxtaposed with the low lying Gwent Levels which supports important plant, bird, invertebrate and mammal populations, and is recognised as one of the best historic landscapes in Wales. Individual project level analysis would be required to understand which specific views from coastal aspects would be affected, and the magnitude of such change, in a landscape which is already under pressure from large industrial, commercial and urban expansion. For Swansea Bay tidal lagoon (Tidal Lagoon Swansea Bay 2014b), significant changes during construction were not identified in part due to the existing industrial and maritime nature of the area, however operational effects were considered to be significant immediately within or adjacent to the development. Foreshortening of views and reduction in the open character of certain views were highlighted, however the increase in amenity and contribution to overall regeneration of the area were also provided as advantages. For any tidal range device, the imposition of the lagoon or barrage walls represents a long-term change. The lifetime for most tidal range proposals exceeds 100 years, and after this period repowering may be possible, or else the bulk of the structure may be left *in situ*, as was proposed for Swansea Bay.

The wave resource in the South West Approaches may lend itself to the deployment of wave based marine renewables. WaveHub was installed in 2010 off the north Cornish coast, which consists on a seafloor interconnector for the demonstration of wave devices. These are likely to generate a short term and small scale visual intrusion as devices of various designs are tested (similarly there is a wave test site off the Pembrokeshire coast and a tidal stream test sites off Lynmouth). In the longer term, wider installation of devices which are deemed to be technically feasible may be a potential source of visual effect, though Welsh, Scottish and Irish studies found that such devices tended to have less of a visual impact than wind or tidal devices with sea surface components (however, see LUC 2019). The scale of deployment in the near term in English and Welsh waters is considered to be demonstration, and large commercial deployments are not considered likely. Any impact would depend on the local characteristics of the coast and the distance from shore that any devices are placed. Floating devices are not so contingent on water depth as those requiring fixed foundations, and so may be placed further offshore where the wave resource is better, negating coastal landscape and visual impacts. Further offshore, MCA 51, 52 and 53 are large offshore areas out to the limits of the UKCS, with a history of maritime trade related to Wales, England and Ireland, with related shipwrecks including those associated with WWI and WWII (and continued use as a submarine training area), and also important areas for fisheries.

A previous strategic level consideration of the potential sensitivity of seascape units (see Appendix 1c) was undertaken for wind, wave and tidal stream technologies by CCW (2008a, b also see Smith *et al.* 2011). The high level character type and sensitivity to these types of developments is provided in Table 5.29. It should be noted that this work used development scenarios and therefore can only be interpreted in a generic way for this SEA and that there will also have also been certain changes in landscape and seascape since its completion.

White *et al.* (2019) undertook a sensitivity assessment for offshore wind farms in relation to Welsh seascapes. Seascape zones were identified based on the extent of visual buffers relating to designated areas, the presence or otherwise of existing wind farms which affect seascape character, and the geometry of the Welsh coastline. These seascape zones and their sensitivity are part of a strategic exercise, with the main drivers being distance from the coastal, and the character and value of the seascape and its receptors. White *et al.* (2019) note that even within smaller zones there may be variation in sensitivity such that there may be opportunity for development; project-specific seascape assessment would still be required for any proposals, and as noted above, appropriate consideration of information presented at the leasing stage in combination with relevant planning policy should be a key consideration in any application.

The levels of sensitivity to offshore wind for the areas relevant to Regional Sea 4 (Severn, Pembrokeshire, and southern Cardigan Bay were all High out to a distance of 22.6km, High/medium out to 44km and Medium/low beyond this distance into the Celtic Sea. Seascapes with a High sensitivity are defined as those, "*…very susceptible to change and/or its values are high or high/medium and it is unable to accommodate the relevant type of development without significant character change or adverse effects*. Thresholds for significant change are very low.", and High/medium as, "…*vulnerable to change and/or its values are medium through to high (although this level of value is not essential where landscape or visual susceptibility are key issues). The seascape zone may be able accommodate the relevant type of development but only in limited situations without significant character change or adverse effects if defined in the relevant zone summary*. Thresholds for significant change are low." Medium/low thresholds of seascape sensitivity were defined as, "…*resilient to change and/or its values are medium/low or low and it can accommodate the relevant type of development in many situations without significant character change or adverse effects. Thresholds for significant change are high*."

Table 5.29: Summary of landscape/seascape assessment for the Welsh coast relevant to Regional Sea 4

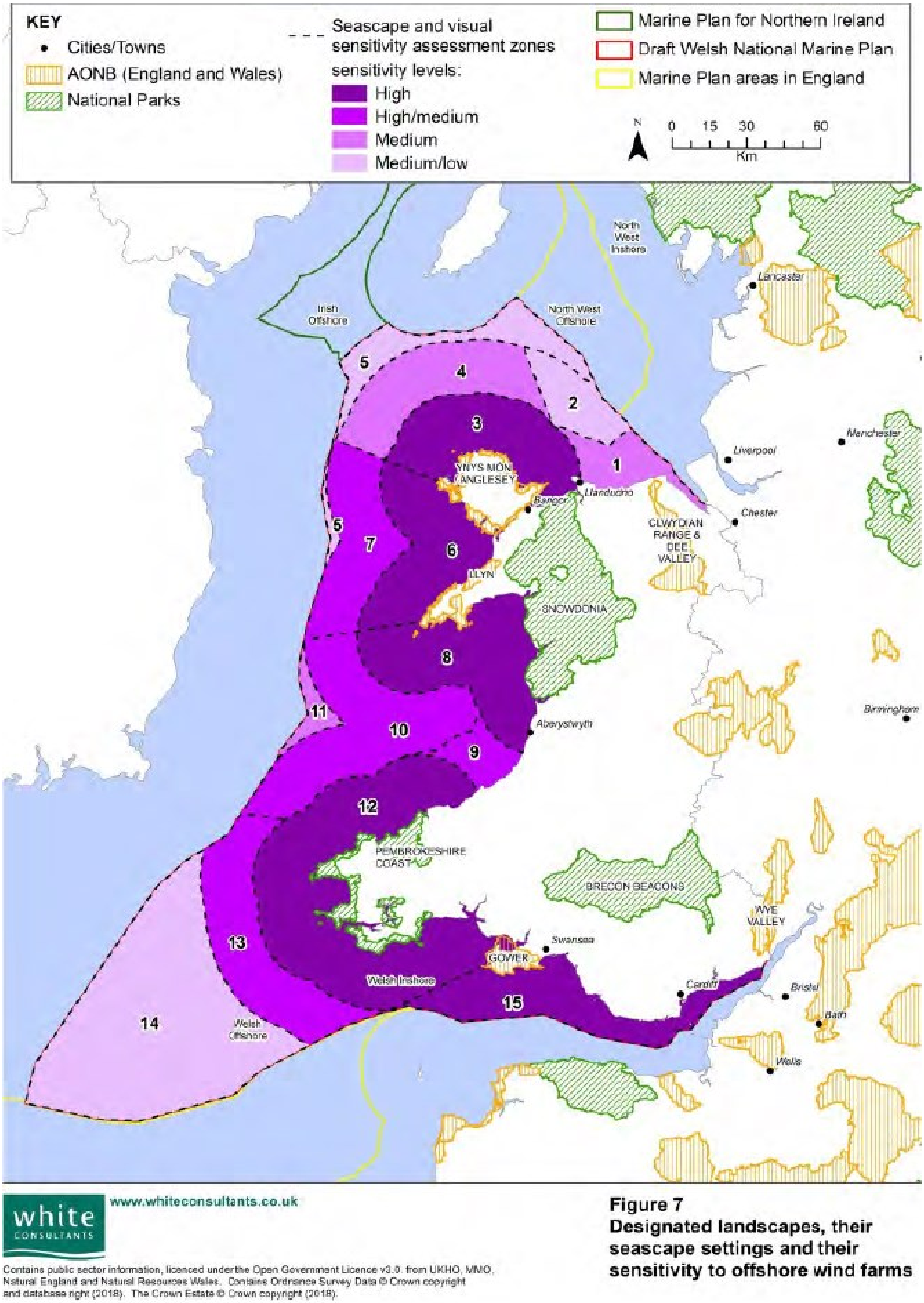
#	Area	Seascape character type	Sensitivity	
			Wave	Tidal Stream
36	Skomer Island to Linney Head	THMR, TSLD	Medium	Medium/High

#	Area	Seascape character type	Sensitivity	
			Wave	Tidal Stream
37	Milford Haven	EHMR, EHMU, EHLR	High	Low/Medium
38	Linney Head to St Govan's Head	THMR	Medium	Medium/High
39	St Govan's Head to Old Castle Head	THMR	Medium	Medium/High
40	Old Castle Head to Giltar Point/Caldey Island	THMR	Medium/High	Medium/High
41	Giltar Point to Pembrey Burrows (Carmarthen Bay)	THMR, THMU, TSLD	Low/Medium	Low/Medium
42	Taf, Tywi and Gwendraeth estuaries	EHMR	High	Medium
43	Loughor Estuary	ESLR	High	Medium
44	Whiteford Point to Worms Head-Rhossili Bay	THMR	Medium	High
45	Worms Head to Mumbles Head-South Gower	THMR	Medium	High
46	Mumbles Head to Porthcawl Point (Swansea Bay)	THMR, TSLU, TSLD, THIU	Low/Medium	Low/Medium
47	Porthcawl to Nash Point	THMR, TSLD, THIU	Low/Medium	Medium/High
48	Nash Point to Lavernock Point	THIR, TSLU	Medium	Medium
49	Lavernock to Gold Cliff	TSLR, TSLU, THMU, THIR	Low/Medium	Low/Medium
50	Gold Cliff to Chepstow	TSLR	Medium	Medium

Key: T=Tidal, L=Tidal current – lateral, E=Enclosed estuary or ria, H=Hard rocked coastline, S=Soft coastline, I=High (>100mAOD 250m inland), M=Medium (25-100mAOD 250m inland), L=Low (<25m 250m inland), R=Rural, U=Urban, D=Dunes. Notes: **Wind**: wind farm development scenario of many parallel turbines (160m to blade tip) at 550m intervals, 13km from the shore. **Wave:** 2 rows of linear objects 500x3m at 500m intervals 5km from the shore. **Tidal Stream**: 1 row of surface point structures 10x3m, at 60m intervals 0.75km from the shore. Visibility is based on a landward and seaward buffer of 24km. Source: CCW (2008a, b)

Tourist pressure continues to increase in the South West with more facilities, caravan parks, golf courses, marinas and holiday and retirement homes. In some cases, tourism has generated the sprawl of small coastal settlements. Defence works on the Isles of Scilly and elsewhere are likely to become a priority if sea-levels rise in coming years, and changes in the location and nature of coastal defence and compensatory habitat, particularly in the Severn, may alter the character and certainly views of certain areas. There is continuing pressure for onshore wind farms and therefore any offshore structures should be considered in relation to these to avoid or reduce any cumulative effects.

Figure 5.59: Designated landscapes and the sensitivity of seascape zones to offshore wind farms



Source: White *et al.* (2020)

Regional Sea 6

Technical resources for offshore wind (mostly for fixed foundation in the east Irish Sea; Figure 5.54), tidal stream (primarily off the Lleyn Peninsula and Anglesey; Figure 5.55) and tidal range (extending east from Anglesey and north to the Solway; Figure 5.57) are located in Regional Sea 6. The wave power in this area is generally regarded to be too low for commercial exploitation. Many oil and gas blocks in the Irish Sea and Cardigan Bay have never been licensed, and to date, any licensing that has taken place in Cardigan Bay has been without commercial success. Additionally, MoD restrictions are in place for much of Cardigan Bay and in the north of the East Irish Sea and North Channel which may restrict or exclude oil and gas activities[214]. The east Irish Sea Basin has been exploited for hydrocarbons (primarily gas, but some oil), and there has been recent interest in exploration in the area, with a number of blocks licensed in the 31st seaward round (2019).

Designations relating to landscape value (see Figure 5.49) include NSAs in the Solway (Nith Estuary, East Stewartry Coast) and in the Firth of Clyde (Arran, Kyles of Bute). On the English site of the border, Hadrian's Wall World Heritage Site, St Bees Heritage Coast and the Lake District National Park are important features. Numerous Heritage Coasts are found in Wales (e.g. Ceredigion Coast, Great Orme) as well as two National Parks (Snowdonia, Pembrokeshire Coast) and the AONBs of Lleyn, Anglesey and coastal aspects of Clwydian Range and Dee Valley. In Wales a number of other non-statutory areas are recognised on the register of landscapes of historic interest, including (amongst others) Lleyn and Bardsey Island, Amlwch and Parys Mountain, Penmon and Creuddyn and Conwy.

Regional Sea 6 contains a number of estuarine or coastal areas which have been the subject of previous tidal range proposals, which include Colwyn Bay, the Mersey, Wyre, Ribble and Solway Firth. Designs have included both barrage and tidal lagoon-type developments. There are two lagoon projects (Colwyn Bay and West Cumbria) at an early stage of proposal for Regional Sea 6. An early concept for the Solway (Solway Energy Gateway) was previously proposed, however, work has not progressed on this. A number of landscape/seascape implications of such devices have already been discussed above in relation to the Severn, and these are likely to be applicable to these sites also, and will require site specific scoping, consultation and assessment both in terms of the siting of any tidal range project and also the potential for cumulative effects. Tidal range developments in Colwyn Bay and in any of the estuaries mentioned above are likely to be visible from a large number of viewpoints as they have a high degree of intervisibility with opposite and adjacent coasts. Additionally, there are also multiple wind farms in this area that are intervisible, and there may be the potential for cumulative effects with other such development. Similarly, any development within the Solway will be highly visible, could lead to the foreshortening of views along the estuary and out to sea, and interact with a range of landscape designations including the Solway Coast AONB, the Nith and East Stewartry Coast NSAs and Hadrian's Wall World Heritage Site (Figure 5.49). The Solway has a high degree of tranquillity and contains a range of nature conservation designations relating to, amongst other factors, intertidal mudflats which support internationally important numbers of wildfowl and waders. Analogous to the Severn, in view of the presence of estuaries and bays which have coincident SAC sites that include estuarine features and pressure from *inter alia* sea-level rise, any impact from barrage or tidal range structures alone or in combination with background changes to these could exacerbate the alteration of landscapes in these areas in the long-term. Unmitigated, this could include changes to intertidal area and a loss of related habitats and species which are a key component of the

[214] See the other regulatory issues published as part of the 32nd seaward licensing round: https://www.ogauthority.co.uk/licensing-consents/licensing-rounds/

character in these areas, in addition to an alteration of the daily contrast in views afforded by the changing tides. Additionally, any project proposed in this area would need to account for transboundary issues in terms of how the project would need to meet the landscape/seascape assessment requirements of the UK and devolved administration in Scotland, and the overall consenting arrangement for any such project.

The coast of England in Regional Sea 6 varies from saltmarsh (e.g. Wyre Estuary) and shingle to localised sections of dunes (e.g. Walney Island), sandy beaches (e.g. Morecambe) and cliffs (e.g. St. Bees Head). The wide, open views of the sea may reduce the sensitivity of the area to offshore developments, however this must be considered in the context of extant offshore energy development. The extensive intertidal sands and dunes of the Sefton coast are a distinctive landscape feature and though views of offshore developments may be focussed from enclosed views through dune slacks, the wide, open views afforded at the coast may reduce the impact of the scale of developments, but there is scope for cumulative effect with existing offshore structures. Barrow-in-Furness, Whitehaven and Workington provide an industrial element to the landscape which may reduce the sensitivity of the seascape to offshore wind or other industrial structures, as will the more developed areas of the Mersey and Dee Estuaries and other sources of industrial character including various nuclear and gas fired power stations located along the coast. Light pollution from these, other urban areas (e.g. Blackpool), and extant offshore navigation and aviation lighting may make them less sensitive to further lighting, however there is scope for cumulative effects.

Parts of the Welsh section of Regional Sea 6 are under considerable development pressure, particularly North Wales around principal urban areas (e.g. Bangor). Recreational pressure including access to coastal paths (see Appendix 1c and 1h), caravan, campsites, tourist infrastructure, golf courses and increased use of coastal waters for watersports, are all generating pressure. Coastal erosion is a problem for much of the coast in Wales and England, and in the future coastal change may locally alter some areas through managed realignment or no active intervention (see Appendix 1b), however many estuarine areas such as the Mersey are already highly managed and it is likely defences will be maintained at the frontages of major towns and infrastructure.

Oil and gas activity in the Irish Sea (primarily in the north-eastern part) is likely to continue to provide an industrial offshore element to the seascape in years to come. Merseyside has the potential for CCS demonstration having high emissions of carbon dioxide in relatively close proximity to suitable storage formations, and existing oil and gas infrastructure which could possibly be reused, and similarly gas storage is prospective in this area (noting the existing CS004 licence in this area). Hynet is a blue hydrogen production project based in the north west aiming to commence production in 2025, with carbon dioxide produced from the plant being transported and stored in depleted Irish Sea gas fields. The project was successful in being selected under Track 1 of the UK Government’s cluster sequencing programme[215], such that it should receive support, subject to final decisions. The combination of the various technologies covered by the draft plan/programme which all have potential to be deployed in Regional Sea 6 could possibly generate cumulative impacts (though wind, wave and tidal resources tend not to coincide). Additionally, a number of sizeable onshore wind farms (e.g. Llŷn Alaw, Trysglwyn on Anglesey) are operational and pressure for such developments is likely to continue. Offshore wind farms characterise parts of the seascape in North Wales (e.g. see Wales marine character areas 2 and 4, Appendix 1c), and are intervisible between some

[215] https://www.gov.uk/government/publications/cluster-sequencing-for-carbon-capture-usage-and-storage-ccus-deployment-phase-1-expressions-of-interest/october-2021-update-track-1-clusters-confirmed

character areas (e.g. Rhyl Flats and Gwynt y Môr) and/or have altered views from the shore (e.g. off West Cumbria). Further offshore wind development within viewable distance of the coast in these and other areas should consider the potential for cumulative effects of further development.

The technical resource for tidal stream is concentrated around Pembrokeshire, the Llŷn Peninsula and Anglesey. These areas coincide with some of the highest valued designations in Wales: Anglesey includes an AONB and Heritage Coast, is a designated geopark and in the east includes Beaumaris Castle, part of the wider Castles and Town Walls of King Edward in Gwynedd World Heritage designation; the Llŷn Peninsula incorporates an AONB and Heritage Coast, as well as the Llŷn and Bardsey Island historic landscape, and Pembrokeshire includes a National Park, Heritage Coast and a range registered historic landscapes. Additionally, visibility of the sea from these areas, and the areas which could therefore contain any tidal stream projects, are very high (Figure 5.49). Several tidal stream proposals are in planning or consented in Welsh waters off Pembrokeshire, Anglesey and also between Bardsey Island and the Llŷn Peninsula. These will introduce additional lighting in these areas at night and possibly also surface structures where waters are shallow (e.g. The Skerries off Anglesey), either in the form of surface lighting, boats for maintenance activities or occasional views of turbines being raised or lowered. Llŷn Peninsula has a strong sense of remoteness and the character has strong natural influences, and has a sense of exposure and wildness, but is also rural and agricultural. Rural qualities and a lack of modern development in the area may not be compatible with industrial offshore developments, whether these are offshore wind farms or tidal stream devices, with night time lighting from each providing new points of focus.

A previous strategic level consideration of the potential sensitivity of seascape units (see Appendix 1c) has been undertaken for wind, wave and tidal stream technologies by CCW (2008a, b also see Smith *et al.* 2011). The high level character type and sensitivity to these types of developments is provided in Table 5.30. It should be noted that this work used development scenarios and therefore can only be interpreted in a generic way for this SEA and that there have also been certain changes in landscape and seascape since its completion (e.g. offshore wind in the Irish Sea). A recent study of the sensitivity of Welsh seascapes to offshore wind has been undertaken (White *et al.* 2019), and so results from the earlier study of CCW (2008a, b) are not presented for wind in the table below.

The sensitivity for the seascape zones in Wales relevant to Regional Sea 6 (White *et al.* 2019) were judged to be High out to 22.6m from Pembrokeshire, the Llŷn Peninsula, north Cardigan Bay and Anglesey, High/Medium out to 44km of Pembrokeshire and to the west of Llŷn Peninsula, Cardigan Bay and Anglesey, and Medium to the north of Anglesey and off the north Wales coast. Beyond 44km, the sensitivity is considered to be Medium/low; refer to Regional Sea 4 for a definition of seascape sensitivity

Table 5.30: Summary of landscape/seascape assessment for the Welsh coast relevant to Regional Sea 6

#	Area	Seascape character type	Sensitivity	
			Wave	Tidal Stream
1	Dee Estuary	ESLR	High	Low/Medium
2	Point of Ayr to Colwyn Bay	TSLR, TSLU, THLU	Low	Low
3	Rhos Point to Great Ormes Head	THIR, THLU, THMR	Low/Medium	Medium

#	Area	Seascape character type	Sensitivity	
			Wave	Tidal Stream
4	Conwy Estuary	EHMR, EHLR, EHLU	High	Medium/High
5	Great Ormes Head to Puffin Island	THIR, THIU, THLR, THMU, THMR	Low/Medium	Low/Medium
6	Puffin Island to Point Lynas	THMR, THLR	Low/Medium	Medium
7	Point Lynas to Carmel Head	THIR, THLU, THLR, THMR	Low/Medium	Low/Medium
8	Carmel Head to Holyhead Mountain North Stack	THIR, THMR	Low/Medium	Low/Medium
9	Holyhead Mountain North Stack to Penrhyn Mawr	THIR, THMR	Low/Medium	Medium/High
10	Penrhyn Mawr to Pen-y-Parc/Maltraeth Bay	THMR, THLR	High	High
11	Holy Island Straits	LHLR	Low/Medium	Medium
12	Menai Straits	LSLR, LHMR	High	Medium/High
13	Maltraeth Bay to Trefor	TSLR, THLR, THMR	Medium	Medium
14	Trefor to Porth Dinllaen	THIR, THMR	Medium	Medium/High
15	Trwyn Porth Dinllaen to Braich y Pwll/Mynydd Mawr	THMR, THIR	Low/Medium	Medium/High
16	Braich y Pwll and Bardsey Island	THIR, THMR	High	High
17	Bardsey Island to Trwyn Cilan	THMR, THLR	High	High
18	Trwyn Cilan to Penrhyn Du (Porth Ceiriad and St Tudwal's Island)	THMR	Medium	High
19	Penrhyn Du to Pen-ychain (Abersoch and Pwllheli)	THLR, TSLR	Medium	Low/Medium
20	Pen-ychain to Morfa Dyffryn (Tremadog Bay)	THLR, TSLR	Medium/High	Medium
21	Porthmadog Estuary	ESMR, ESLR	High	Medium/High
22	Morfa Dyffryn to Pen Bwch Point (Barmouth Bay)	TSLR, THMR, THIR, TSMR	Medium	Medium
23	Mawddach Estuary	ESLR, EHMR	High	High
24	Pen Bwch Point to Upper Borth	TSLR, THMR	Low/Medium	Medium
25	Dyfi Estuary	ESMR, ESLR	High	Medium/High
26	Upper Borth to Newquay (central Cardigan Bay)	THMR, THIU	Low/Medium	Medium
27	Newquay to Cardigan Island	THMR, THIR	Medium	Medium/High
28	Teifi Estuary	EHMR, ESLR	High	Medium/High

#	Area	Seascape character type	Sensitivity	
			Wave	Tidal Stream
29	Cemaes Head to Trwyn y Bwa	THIR, THMR	Medium/High	High
30	Trwyn y Bwa to Dinas Head (Newport Bay)	THMR	Medium	Medium/High
31	Dinas Head to Crincoed Point (Fishguard Bay)	THMR, THMU	Medium	Medium
32	Crincoed Point to Strumble Head	THMR	Medium	Medium/High
33	Strumble Head to St David's Head	THMR	Medium/High	High
34	St David's Head to Ramsey Island	LHMR, THMR	High	High
35	Ramsey Island to Skomer Island (St Brides Bay)	THMR, TSLR	Medium/High	High

Key: T=Tidal, L=Tidal current – lateral, E=Enclosed estuary or ria, H=Hard rocked coastline, S=Soft coastline, I=High (>100mAOD 250m inland), M=Medium (25-100mAOD 250m inland), L=Low (<25m 250m inland), R=Rural, U=Urban, D=Dunes. Notes: **Wind**: wind farm development scenario of many parallel turbines (160m to blade tip) at 550m intervals, 13km from the shore. **Wave:** 2 rows of linear objects 500x3m at 500m intervals 5km from the shore. **Tidal Stream**: 1 row of surface point structures 10x3m, at 60m intervals 0.75km from the shore. Visibility is based on a landward and seaward buffer of 24km. Source: CCW (2008a, b)

Regional Sea 7

The majority of Regional Sea 7 falls within the bay closing lines subject to landward oil and gas Regulations. The remaining area has not been commercially exploited to date, but blocks in Northern Irish waters around Rathlin Island have been previously licensed but are now relinquished. It is possible that further blocks could be applied for in the future and therefore activities relating to exploration and production of offshore hydrocarbon could take place in Regional Sea 7.

The coast in Regional Sea 7 from Cape Wrath to the Mull of Kintyre has a high density of NSAs and also the highest number of wild land areas (see Appendix 1c). The area to the west of Scotland is generally not considered prospective for oil and gas, and is also within internal waters which are not considered for oil and gas licensing. The area therefore primarily prospective for renewable types of offshore energy however these are not a consideration of this draft plan/programme for Scottish waters. Should seaward blocks be applied for in Regional Sea 8, activities may be visible from some coasts in Regional Sea 7 (for example the west of the Outer Hebrides, Islay and Mull of Kintyre), and also Northern Ireland (see Figure 5.58). In the most part however, blocks immediately to the west of these areas have never been licensed, prospectivity is considered low, and the likelihood of seaward oil and gas licensing here is also considered to be low.

The area to the south and west of Islay and around Rathlin Island has a potentially viable tidal stream resource, and projects are in-planning at these locations. It may be reasonably expected that activities associated with such developments may take place in the coming years, and that these have the potential to visually interact with oil and gas exploration, however as noted above, low prospectivity in the area makes this unlikely. The Antrim Coast and Rathlin Island have some of the most varied scenery in Northern Ireland and is recognised by an AONB. To the south west of this, the Giant's Causeway and Causeway Coast WHS is of global geological importance and has strong artistic, cultural and historic associations. Should any exploration activity take place within this area, the potential long-term effects of development scale activity would need to be considered in relation to seascape, particularly should this coincide with any other offshore energy development.

Much of the west coast is under increasing pressure from tourism and tourist related developments including holiday/retirement homes and improved access and infrastructure. Such developments may influence the perception of remoteness. Pressure for onshore wind developments is increasing all along the coast, and any development that takes place which influences views in Regional Sea 7 will alter the landscape and may change the perception of some areas as "wild". Any cumulative effects with marine energy development undertaken in Scottish waters may also generate cumulative impacts as an increasing number of built, industrial structures are imposed on this largely rural coast. The interaction between these and any expansion in aquaculture should also form part of any cumulative consideration.

Regional Sea 8

The western extent of Regional Sea 8 which is covered by the Rockall Basin is generally under explored, and a single gas discovery has been made in the area. It is possible that further blocks will be applied for in the future (subject to periodic Climate Compatibility Checkpoints), but prospectivity is considered to be generally low, and large scale and expansive changes to landscape character are not considered likely in viewable distance from the coast, eliminating visual effects. Should any development be proposed which would interact with views from the coast, or where effects on landscape or seascape character are predicted, then the impact of development would need to be considered, given the relative rural and wild nature of the islands and coasts of Regional Sea 8, as recognised in the high concentration of NSAs, in addition to the World Heritage Sites of St Kilda and the Heart of Neolithic Orkney (Figure 5.38). Other recent plans, such as ScotWind (not directly connected with this draft plan/programme) and the Pentland Floating Offshore Wind project, would need to be considered in a cumulative context should leasing and development proceed in the north and west.

Regional Sea 8 includes the high cliffs of Scotland's northern coast, affording wide open views which could accommodate offshore structures, though depending on their scale and location, they could diminish the appreciation of the scale of the cliffs. Views to Hoy and Orkney would be compromised by developments in the Pentland, though development here is unlikely due to practical considerations. The wide, open views afforded from many locations of the coast of Orkney (and Shetland) may help to prevent the coastal scale and complexity being diminished with developments at distance from the shore. The remote, small-scale and rural character of the west coast of the Outer Hebrides would not easily accommodate the industrial character of offshore energy developments. The perception of "wildness" provided by the remote, undeveloped and natural form of most of Regional Sea 8 would be degraded should offshore developments be visible from the coast at day or night. The seas to the west of the Western Isles contain some of the best wave resource on the UKCS and may therefore be subject to the installation of such devices once they are technically proven (not considered by this draft plan/programme). The Fair Isle and West of Shetland basins are considered to have a higher level of prospectivity for hydrocarbons, but development close to the coast is considered unlikely (also see the anticipated scale of future licensing in Section 2.5).

The north coast of Scotland is under increasing pressure for onshore wind developments and cumulative effects may arise should offshore structures be intervisible with these, which would in turn increase the sensitivity of this area. Increasing use of the seas around Orkney and Shetland for aquaculture and the Orkney EMEC marine energy testing sites may conflict with other offshore energy developments. On Lewis and the Uists there is increasing pressure for improved roads and onshore wind developments, which could introduce incremental industrial elements to the landscape.

5.8.4 Controls and mitigation

The form of offshore structures is largely functional, and therefore mitigation opportunities are limited to siting and certain elements of development aesthetics, though the former will be restricted by spatial and technical constraints, or due to the location of particular energy resources. DTI (2005) highlights a number of considerations which may help to reduce the impact of a given development, in this case offshore wind, though these may be reasonably extrapolated to other offshore energy development:

Siting:

- Try to locate in low sensitivity or high capacity seascapes
- Place development as far offshore as possible
- Try to locate developments away from coastal landscape designations
- Try to use development siting to minimise visibility (e.g. behind headlands)
- Consider siting relationships with other offshore infrastructure (cumulative effects)

Layout and design:

- Consider different viewpoints, try to attain the best possible arrangement of structures
- Through the SVIA process, try to design out aspects of the development that are the source of most significant impacts
- Make the SVIA process iterative in order to try a variety of locations, patterns and number of structures
- Where possible, while taking account of all navigational standards and recommendations, the use of colour most appropriate for prevailing/average meteorological conditions may reduce the actual visibility of structures, particularly at increasing distances

All offshore developments are subject to the planning process and related assessment through EIA. The NPS for renewable energy infrastructure (EN-3)[216] provides an overview of what should be expected in an applicant's assessment, which includes an assessment taking account of many of the factors outlined above, such as the limit of visual perception from the coast, individual characteristics of the coast which affect its capacity to absorb a development and how people perceive and interact with the seascape. It is further indicated that SVIA and cumulative SVIA should be undertaken where appropriate.

The inshore and offshore marine plans also provide further policy direction, however at a high level, which is that proposals should ensure they are compatible with their surroundings and should not have a significant adverse impact on the character and visual resource of the seascape and landscape of the area. It is further noted that proposals that have a significant adverse effect should demonstrate, in order of preference, how they would avoid, minimise or

[216] Note that these are presently subject to review: https://www.gov.uk/government/consultations/planning-for-new-energy-infrastructure-review-of-energy-national-policy-statements

mitigate effects so they are no longer significant. In the event that mitigation is not possible, the public benefits of the proposal must outweigh any effects. Furthermore, it is indicated that proposals in or close to statutory designations must take account of the statutory purposes of their designation. In terms of decision making in relation to renewables which are nationally significant infrastructure projects, as defined under the *Planning Act 2008* (as amended), the Planning Inspectorate should not refuse the granting of consent solely on the grounds that there is an adverse effect on seascape or visual amenity unless, taking account of other constraints it considers there is an alternative project layout that would minimise harm, and, that harmful effects are considered to outweigh the benefits of the project (taking account of the sensitivity of the receptor, as set out in EN-1).

As noted earlier, and in EN-3, turbine layout may present some source of mitigation, but options to further mitigate effects on seascape from a proposal may be limited.

5.8.5 Summary of findings and recommendations

The following summarises the consideration of the evidence and spatial consideration above:

- Viewable distance is restricted by the curvature of the earth, atmospheric haze and prevailing meteorological conditions. The height, form, lighting, motion and aspect of an offshore object affects how well it can be seen and its relative impact on the coast, however, impact assessments relating to visibility must assume conditions free from meteorological factors that could limit visibility, even if these are on the majority of days per year, to reflect a worst case impact.
- A range of physical attributes which are locally variable, in combination with the design of a development, and the attitudes of individual receptors, define the sensitivity and capacity of a particular location to change, which includes the purely visual resource and perceptions relating to historical and cultural context.
- Landscape designations provide a relatively objective general assessment of the 'value' attached to certain areas of the coast (but note the outcome of the Glover review[217]; see Appendix 1c), though in keeping with the European Landscape Convention, all landscapes should be considered in seascape assessment. The occurrence of multiple overlapping designations (e.g. Heritage Coast, National Park, World Heritage Site, AONB) may be taken to indicate areas of particularly high value. In deciding future offshore wind bidding areas, and subsequent project lease areas, the potential for developments to significantly affect landscape and seascape, and indeed to be refused on the basis of landscape/seascape issues, particularly where these indirectly generate economic effects on tourism, should be considered. Siting wind farms further from shore is likely to generate fewer effects at the coast and experience to date suggests less public opposition to such projects.
- Wind farm proposals in the UK, and other European countries, have progressively moved further offshore in recent years, reducing shore based visual effects. There

[217] https://www.gov.uk/government/publications/designated-landscapes-national-parks-and-aonbs-2018-review/landscapes-review-summary-of-findings and https://www.gov.uk/government/publications/landscapes-review-national-parks-and-aonbs-government-response/landscapes-review-national-parks-and-aonbs-government-response

remains potential for future leasing to take place closer to the shore, and within the broad ranges of visibility defined in Section 5.8.2, however, this should be considered in the context of the diminished area available for future nearshore fixed and floating offshore wind farms in seas relevant to the draft plan/programme (see Section 5.15), and the likely desire for new developments to exploit the greater energy resources available at distance from shore.

- Following initial project selection as part of any future leasing round, project specific assessment will be necessary to gauge the potential for significant effects on landscape/seascape (see Section 5.8.4). Assuming future offshore leasing rounds provide detailed characterisation of bidding areas as was undertaken for Round 4, developers should be mindful of the potential for significant landscape/seascape effects outlined in any such characterisations, along with the wording of the current, and when published, updated National Policy Statements, which reflect the potential for project refusal on the basis of effects on landscape and seascape. More broadly, projects should also be consistent with the policies of the inshore and offshore marine plans in England, and the Welsh National Marine Plan. Impacts on terrestrial landscapes and coastal seascapes, and also marine character areas, should be considered.
- The scope for cumulative impacts between different renewables aspects of the draft plan/programme is minimised by little overlap in the geographical range of energy resources. The exception is the wave energy and floating wind farm resource in the South West Approaches, but the high energy nature of this area may make central North Sea locations more likely for early deployment of floating wind technology (see Section 5.15).
- Cumulative impacts are most likely to occur in the future between multiple wind farm developments, particularly if these are sited close to shore. Further effects could be possible from a variety of offshore oil and gas, carbon dioxide storage, gas storage and wind farm development in the East Irish Sea, Moray Firth, English Channel and areas of the southern North Sea off Holderness and Thames Estuary. As noted above, the potential for effects from offshore wind farms is diminishing by the general trend for projects to be sited further from shore, and the remaining fixed-wind resource.
- A development specific seascape assessment incorporating cumulative impact assessment is necessary in order to minimise visual impacts from the variety of activities covered in the draft plan/programme, and existing and likely future uses of the sea. Strategic level sensitivity analyses for Wales and parts of England indicate a high or high/moderate sensitivity to wind farm development within a distance where magnitude of effect is low, this being in relation to areas with a higher value as inferred from landscape designations.
- The NPSs are subject to review and any changes to these in relation to landscape/seascape issues must be considered as part of future relevant applications. There may be further future changes following completion of the Glover review.
- England’s seascape presently lacks a comprehensive or high level analysis of seascape sensitivity to offshore energy development. The seascape characterisation work which has been undertaken for the English and Welsh marine plans is informative and in time

could be useful in monitoring the influence of marine energy installation offshore, particularly where they have started to form a key component of views and landscapes. In offshore locations in the southern North Sea and East Irish Sea, the components of the seascape which have associations with offshore energy may transpose from oil and gas activity to offshore wind energy in the coming years.

5.9 Marine Discharges

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
The introduction and spread of non-native species	X	X	X	X	X	X	X	X
Potential for effects on flora and fauna of produced or treated water and drilling discharges	X	X	X	X	X	?	X	X
The nature and use of antifouling materials				?	X	?	X	
Sediment modification and contamination by particulate discharges from drilling etc or resuspension of contaminated sediment	X	X	X	X	X	X	X	X
Effects of reinjection of produced water and/or cuttings and carbon dioxide	X	X	X					
Contamination by soluble and dispersed discharges including produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction	X	X	X	X	X	?	X	X
Changes in seawater or estuarine salinity, turbidity and temperature from discharges (such as aquifer water and halite dissolution) and impoundment		X	X			X		
Potential for effects on human health associated with discharges of naturally occurring radioactive material in produced water	X	X	?					

5.9.1 Sources of potentially significant effect

As described in previous SEAs, marine discharges from oil and gas exploration and production activities include produced water, sewage, cooling water, drainage, drilling discharges and residual water based mud (WBM), some of which may contain a range of hydrocarbons in dissolved and suspended droplet form, various production and utility chemicals, metal ions or salts (including Low Specific Activity (LSA) radionuclides). In addition to these mainly platform-derived discharges, a range of discharges are associated with operation of subsea infrastructure (hydraulic fluids), pipeline testing and commissioning (treated seawater), and support vessels (sewage, cooling and drainage waters). The effects of the majority of these are judged to be negligible and are not considered further here (chemical risk assessments are considered under existing activity specific permitting procedures, see Appendix 3).

The use of depleted hydrocarbon reservoirs, saline aquifers and halite deposits for storing carbon dioxide, and potentially hydrogen, is at an early stage of development. Licence applications have been made in recent years to assess the viability of formations for geological storage in advance of storage applications (and associated assessments, e.g. EIAs being made) (see Section A1.h7 for details) and no storage sites are yet operational. The list of drilling-related discharges, and some operational discharges, above, also applies to gas storage or CCUS activities in depleted reservoirs or saline aquifers. One of the main operational discharges from carbon dioxide storage may be saline aquifer water, which may need to be discharged to control pressure build-up in a saline aquifer formation; concentrations of sodium chloride in such aquifer water can be near saturation. In addition to discharges associated with drilling and support activities, construction of salt caverns involves the discharge of relatively large volumes of high salinity brine, which in addition to dissolved halites, may potentially contain trace quantities of other materials.

OWF and other renewable energy developments have discharges associated with their installation, principally drilling muds and cements/grouts where drilling is required, e.g. where piles cannot be driven due to the presence of shallow subcropping hard geology. Similar but smaller scale drilling may be required to install piles for platform jackets, substation jackets and those associated with any hydrogen production facility. Various chemicals are used during operation (maintenance), the majority of these are used in closed systems, and any discharge is minimal. Maintenance can include the use of paints, but this is done infrequently (e.g. minor paint work may be carried out every three years, whilst full painting (of the transition piece) taking place every ten years, and any marine growth present is generally removed using seawater.

Discharges from offshore oil and gas facilities have been subject to increasingly stringent regulatory controls over recent decades, and oil concentrations in the major streams (drilling discharges and produced water[218]) have been substantially reduced. Mainly due to increasing water cut from mature oil reservoirs and the use of water injection to maintain reservoir pressure, the total volume of produced water discharges on the UKCS had been increasing, but since 2015 has been falling year on year as production levels decline; in 2020, produced water discharges to sea decreased to 129 million m^3, from 140 million m^3 in 2019, a decrease of over 7% (OGUK 2021). Conversely, the amount of produced water re-injected at source increased by ~10% in 2020, with 75 million m^3 reinjected in 2020 compared to 68 million m^3 in 2019 (OGUK 2021). The majority of produced water discharge volume to the North Sea and elsewhere is associated with oil production and produced water volumes from gas fields are extremely small in comparison. OSPAR Recommendation 2001/1[219] for the Management of Produced Water from Offshore Installations includes a presumption against the discharge to sea of produced water from new oil and gas developments. The assumption that reinjection will be the normal method of produced water disposal (at least 95% by volume) is fundamental to the consideration of potential effects of produced water in the SEA process, although it is also noted that under certain circumstances (e.g. injection pump maintenance) the produced water may be routed to sea. Any produced water discharged will be treated since it is still required to meet legal quality standards for oil in water concentration.

Drilling discharges are a major component of the total waste streams from offshore oil and gas exploration and production, with typically around 1,000 tonnes of cuttings resulting from an exploration or development well. Water-based mud (WBM) cuttings are discharged at, or relatively close to, the sea surface during “closed drilling” (i.e. when steel casing and a riser is in place so that cutting can be returned to the rig). Surface hole cuttings will be discharged at seabed during “open-hole” drilling, however, the surface hole is generally drilled using seawater and bentonite sweeps. Use of oil-based mud (OBM) systems, for example in highly

[218] Produced water is derived from reservoir water and from breakthrough of treated seawater injected to maintain reservoir pressure, and is generally the largest single wastewater stream in oil and gas production.
[219] This recommendation, as amended by OSPAR Recommendations 2006/4 and 2011/8, was further amended by Recommendation 2020/02, which came into effect from January 2021

deviated sections or in water reactive shale sections, would normally require the onshore disposal or reinjection of the waste material.

The contaminant composition of drilling discharges has changed significantly over the last few decades, in response to technical and regulatory developments. Since 2001[220], discharge to sea of drill cuttings contaminated with oil-based (non-aqueous) drill fluids at a concentration greater than 1% by weight on dry cuttings has been prohibited on the UKCS. Cuttings cleaning technologies (thermal processing) capable of reducing oil on cuttings drilled with OBMs to levels below 1%[221] which are sometimes used offshore with discharge to sea of the treated cuttings under an approved BEIS permit[222]. The thermal processing unit heats the cuttings to a temperature at which the hydrocarbons are released from the solids, leaving solids with <1% oil in cuttings content, thereby reducing the OBM to a level that the cuttings may be discharged and enabling the recovered oil to be re-used in the drilling fluid. Sampling is undertaken on the cuttings being sent to the thermal processing unit, with the recovered water also tested; in the case of operational issues with the equipment, testing is also carried out prior to discharge. The cuttings material has a very fine particle size distribution following processing, with almost all of the material likely measuring <100µm.

The contamination background of the UK marine environment is reviewed in Appendix A1b.15.3. Good Environmental Status (see Appendix A1b.15.3) has been largely, but not fully, achieved for contaminants, due to the persistence of some contaminants (including polychlorinated biphenyls (PCBs)) in biota and marine environments; the industrial history of primarily onshore activity in the UK and Europe has resulted in a widespread legacy of contamination of sediments, particularly in major estuaries and coastal waters and whilst there was a downward trend for the majority of contaminants, the persistence of others such as PCBs means they will continue to be recorded for some time (DEFRA 2019b).

Contamination by a number of metals and pollutants (cadmium, mercury, lead, PAHs and PCBs) in offshore sediments was considered largely acceptable (i.e. below the Background Assessment Concentration, or significantly below the Effects Range-Low (ERL) concentration) though mercury and lead remained at or above the ERL for a significant number of the monitoring sites assessed (DEFRA 2019b).

Assessment of regional surveys of contaminants and ecological status in areas of oil industry activity have shown significant reductions in sediment hydrocarbon concentrations (since the cessation of oil-based mud discharges), including areas such as the Fladen Ground and the East Shetland Basin; long term studies of single OBM wells have shown that after 25 years, recovery is almost complete, while regional scale benthic ecological perturbation attributed to oil industry activities has not been detected (e.g. Cranmer 1988, Hartley Anderson 2005, Daan *et al.* 2006, Bakke *et al*. 2013) . In line with OSPAR requirements, sources of contamination from the oil and gas industry (e.g. oil based mud contaminated cuttings and oil and chemical discharges) have declined. There remains a legacy of oily cuttings pile deposits around the footings of installations, predominantly in the northern North Sea, which were produced prior to the ban on the discharge of such cuttings. It may be impossible to remove an installation being

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[220] OSPAR Decision 2000/3 on the Use of Organic-Phase Drilling Fluids (OPF) and the Discharge of OPF-Contaminated Cuttings
[221] Thermal processing of cuttings whereby these are heated to a temperature at which hydrocarbons are released from the solid, leaving solids with <1% oil in cuttings content
[222] This would require a chemical permit and an oil discharge permit, if there was also the presence of reservoir hydrocarbons, details of which can be found here: https://www.gov.uk/guidance/oil-and-gas-offshore-environmental-legislation

decommissioned without disturbing or removing the drill cuttings pile(s). OSPAR Recommendation 2006/5 governs the management of offshore cuttings piles, established a two-stage process for their management[223]. In their review of drill cutting management studies during decommissioning, OSPAR (2019) estimated the total volume of oil-based cuttings in UK waters to be 1,150,086m^3, giving an average volume of a single pile in UK waters of around 6,610m^3. Based on the studies reviewed, they found the majority of impacts were within 100m of the centre of the pile, and beyond 500m there is normally little discernible impact. If disturbed, aeration of the pile allowed some additional degradation to take place, but the disturbance resulted in additional, but short-term and localised impacts on the water column and in some (but not all) cases could potentially cause contamination of the seabed outside the area impacted by the original discharge. They also noted that seabed recovery time following deposition of cuttings was influenced by the rate of biodegradation of the hydrocarbons and other contaminants in the drilling fluids, the resuspension and redistribution of matter on the seabed by currents and wave action, and the time for recolonisation of the biota (OSPAR 2019).

5.9.2 Consideration of the evidence

5.9.2.1 Produced water

Potential effects of produced water discharges from oil and gas activities are described in previous SEAs; produced water is not a by-product of renewable (e.g. offshore wind) energy activities, but construction of gas storage caverns in salt formations can result in discharges of brines, and high salinity discharges may result from CO_2 storage in saline aquifers, see below. A general presumption is in place that produced water from future oil and gas developments on the UKCS will be reinjected and not discharged. Most studies of produced water toxicity and dispersion, in the UK and elsewhere (see E&P Forum 1994, OLF 1998, Riddle *et al.* 2001, Berry & Wells 2004) have concluded that the necessary dilution to achieve a No Effect Concentration (NEC) would be reached at <10 to 100m and usually less than 500m from the discharge point. The review by Kenny *et al.* (2005), which included analyses of produced water composition from Irish Sea facilities, reached a similar conclusion. However, under some circumstances (e.g. strong stratification, Washburn *et al.* 1999), a plume concentration sufficient to result in sub-lethal effects may persist for >1,000m (Burns *et al.* 1999).

The OSPAR Quality Status Report (QSR 2010) noted that water column monitoring to determine possible effects from polycyclic aromatic hydrocarbons (PAHs) and other chemicals such as alkyl phenols discharged with produced water has been carried out to a limited extent in the OSPAR area. Monitoring with caged mussels in the Netherlands and Norwegian sectors of the North Sea has shown that mussels exposed to produced water discharges may accumulate PAH and show biological responses up to 1000m from the discharge. Concentrations of PAHs and alkyl phenols and measured biological responses in wild fish such as cod and haddock caught in the vicinity of offshore installations from Norwegian waters in 2002 and 2005 showed a mixed pattern mostly with no increased concentrations, but some elevated biological responses suggesting past exposure. Exposure of cod sperm cells to environmentally relevant concentrations (100, 200, 500 ppm) of produced water from the

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[223] The OSPAR Recommendation: https://www.ospar.org/convention/agreements?q=2006%2F5&t=&a=&s=#agreements-search, see also BEIS decommissioning guidance, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760560/Decom_Guidance_Notes_November_2018.pdf, this currently under review, with an update expected Q1/2 2022

Hibernia platform, Newfoundland, did not result in a strong toxicity to the cells (only subtle changes were observed) or a significant change in fertilisation rate (Hamoutene *et al.* 2010).

The QSR further noted that results from water column monitoring are complex to interpret, particularly for wild fish for which it is not possible to link observed biological responses to a specific exposure source. Monitoring data are limited and do not yet allow conclusions to be drawn on the significance of observed responses for marine life and ecosystems. The concentrations of radionuclides in water and sediments surrounding platforms are low and there is no evidence of a pathway that could lead to significant accumulation in fish, and consequently effects on human health are not predicted.

The next QSR is expected in 2023, but in the interim, OSPAR published an intermediate assessment in 2017 which included details of PAH concentrations in sediment samples collected between 1995 to 2015 from monitoring sites[224] throughout much of the Greater North Sea, Celtic Sea, Bay of Biscay and Iberian Coast. The report noted that mean PAH concentration in sediment were at background levels in two (Gulf of Cadiz and Irish and Scottish west coast) of the six assessment areas, whilst in four (northern North Sea, southern North Sea, English Channel and Irish Sea) mean concentrations were below the ERL[225], but not statistically significantly below the BAC. As mean PAH concentrations are below the ERL in all six assessment areas, adverse effects in marine organisms is considered unlikely, although concentrations need to be monitored as these are above background levels in four of the six areas (OSPAR 2017). PAH concentrations are decreasing in the Gulf of Cadiz and the English Channel although no statistically significant trend is apparent in the other four areas.

Bakke *et al*. (2013) reviewed research on the biological effects of offshore produced water (and drill cuttings) discharges, with focus on the Norwegian waters. Produced water discharges are a continuous source of contaminants to continental shelf ecosystems, and alkylphenols and PAHs were found to accumulate in cod and mussels caged near the discharge points, but these compounds are rapidly metabolized in cod. Such compounds may affect reproductive functions, and various chemical, biochemical and genetic biomarkers but Bakke *et al*. (2013) concluded that the risk of widespread impact from such operational discharges is low.

A small number of dispersion modelling studies of produced water plumes from offshore installations have been published (e.g. Washburn *et al*. 1999 (produced water outfall in 12m water Santa Barbara Channel, California), Burns *et al*. 1999 (produced water from Harriet A platform, northwest shelf of Australia), Riddle *et al*. 2001 (distribution of dispersed oil, East Shetland Basin, North Sea), Berry & Wells 2004 (dispersion in nearfield (0-150m) depths on Sable Island Bank, Scotian Shelf, Canada)). As part of a long-term programme of studies in Norway, mussels and semi-permeable membrane devices (SPMDs) were deployed in the Ekofisk and Tampen Regions and analysed for more than 50 polycyclic aromatic hydrocarbons (Durell *et al*. 2006). PAH concentrations in ambient seawater were estimated based on the mussels and SPMD concentrations, and compared to model predictions using the DREAM model (Reed *et al*. 2001). Surface water total PAH concentrations ranged from 25 to 350 ng/l within 1km of the platform discharges and reached background levels of 4–8 ng/l within 5–10 km of the discharge; a 100,000-fold dilution of the PAH in the discharge.

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[224] Sampling frequency was variable, ranging from annually to once every five years
[225] PAH concentrations are compared against two assessment criteria; the OSPAR Background Assessment Concentration (BAC) and the United States Environmental Protection Agency's Effects Range-Low (ERL). See https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/pressures-human-activities/contaminants/pah-sediment/

Overall, the consensus of both predictive modelling and observational studies (using dye and contaminated tracers) is that dilution in the range of several thousand to several hundred thousand will be achieved over a down-plume distance of the order of 1,000m; the achieved dilution being largely dependent on water depth and degree of vertical mixing.

Studies of "whole effluent" toxicity of produced water have generally concluded that No Effect Concentrations are in the range 500-10,000 ppm of produced water. For example, in two of three experiments, additions of fresh produced formation water to seawater had little or no effect on 14C uptake by phytoplankton up to concentrations of 1% (10,000 ppm v/v). In contrast dilutions of 500 ppm (v/v) (<1/2,000) resulted in clear inhibition of bacterial thymidine uptake in three out of four experiments (Burns *et al.* 1999).

At a wider scale, produced water discharges are distributed at a broadly comparable density (i.e. discharges of comparable rate, at comparable spatial separation) over developed reservoir basins in the central and northern North Sea (although large areas of the North Sea are without production discharges), and an overall affected spatial proportion of around 1% is probably a reasonable estimate. This conclusion would support the assumption that dispersion of any individual plume is by sea water with no significant contamination from other sources (i.e. that there is no cumulative effect of multiple discharges). A further consideration in assessment of the overall effects of produced water discharges is the assumption of conservative behaviour of the toxic components of the discharge. In reality, volatilisation and biodegradation of many organic components will be significant within a short modelled timeframe (i.e. 96h) and toxicity effects would be expected to be correspondingly reduced.

5.9.2.2 Drilling discharges (muds and cuttings)

Mud systems used in surface hole drilling for oil & gas and CCUS wells and drilling associated with renewables (e.g. some offshore wind foundations), are usually simple (seawater with occasional viscous gel sweeps) and would not result in significant contamination of sediments. However, the composition of closed drilling discharges likely to result from exploration, appraisal and development drilling (and to a lesser extent from well maintenance activities) is more complex, and will include cuttings (i.e. formation solids, in varying degrees of consolidation and in a range of particle sizes), barite (barium sulphate used as a weighting agent to aid well control although other dense materials such as ilmenite or haematite may also be used), salts (sodium and potassium chloride), bentonite clay and a range of mud additives in much smaller quantities. Water-based mud additives perform a number of functions, but are predominantly polymeric organic substances and inorganic salts with low toxicity and bioaccumulation potential. In addition to mud on cuttings, residual water-based mud may be discharged at the sea surface during or following drilling operations. Due to its density, a proportion of the particulate component of the mud (including barite) may settle in the immediate vicinity of the discharge.

The bulk of WBM constituents (by weight and volume) are on the OSPAR list of substances used and discharged offshore which are considered to Pose Little or No Risk to the Environment (PLONOR) – see below. A major insoluble component of water-based mud discharges, which will accumulate in sediments, is barite. Barite has been widely shown to accumulate in sediments following drilling (reviewed by Hartley 1996). Chemically inert, suspended barite has been shown under laboratory conditions to potentially have a detrimental effect on suspension feeding bivalves. Standard grade barite, the most commonly used weighting agent in WBMs, was found to alter the filtration rates of four bivalve species (*Modiolus modiolus, Dosinia exoleta, Venerupis senegalensis* and *Chlamys varia*) and to damage the gill structure when exposed to 0.5mm, 1.0mm and 2.0mm daily depth equivalent doses (Strachan 2010, Strachan & Kingston 2012). All three barite treatments altered the filtration rates leading to 100% mortality. The horse mussel (*M. modiolus*) was the most tolerant to standard barite with the scallop (*C. varia*) the least tolerant. Fine barite, at a 2mm daily depth equivalent, also altered the filtration rates of all species, but only affected the mortality of *V. senegalensis*, with 60% survival at 28 days. When the suspended barite levels used in laboratory studies are translated to field conditions (i.e. distances from the point of discharge) it is clear that any effects will be very local to a particular installation (in the case of oil and gas facilities, well within 500m).

Barium sulphate is of low bioavailability and toxicity to benthic organisms. Other metals, present mainly as salts, in drilling discharges may originate from formation cuttings, from impurities in barite and other mud components or from other sources such as pipe dopes. Although a variety of metals (especially chromium) are widely reported to accumulate in the vicinity of drilling operations, the toxicity of settled drill cuttings appears to be related primarily to hydrocarbon content, even in WBM discharges.

Dispersion of mud and cuttings is influenced by various factors, including particle size distribution and density, vertical and horizontal turbulence, current flows, and water depth. In deep water, the range of cuttings particle size results in a significant variation in settling velocity, and a consequent gradient in the size distribution of settled cuttings, with coarser material close to the discharge location and finer material very widely dispersed away from the location, generally at undetectable loading. In low hydrodynamic energy environments such as the central and northern North Sea, redistribution of cuttings accumulations will be slow, and the topographic pile will probably persist over decades (unless disturbed by future activity at the well, decommissioning or other anthropogenic disturbance); in contrast cuttings discharged in the southern North Sea, a high hydrodynamic energy environment, rapidly disperse and piles are generally not present.

The past discharge to sea of drill cuttings contaminated with OBM resulted in well documented acute and chronic effects at the seabed (e.g. Davies *et al.* 1989, Olsgard & Gray 1995, Daan & Mulder 1996). These effects resulted from the interplay of a variety of factors of which direct toxicity (when diesel based muds were used) or secondary toxicity as a consequence of organic enrichment (from hydrogen sulphide produced by bacteria under anaerobic conditions) were probably the most important. Through OSPAR and other actions, the discharge of oil based and other organic phase fluid (i.e. LTOBM) contaminated material direct to sea is now banned; technology has been developed whereby cuttings containing oil-based may be treated offshore prior to discharge (as noted above).

In response to the progressive tightening of OSPAR and UK discharge and other standards for cuttings drilled with OBM and organic phase fluids, and for the oil content of produced water and production, drilling and cementing chemicals, the UK Government/Industry Environmental Monitoring Committee reviewed UK offshore oil and gas monitoring requirements. The committee has developed a monitoring strategy which aims to ensure that adequate data is available on the environmental quality status in areas of operations for permitting assurance and to meet the UK's international commitments to report on UK oil industry effects. This strategy has been implemented since 2004 and has included regional studies in various parts of the North Sea, and surveys around specific single and multi-well sites (see Appendix A1b.15.3, Figure A1b.21).

In contrast to historic oil based mud cuttings discharges, effects on seabed fauna of the discharge of cuttings drilled with WBM and of the excess and spent mud itself are usually subtle or undetectable, although the presence of drilling material at the seabed close to the drilling location (<500m) is often detectable chemically (e.g. Cranmer 1988, Neff *et al.* 1989, Hyland *et al.* 1994, Daan & Mulder 1996, Currie & Isaacs 2005, OSPAR 2009b, Bakke *et al*. 2013). Recent studies (e.g. Nguyen *et al*. 2021, Gillett *et al*. 2020, Dijkstra *et al*. 2020, Aagaard-Sørensen *et al*. 2018, Junttila *et al*. 2018) have investigated the spread and effects of WBM discharges on various aspects of seabed ecology including those not typically included in benthic monitoring programmes; the results indicate that, where effects were detected, they were of small spatial scale and relatively short duration.

Considerable data has been gathered from the North Sea and other production areas, indicating that localised physical effects are the dominant mechanism of ecological disturbance where water-based mud and cuttings are discharged. Modelling of WBM cutting discharges has indicated that deposition of material is generally thin and quickly reduces away from the well. Jones *et al*. (2006, 2012) compared pre- and post-drilling ROV surveys of a West of Shetland exploration well in Block 206/1a in *ca*. 600m water depth and documented physical smothering effects within 100m of the well. Outside the area of smothering, fine sediment was visible on the seafloor up to at least 250m from the well. After 3 years, there was significant removal of cuttings particularly in the areas with relatively low initial deposition (Jones *et al*. 2012). The area impacted by complete cuttings cover had reduced from 90m to 40m from the drilling location, and faunal density within 100m of the well had increased considerably and was no longer significantly different from conditions further away. The use of a ROV has also allowed the detection of small scale changes in benthic fauna in the immediate vicinity of a wellbore in the Norwegian sector of the North Sea, for example Hughes *et al*. (2010) found declines of the density of sea urchin *Gracilechinus acutus* within 50m of a well; such effects are considered temporary and negligible.

Cranford & Gordon (1992) reported low tolerance of dilute bentonite clay suspensions in sea scallops (*Placopecten magellanicus*). Cranford *et al.* (1999) found that used water based mud and its major constituents, bentonite and barite caused effects on the growth, reproductive success and survival of scallops, which were attributed to chronic toxicity and physical disturbance. It may be that *P. magellanicus* is especially sensitive to drill muds (or fine sediments in general) or that in the field, water based drilling discharges very rapidly disperse to below effective concentrations. Barlow and Kingston (2001) report damage to the gills of two species of coastal bivalves where barite was added to an experimental system although no controls with other sediment added were tested and the concentrations of material added were very high so it is unclear how or if the results apply to the field situation.

The effect of water-based drill cuttings on the benthic ecosystems and geochemical fluxes has been examined in a series of mesocosm (Schaanning *et al*. 2008, Trannum *et al*. 2010) and field experiments (Trannum *et al*. 2011). The mesocosm experiments highlighted a potential reduction in number of taxa, abundance, biomass and diversity of macrofauna with increasing thickness of drill cuttings, possibly as a result of oxygen depletion, which Trannum *et al*. (2011) in comparing difference between the mesocosm and field-based experiments results, suggested that it was probably due to the lack of continuous water flow over the sediment surface in the mesocosm experiments. In addition, the mesocosm results cannot be readily extrapolated to field effects since operational discharge of WBM drilling waste is intermittent and near surface, allowing differential settlement of particulates and dispersion of water soluble components as the material passes through the water column. The field experiments found that the difference in faunal composition between the controls and those treated with drill cuttings was of small magnitude 6 months after drill cuttings deposition indicating a relatively rapid recovery process following discharge of water-based drill cuttings.

A comprehensive synthesis and annotated bibliography of the composition, environmental fates and biological effect of WBM and cuttings was prepared on behalf of the Petroleum Environmental Research Forum (PERF) and American Petroleum Institute by Neff (2005). The review, covering more than 200 publications and reports, concludes that effects of WBM cuttings piles on bottom living biological communities are caused mainly by burial and low sediment oxygen concentrations caused by organic enrichment. Toxic effects, when they occur, probably are caused by sulphide and ammonia byproducts of organic enrichment.

Although suspensions of finer particles may be dispersed over greater distances than those of coarser particles, they will also be more dilute and therefore can be expected to have less impact on the marine environment. Although chemically inert, suspended barite has been shown under laboratory conditions to potentially have a detrimental effect on suspension feeding bivalves causing demonstrable damage to the gill filtration system and, after prolonged exposure, mortality. When the suspended barite levels used in laboratory studies are translated to field conditions (i.e. distances from the point of discharge) it is clear that any effects will be very local to a particular installation (in the case of oil and gas facilities, well within the 500m statutory exclusion zone).

Most studies of ecological effects of drilling discharges have involved soft-sediment species and habitats. Studies of the effects of water based mud discharges from 3 production platforms in 130-210m water depth off California found significant reductions at some stations in the mean abundance of 4 of 22 hard bottom taxa investigated using photographic quadrats (Hyland *et al.* 1994). These effects were attributed to the physical effects of particulate loading, namely disruption of feeding or respiration, or the burial of settled larvae. The impacts from WBM discharges may be of more concern in areas with sensitive benthic fauna, for example corals and sponges. Laboratory experiments by Allers *et al*. (2013) indicated that cold water coral (*Lophelia pertusa*) fragments were resilient to sedimentation-induced oxygen stress, but if coverage by sediment was complete and lasted long enough, the coral could not recover and died. Such effects can be mitigated in areas of sensitive species presence through site specific controls on whether, and where, drilling discharges are made. Järnegren *et al*. (2017) noted that natural high turbidity events lasting hours or days can occur in areas with adult corals, but based on their experiments suggested that the planktonic larvae of *L. pertusa* were susceptible to damage or mortality from suspensions of drill cuttings which included bentonite.

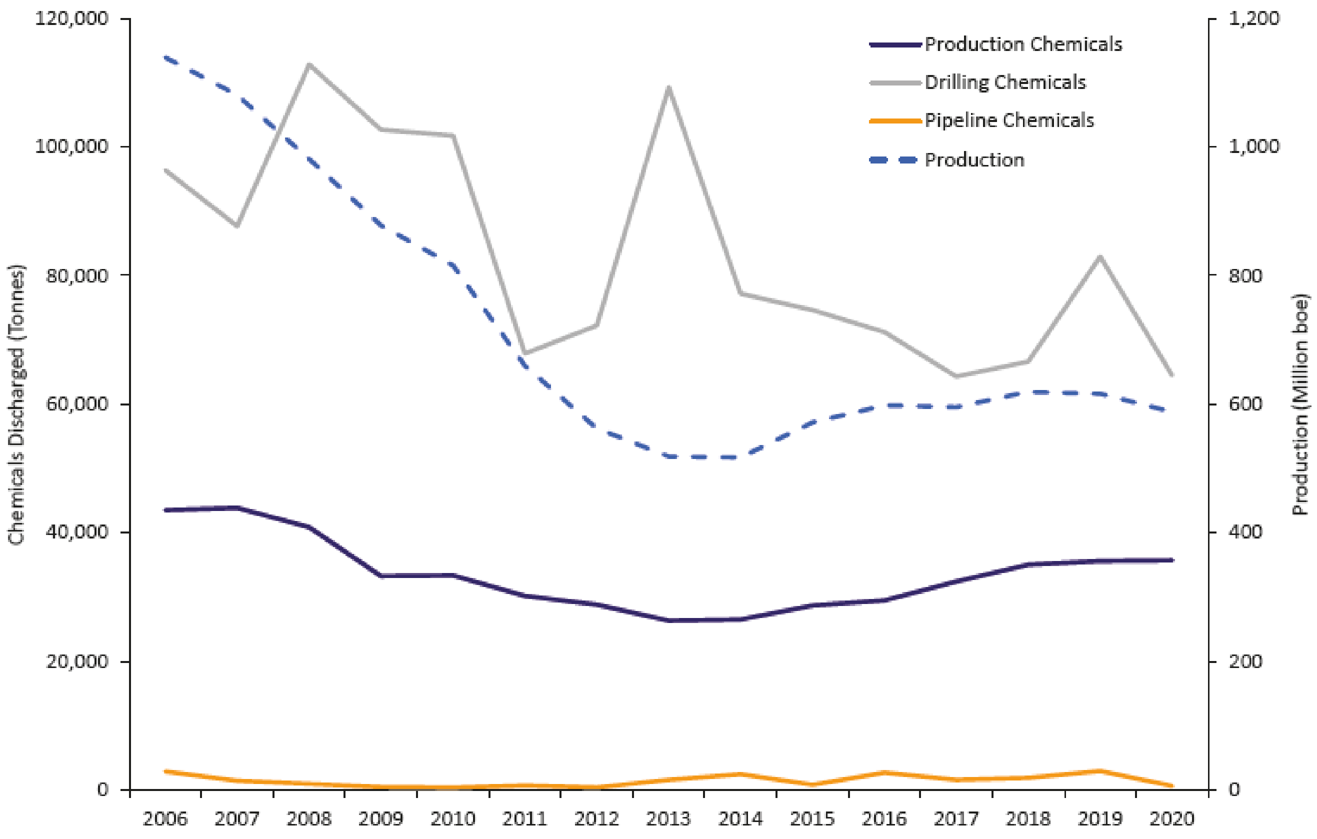
5.9.2.3 Chemical discharges

Chemicals are used and discharged during all phases of oil and gas activities: exploration; appraisal; operation and decommissioning. Most of the mass of chemicals discharged is from drilling activity (drilling fluids and cement) and this discharge has fallen over the last decade (Figure 5.60) as the level of drilling activity has decreased (Figures A1.h.10-12). There is an expectation of a continued overall decline in UKCS oil and gas activity toward 2050. Chemicals discharged in the installation and maintenance of pipelines (e.g. brines, dyes, biocides, corrosion inhibitors) will also fluctuate between years reflecting activity levels.

Cementing chemicals are also used during decommissioning during the plugging and abandonment of wells, and as the level of decommissioning activity increases, a corresponding increase in cementing chemical use and discharge is also expected; the majority of cementing chemical used remains downhole, this forming the cement plugs used to plug the well, and discharge is typically 10-20% of the use, and typically comprises tank washings. All chemical use and discharge is assessed and can only be carried out under an approved BEIS permit (see controls below).

Whilst hydrocarbon production has been in decline over the last 20 years, production chemical use and discharge has tracked a more gradual mirroring of this, however, as reservoirs mature, and for example water production increases, and recovery becomes more difficult, more chemicals are needed to improve recovery rates and treat water discharge. Although there has been an increase in production chemical discharge, this has lessened over the past few years, from a 2,600 tonne increase in 2018 (from that of 2017), to a 600 tonne increase in 2019 and a 90 tonne increase in 2020.

Figure 5.60: Production, Drilling and pipeline chemical discharge, 2006-2020



Notes: The spike in drilling chemicals in 2013, was due to chemical requirement for more complex wells. Source: OGUK (2021), using EEMS (2021) data

The vast majority of the chemicals discharged offshore from oil and gas activities are considered to Pose Little or No Risk to the Environment (PLONOR), a classification given after assessment of the chemicals[226] and, as such, they do not need to be risk assessed in a chemical permit for offshore oil and gas activity; in 2020, 71% of chemicals discharged to sea from offshore operations were PLONOR.

Chemicals requiring risk assessments are those which contain components which have been identified for substitution, as they are considered harmful to the environment. A chemical/chemical component can be identified for substitution for a number of reasons,

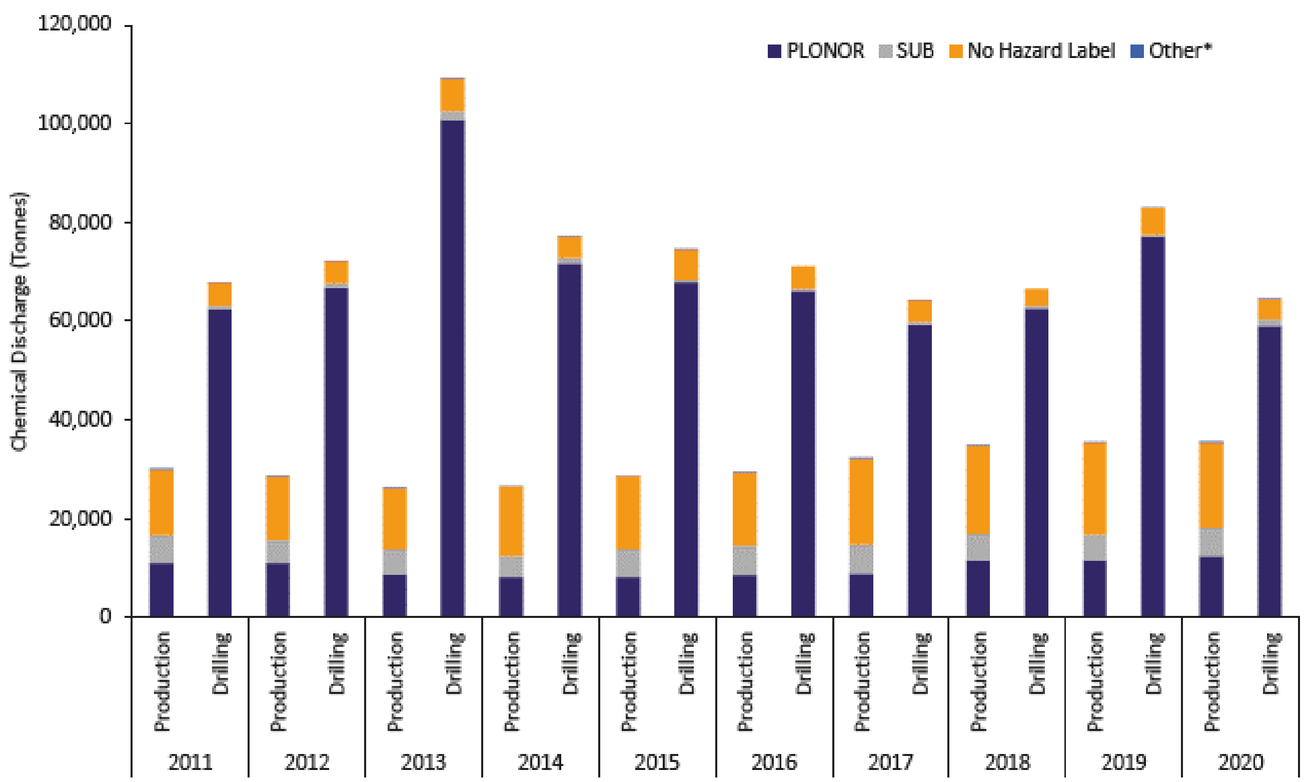
[226] The OSPAR Commission publishes a list of PLONOR chemicals, which are subject to expert judgement by the competent national authority of Contracting Parties and, from these assessment, are considered to pose little/no risk to the environment. The list is regulatory updated and the most recent list was published in 2021 https://www.cefas.co.uk/media/p3sbu3bn/ospar-list-of-substances-used-and-discharged-offshore-which-are-considered-to-pose-little-or-no-risk-to-the-environment-plonor-update-2021.pdf

including if it is (or contains a substance that is) toxic (toxicity levels applied), has poor biodegradability and has bioaccumulation potential[227]. In 2020, 7% of chemicals discharged were chemicals identified (or contained components) for substitution (OGUK 2021). A number of different chemicals can contain substances identified for substitution, a number of which are part of the oil-based mud system and are therefore not discharged. Others include scale inhibitors, emulsifiers and cement/cement additives, many of which are identified due to poor biodegradability, or identified as toxic, or have bioaccumulation potential. A programme under the OSPAR Recommendation 2006/3 on Environmental Goals for the Discharge by the Offshore Industry of Chemicals that Are, or Which Contain Substances Identified as Candidates for Substitution (as amended) is continuing.

A breakdown of chemical discharge by classification is shown in Figure 5.61.

The protection and maintenance of monopiles, jackets or gravity based structures, can involve chemicals such as biocides and corrosion inhibitors. These chemicals are typically drawn from the list of those approved for use in the oil industry, which are registered through the Offshore Chemical Notification Scheme. Some wave energy devices have significant inventories of hydraulic fluids, i.e. to activate valves, although there is no planned discharge of these (see also Section 5.9.3.2). Renewable energy technologies may use antifouling coatings, paints or surfaces to prevent the accumulations of excessive loads of algae and encrusting fauna; chemicals used in antifouling in UK and European waters are strictly controlled and significant effects would not be anticipated.

Figure 5.61: Drilling and production chemical discharge by classification, 2011-2020



[227] Information on substitution warnings and criteria can be found here: https://www.cefas.co.uk/data-and-publications/ocns/substitution-warning/

Notes: Other includes those chemicals reported in EEMS that are not classified as PLONOR or marked for substitution (“SUB”) but contain hazardous materials listed under OSPAR Annex A. Source: OGUK (2021), using EEMS (2021) data

OWF marine licence applications have been reviewed to identify chemical use in windfarms, and their types of use, frequency and quantity (where known) listed, with any risk assessment to determine their use in the marine environment noted (CEFAS 2022). Chemicals used in common between the oil & gas and OWF sectors included lubricants, greases, cement and grout, corrosion inhibitors, rigwash and dyes; predominantly chemicals found to be used in large quantities were within closed systems with no intentional discharge (CEFAS 2022). The review also identified inconsistencies across permit conditions, for example, 10 OWFs were tasked with providing information on all chemicals used, but this was not universally applied across all OWFs. Monopiles can corrode from the inside or the outside and require either sacrificial anodes or cathodic corrosion inhibitors. Coatings can offset this and some structures are now coated in plastics. Whilst initially it was thought that monopiles would be airtight and corrosion inside would be minimal, this is now found not to be the case, and corrosion control systems can require replacement of internal water (CEFAS 2022). Aluminium based anodes can contain up to 26 different elements and research has shown that there is potential impact in the marine environment from corrosion protection on the foundation of a single monopile. For other foundation structures, such as tripods, the quantities emitted are even larger (Kirchgeorg *et al*., 2018; Reese *et al*., 2020). The review also noted that there was little information in the UK of the type and quantity of sacrificial anodes (and associated release of metals), as data on the numbers used and replaced is not readily available (CEFAS 2022).

5.9.2.4 Saline aquifer and halite cavern construction discharges

The construction of caverns in rock salt formations and the displacement of saline formation fluids from aquifers during carbon dioxide storage site operation will potentially result in the discharge of significant quantities of brine.

There are presently no offshore natural gas storage facilities in the UK following the closure of the Rough field installations in 2017. Various proposals for new gas storage facilities have been made in the last decade[228] (e.g. Gateway Storage in the Irish Sea, the Aldbrough, Whitehills, Baird and Deborah storage projects in the North Sea), but none has yet been taken forward, (or past the Phase 1 stage, as in the case of the Aldbrough gas storage facility) and there are presently no leases or licences for hydrocarbon gas storage on the UKCS. In 2021, the Northern Endurance Partnership’s[229] East Coast Cluster was selected as a priority project in Phase 1 of the UK government’s CCUS cluster sequencing process. A multi-operator partnership, this is progressing the development of a carbon store in a saline aquifer in the Bunter sandstone (the Endurance geological storage site) some 80km off from the Humber/Yorkshire coast.

The Gateway gas storage project (eastern Irish Sea) proposed the solution mining of 20 salt caverns (total gas capacity 1.136 billion cubic metres) over a four year period. The assessment estimated the leaching process at each cavern would involve cycling large amounts of seawater through a well to dissolve the salt with the resultant brine mixture discharged to sea at a maximum rate of 386 m^3/hour. The maximum anticipated discharge salinity, which would occur during the cavern commissioning, was estimated to be in the order

[228] Details of these and the information from their respective risk assessments were provided in OESEA3, Section 5.9.2.3 (DECC 2016)
[229] https://www.netzeroteesside.co.uk/northern-endurance-partnership/

of 7 times that of seawater (*ca*. 250 parts per thousand (ppt)), although it was anticipated to be much less than this during most of the leaching process. The maximum temperature of the discharge was estimated to be 8.68ºC and would also occur during cavern commissioning.

Modelling studies of dispersion of the brine plume around each of the discharges indicated that the brine effluent would be best discharged through two 0.15m diameter horizontal ports located at right angles to the main current direction at about 10m above the seabed. This configuration would be expected to give at least a 33 times dilution at the point of seabed impact and a maximum salinity rise at the seabed of less than 7ppt. Further 3D hydrodynamic modelling of the saline discharges showed that the dilution and dispersion of the discharge by the tidal currents would result in a number of separate plumes from each monopod. It was predicted that there would be some merging of the plumes, but only at low salinities (less than about 1ppt above ambient). The saline plumes were expected to be confined to the bottom 0.5 to 1.0m of the water column. Central concentrations were *ca*. 7ppt, consistent with the initial dilution (i.e. no significant build-up was expected, that would reduce the dilution efficiency). The average impact at more than 1ppt above ambient was expected to be confined to an area within some 100m of each monopod during spring tides and within about 300m of each offshore structure during neap tides.

It was anticipated that the effluent temperature would reduce to about 2ºC above ambient or less within 1m of the point of discharge. An insoluble fraction to the discharge was also predicted, mainly comprising fine mudstone particles. Modelling of this fraction found that in all cases the suspended sediment concentration that resulted from the discharge was very low, less than 0.5ppm. This was negligible compared with natural levels of suspended sediment and would not be expected to result in visible discolouration of the water. Very little data is available on the composition of trace minerals in aquifer formation water which may potentially include toxic species; however, the available information suggests a high proportion of sodium chloride (and much smaller proportions of calcium, magnesium, sulphate, carbonate and bicarbonate, all of which are present in seawater). Halite deposits, being generally formed by evaporation of seawater over geological timescales, have a composition which is comparable to dissolved salt in sea water (i.e. predominantly sodium chloride). There is little data on the composition of brines from solution mining of halite caverns on the UKCS.

The Aldbrough Gas Storage Facility is some 12.5km south of Hornsea on the Holderness coast, Yorkshire. Phase 1 involved the creation of salt caverns in the Zechstein salt deposits under the coast by drilling wells into the salt strata and dissolving the halites with seawater pumped down the well (SSE & Statoil 2006).

Phase 1 salt cavern leaching began in March 2005 with brines being discharged to sea and was estimated to take some 52 months. Brine discharge modelling was undertaken based on a discharge rate of 2,050m^3/hr with a Practical Salinity Unit (psu) value of 284. The Environment Agency consent conditions for the brine discharge included a regulatory mixing zone 250m from the diffuser within which a salinity of 40 psu was acceptable. During the first year of monitoring discharge flow rates reached a peak of 1,942m^3/hr with a salinity of 235 psu, averaging at 721m^3/hr with a salinity of 171 psu. Surveys following commencement of discharge indicated that stratification or pooling did not occur. The regulatory mixing zone limit was not approached; maximum ambient salinity monitored was 37 psu at 250m from the diffuser (SSE & Statoil 2006). Consent was granted for a second phase of development at Aldbrough although this phase of the development has yet to occur.

While a terrestrial project, the proposed Preesall Saltfield Gas Storage project on the Lancashire coast includes a discharge pipeline extending *ca*. 2km offshore into the Irish Sea from Rossall, Fleetwood to discharge brine from salt cavern construction. The Environment Agency granted a discharge consent in connection with a previous planning application in 2007 to permit the discharge of brine of up to 80,000m^3 per day, subject to conditions on the quantity and content of the brine, including its salinity (not exceeding 40 psu within 50m, or 10% above ambient conditions within 250m) and presence of other elements (e.g. tributyltin, copper).

This, along with the Aldborough gas storage example, gives an indication of the type of discharge that can be expected from similar operations offshore. Modelling, and monitoring of the Aldborough gas storage project, have indicated potential ecological effects from both saline aquifer and halite solution mining discharges are likely to be associated with osmotic effects of hypersalinity rather than toxicity, and will be mitigated by effective dispersion of brine plumes. Although there have been no developments of offshore salt caverns in the UK (noting that Aldborough provides a proxy of offshore discharge effects from an onshore facility), the environmental effects of brine discharges have been well studied in other countries, notably in relation to discharges from desalination plants but also in relation to solution mining. Construction of salt caverns on the coast of the Gulf of Mexico as part of the US Strategic Petroleum Reserve Program in the 1970s was accompanied by a major environmental monitoring study of the discharge from the Bryan Mound (Texas) site, coordinated by Texas A&M University (Randall & Hann 1981). This included extensive measurement of the brine plume and baseline and post disposal evaluation of water and sediment quality, nekton (free swimming fauna), benthos, phytoplankton and zooplankton. Biological and water and sediment quality data indicated no substantial effects of the brine plume, which extended over a maximum recorded area of 7.4km^2 and vertical height above the seabed of 7.6m. A complementary study of the West Hackberry (Louisiana) site found no demonstrable effects on sediments or phytoplankton, and limited long-term effects on zooplankton, benthos and nekton (Giammona & Darnell 1990). Seasonal variability in species abundances was a predominant feature as dramatic population fluctuations occurred in all groups studied.

Differences among stations of relatively small magnitude were observed for many species and biomass estimates. Some of the differences were consistent when specific comparisons were made between control and diffuser area stations. They include: statistically significant differences in population densities of certain numerically dominant macrobenthic species, and significantly lower values for coefficient of condition (weight at length) of certain nekton target species collected in the vicinity of the brine diffuser. None of the observed changes in biotic communities were catastrophic in nature and all other measured parameters were either within expected ranges of or could not be attributed to diffuser activities (DeRouen *et al.* 1983).

5.9.2.5 Ballast water discharges

The introduction of non-native species through vessel ballast water discharges has also been considered in previous SEA Environmental Reports. The majority of rigs and vessels likely to be used will already be operating in NW Europe and hence not a potential source of exotic species introductions (although they could facilitate the spread of species). The International Convention for the Control and Management of Ships Ballast Water[230] and Sediments was adopted in February 2004, and entered into force in 2017. Under the Convention, all ships using ballast water exchange should (wherever possible) conduct this at least 200 nautical miles from the nearest land, and in water at least 200m depth. Where this cannot be undertaken, exchange should be undertaken as far as possible from the nearest land (at least 50nm) and in water at least 200m depth; where these requirements cannot be met, areas may

[230] https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships%27-Ballast-Water-and-Sediments-(BWM).aspx

be designated where ships can conduct ballast exchange[231]. Regulations to ratify the Convention in the UK, the *Merchant Shipping (Control and Management of Ships' Ballast Water and Sediments) Order 2022*[232] have been drafted. In view of these mitigation measures and the limited scale of activity predicted significant effects are not anticipated.

5.9.3 Controls and mitigation

5.9.3.1 Hydrocarbon related activities

Marine discharges associated with exploration drilling or development projects on the UKCS require to be assessed under the *Offshore Oil and Gas Exploration, Production, Unloading and Storage (Environmental Impact Assessment) Regulations 2020*, and the management of produced water and chemical discharges will continue to be a key issue addressed through the environmental assessment process.

OSPAR Recommendation 2001/1 for the Management of Produced Water from Offshore Installations aims to prevent and eliminate pollution by oil and other substances caused by discharges to sea of produced water, by, for example, lowering the discharge concentration from each installation to 30mg/l and including the presumption against the discharge to sea of produced water, from new developments; this Recommendation was further amended in 2006 (OSPAR Recommendation 2006/4, 2011 (OSPAR Recommendation 2011/1) and most recently in 2020 (OSPAR Recommendation 2020/2). In the UK, the Recommendation is implemented through the *Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005*[233] which prohibit the discharge of oil to sea unless under an approved permit; the permit application includes a full assessment of the proposed discharge and is supported by an assessment of best available techniques (BAT) and best environmental practices (BEP) to justify the measures proposed to minimise pollution and limit the discharges.

A permit is required in advance for the use of chemicals offshore including drilling, well workover, production and pipeline chemicals (*Offshore Chemicals Regulations 2002*). The permit application includes mandatory risk assessment and any variation in use from that permitted must have prior approval. Chemical use and discharge must be reported at the end of the activity. Chemicals are ranked by hazard, based on a PEC:PNEC (Predicted Effect Concentration:Predicted No Effect Concentration) approach.

5.9.3.2 Renewable energy activities

Although the depth of boreholes potentially drilled as part of OWF development is significantly shallower than those drilled in connection with hydrocarbon E&P or gas storage, drilling muds may also be used. The use and discharge of these muds and associated cuttings are controlled in England and Wales under the MMO's Marine Licence permitting system. Should any system other than a water-based mud be considered for use in the drilling operation written approval and guidance of disposal of any arisings will be required from the Licensing Authority.

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[231] Areas have been identified in the North Sea for exchange, see https://www.gov.uk/guidance/control-and-management-of-ballast-water and also https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1003522/BW_-_FAQ_-_GOV.UK.pdf

[232] https://www.legislation.gov.uk/ukdsi/2022/9780348228748/data.pdf

[233] The Regulations were amended in 2010, 2011, 2016 and 2017 to effect provisions related to offshore gas and CCUS operations, fee charging powers etc.

All chemicals used in oil industry drilling operations must be selected from the List of Notified Chemicals assessed for use by the offshore oil and gas industry under the *Offshore Chemicals Regulations 2002* (this list is derived from the OSPAR list and is available at www.cefas.co.uk). The OCNS does not apply to chemicals used by other industries, however, most of the chemicals used by the renewables industry (e.g. cement) are similar to those used in the oil industry there seems a logic to standardise their control and reporting (including those chemicals listed by OSPAR for priority action or candidates for substitution) in a similar manner. In their review of licence conditions, CEFAS (2022) found that, although it was the most common licence condition, only 56 of 316 conditions extracted from Development Consent Orders stipulated that the chemicals used must be on a published list of ranked chemicals or that approval would be needed from the regulator prior to use. Some licence conditions were found to perform a similar function but differences in wording led to there being variation in requirements for use of chemicals in construction and operation and in the reporting of their use.

5.9.4 Summary of findings and recommendations

5.9.4.1 Marine renewables leasing

With the potential exception in some instances of drill muds and cuttings, and a range of maintenance and operational chemicals, no significant discharges to the marine environment are predicted to result from the proposed leasing for future OWF and other marine renewable energy developments. However, standardising the control and reporting of chemicals and the language used in Development Consent Order conditions is recommended.

5.9.4.2 Oil & gas including gas storage and CO_2 storage in depleted reservoirs

The environmental effects of the major discharges from oil and gas activities have been extensively studied, and are considered to be relatively well understood. The environmental effects of produced water discharges not reinjected are limited primarily by dispersion. Discharges of WBM cuttings in the North Sea and other dispersive environments have been shown to have minimal ecological effects.

5.9.4.3 Gas storage in saline aquifers and halite cavern construction

Carbon dioxide storage in saline aquifers may result in the production and discharge of aquifer water. The *Offshore Petroleum Activities (Oil Pollution Prevention and Control) Regulations 2005* similarly apply to discharges relating to gas storage operations. The quality of aquifer water is variable and the concentrations of elements and compounds of potential environmental concern are relatively poorly characterised: a permitting mechanism is needed to ensure that such discharges can be controlled. On the basis of dispersion modelling and experience from the Gulf of Mexico and elsewhere, effects of saline brine discharges resulting from solution mining of halite caverns or pressure relief in saline aquifer CCUS, are predicted to be localised, and not to result in significant ecological effects.

5.10 Waste

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Onshore disposal of returned wastes – requirement for landfill	X	X	X	X	X	X	X	X

5.10.1 Introduction

Waste is defined as "any substance or object which the holder discards or intends or is required to discard"[234]. This section considers wastes from relevant offshore operations transported and disposed of onshore.

Large-scale offshore oil and gas production facilities can generate significant quantities of waste (comparable to an equivalent onshore industrial/residential development) throughout its life cycle from initial exploration and appraisal, through production to decommissioning. In recent years decommissioning activity has increased, resulting in large quantities of oil and gas infrastructure (jackets, topsides and associated wastes such as marine growth, bulk liquids, NORM/LSA scale[235]) being returned to shore for processing.

Offshore renewables developments are not manned and produce limited waste during operations. With some of the early demonstrator projects and commercial windfarms now decommissioned (e.g. Blyth in 2019, Vindeby in 2017), the level of waste being returned can be expected to increase. It may be viable to repower some renewable devices (e.g. with new generating units and blades), enabling the operational life to be extended, but this may not always be practical, particularly given the pace of technological development, and units may need to be replaced in their entirety.

As for onshore industrial waste streams, waste from offshore can be characterised (for management and regulatory purposes) as: hazardous[236] (called special waste in Scotland) (e.g. chemicals, paints, solvents, oils and sludges, hazardous waste containers); general non-hazardous waste (e.g. scrap metal and segregated recyclables) and other (e.g. radioactive materials).

5.10.2 Sources of potentially significant effect

The transfer of offshore wastes to shore for treatment and disposal generally involves the waste being landed at a port and then transferred to a licensed contractor. This can result in a

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[234] Government guidance on the definition of waste: 2018 Waste Framework Directive amendments and the definition of waste is as defined in the Waste Framework Directive (2008/98/EC): https://www.gov.uk/government/publications/legal-definition-of-waste-guidance/definition-of-waste-2018-waste-framework-directive-amendments The Waste (Miscellaneous Amendments)(EU Exit) Regulations 2019) make amendments to legislation with respect to waste, arising from the withdrawal from the EU.

[235] Solid and liquid wastes (i.e. sludges) from downhole can contain Normally Occurring Radioactive Material (NORM) and Low Specific Activity (LSA) scale, this discharged offshore or returned to shore for processing in accordance with BEIS regulation

[236] Note – solids and liquids that contain small amounts of oil are classified as hazardous waste

variety of effects including visual intrusion, noise, nuisance, changes in air quality, onshore land use and cumulative effects, with the scale of effect dependent on quantity, effective waste management and eventual disposal location and method.

5.10.3 Consideration of the evidence

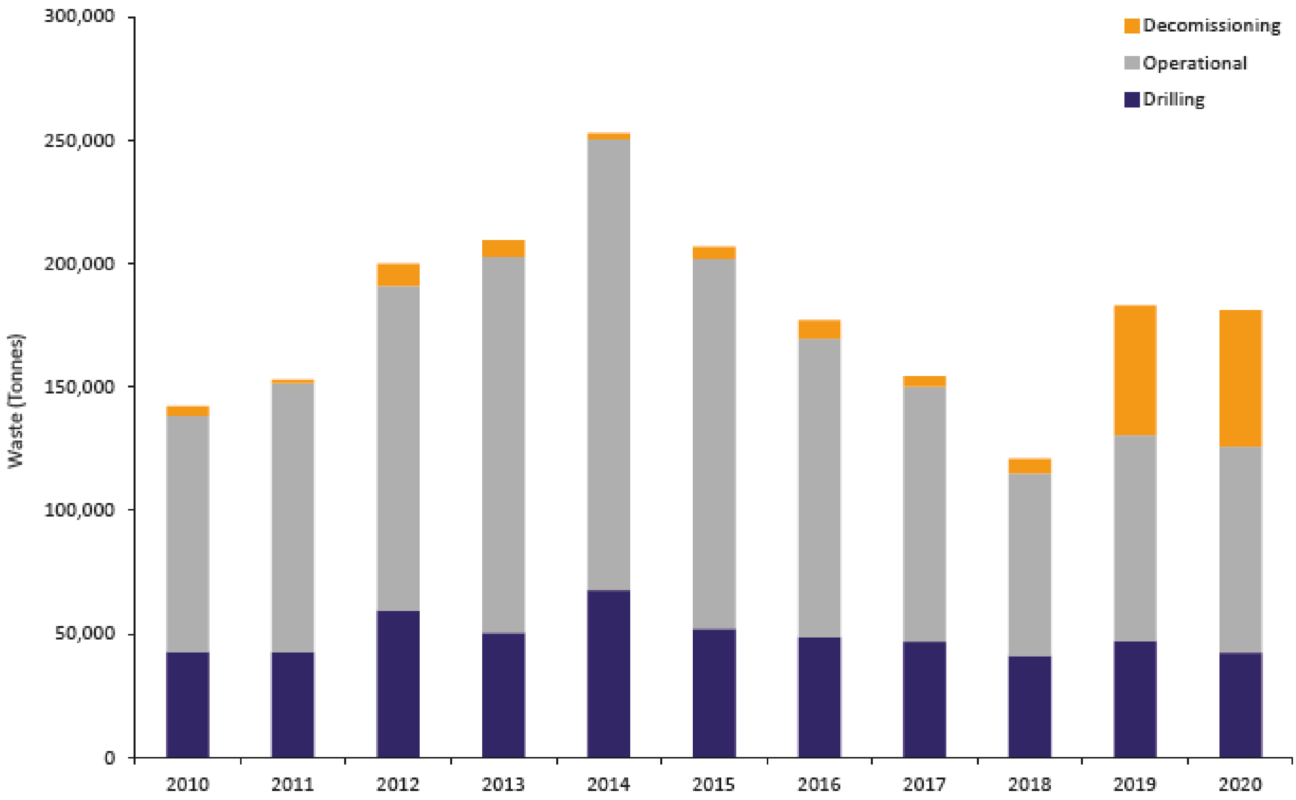
5.10.3.1 Oil and Gas

The quantity of waste generated offshore and transported onshore will vary from year to year depending on the level and type of offshore industrial activity.

In 2020, the UK's offshore oil and gas industry returned 180,995 tonnes of waste material to shore, just over a 1% reduction from 2019 (183,082 tonnes); this was a rise of 60% from that returned in 2018 (<150,000 tonnes), the lowest figure in the preceding 8 years. The increase in waste seen in both 2019 and 2020 was largely accounted for by the increase in decommissioning waste (this being 8 times greater in 2019 compared to 2018, see Figure 5.62) (OGUK 2021). Between 2010 and 2018, the annual return of decommissioning waste accounted for a very small proportion of the overall waste returned, compared to operational and drilling wastes. Of the waste returned in 2020, the majority of this was operational wastes (>70,000 tonnes) followed by decommissioning waste, the latter volume (and proportion) is likely to increase in the future with further decommissioning activity.

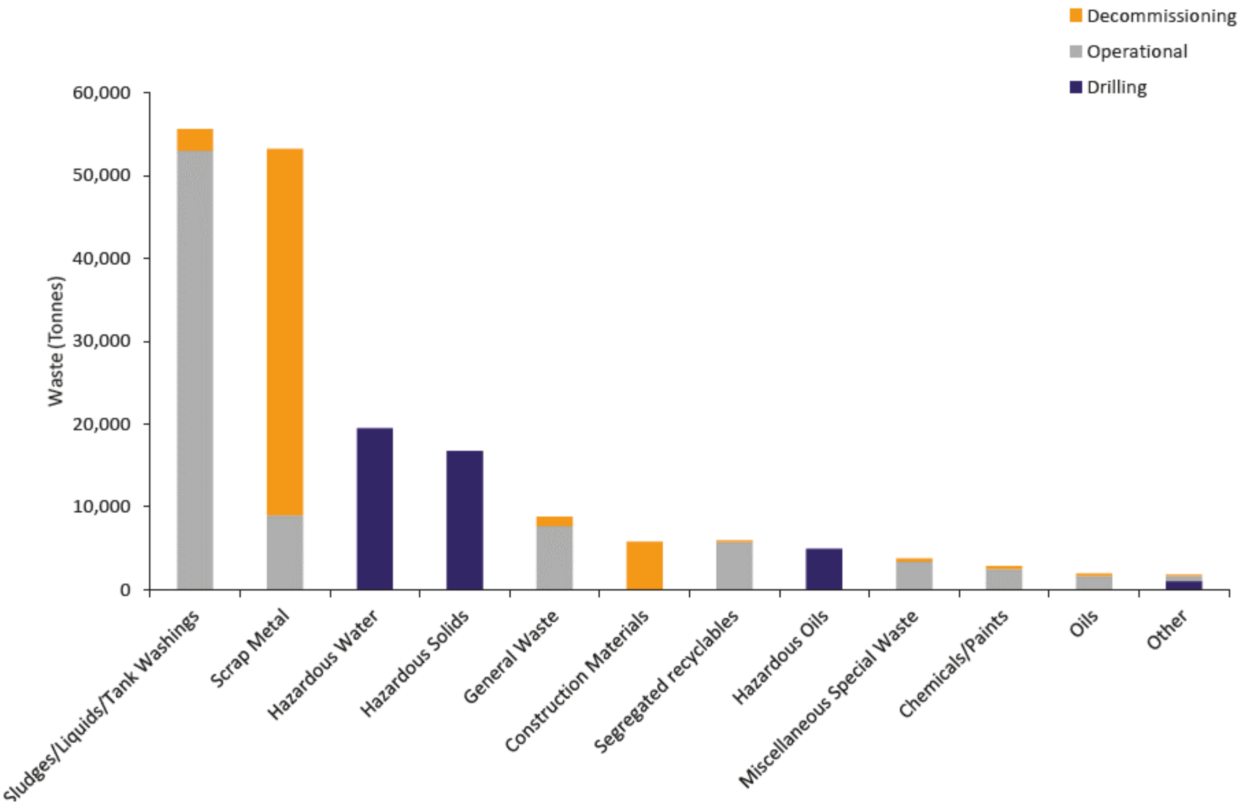
In 2020, the majority of waste being returned to shore was from operational sludges, liquids and tank washings (>50,000 tonnes), followed closely by decommissioning waste, primarily scrap metal (Figure 5.63) (OGUK 2021). All hazardous waste returned (water, solids and oils), amounting to approximately *ca*. 42,000 tonnes, was from drilling activity.

Figure 5.62: Waste generated offshore by activity (2010-2020)



Source: OGUK (2021), using EEMS data

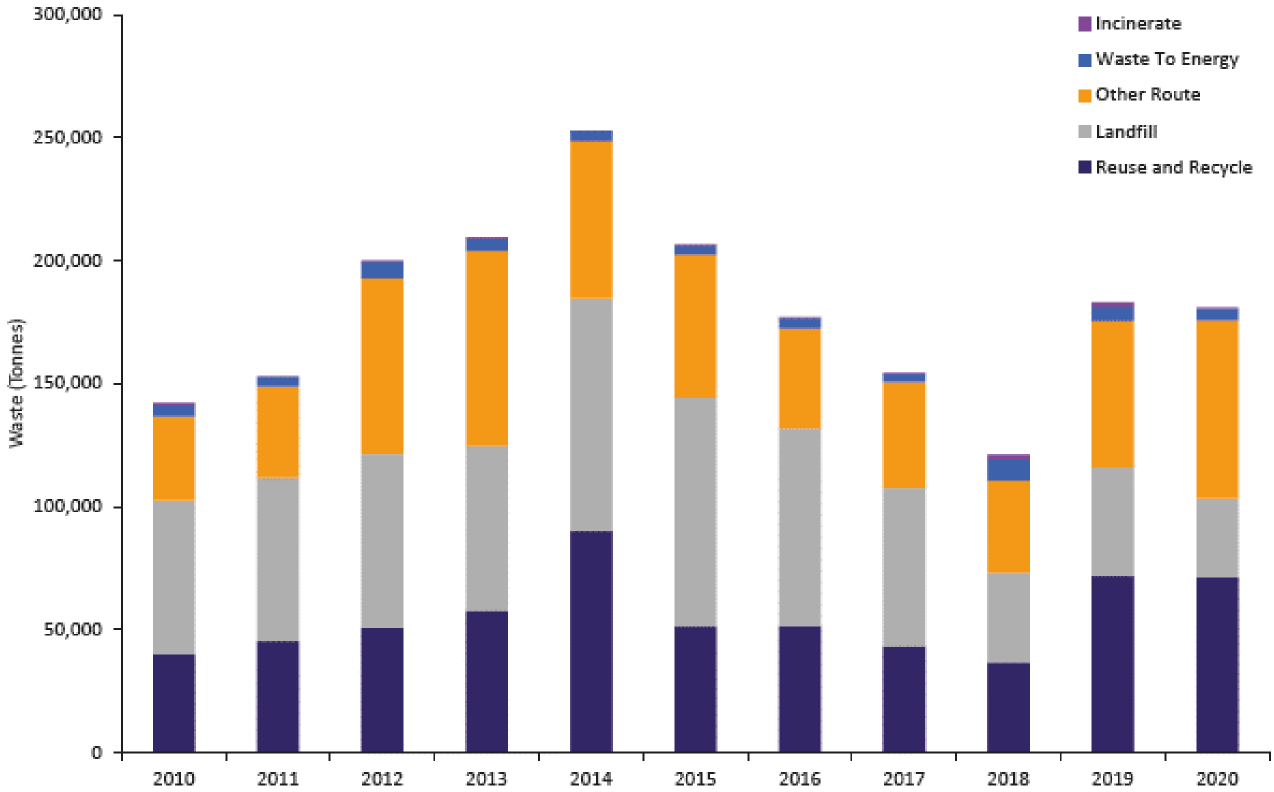
Figure 5.63: Drilling, operational and decommissioning waste by type, 2020



Source: OGUK (2021)

Since 2010, there has been a year on year reduction of waste material returned going to landfill (Figure 5.64). Approximately 12,200 tonnes less waste was sent to landfill in 2020 compared to 2019, with over 71,000 tonnes of waste re-used, or recycled (OGUK 2021). Over the past two years, there has been an increase in waste disposed of via “Other” disposal routes, these include the treatment of aqueous wastes, composting and land spreading. In 2020, 74,500 tonnes of wastes returned were disposed of via this route, nearly double the 2018 amount.

Figure 5.64: Total wastes generated offshore by waste disposal route, 2010-2020



Note: *Other includes any other disposal route such as treatment of aqueous wastes, composting and land spreading. Source: OGUK (2021), using EEMS data

Since 2001[237], discharge into the sea of drill cuttings contaminated with oil-based (non-aqueous) drill fluids at a concentration greater than 1% by weight on dry cuttings has been prohibited on the UKCS, (discharge of cuttings contaminated with synthetic organic phase drill fluids is effectively prohibited). Cuttings from wells drilled with water-based drill fluids may still be discharged (note, the use and discharge of offshore chemicals on the UKCS are regulated, See Appendix 3).

Cuttings cleaning technologies capable of reducing oil on cuttings drilled with oil-based muds to levels below 1%[238] are used offshore in some cases, and may in future reduce quantities of cuttings returned to shore and disposed of to landfill; in 2020, four drilling operations, compared to 3 in 2019, discharged oil-based fluid cuttingswith all cuttings undergoing cleaning and processing offshore (e.g. thermally treated) to bring the oil content to <1% (OGUK 2021). As with drilling chemicals, the quantity of cuttings generated correlates to drilling activity (Figure 5.65). In 2020, 38,000 tonnes of oil-based fluid cuttings were generated offshore, and 24,200 tonnes of this (64%) were returned to shore, whilst the remaining 36% were either re-injected or treated and discharged offshore. Drill cuttings returned to shore are processed at specialist treatment plants to separate oil (or synthetic fluids) and water from the cuttings (solids) prior to disposal.

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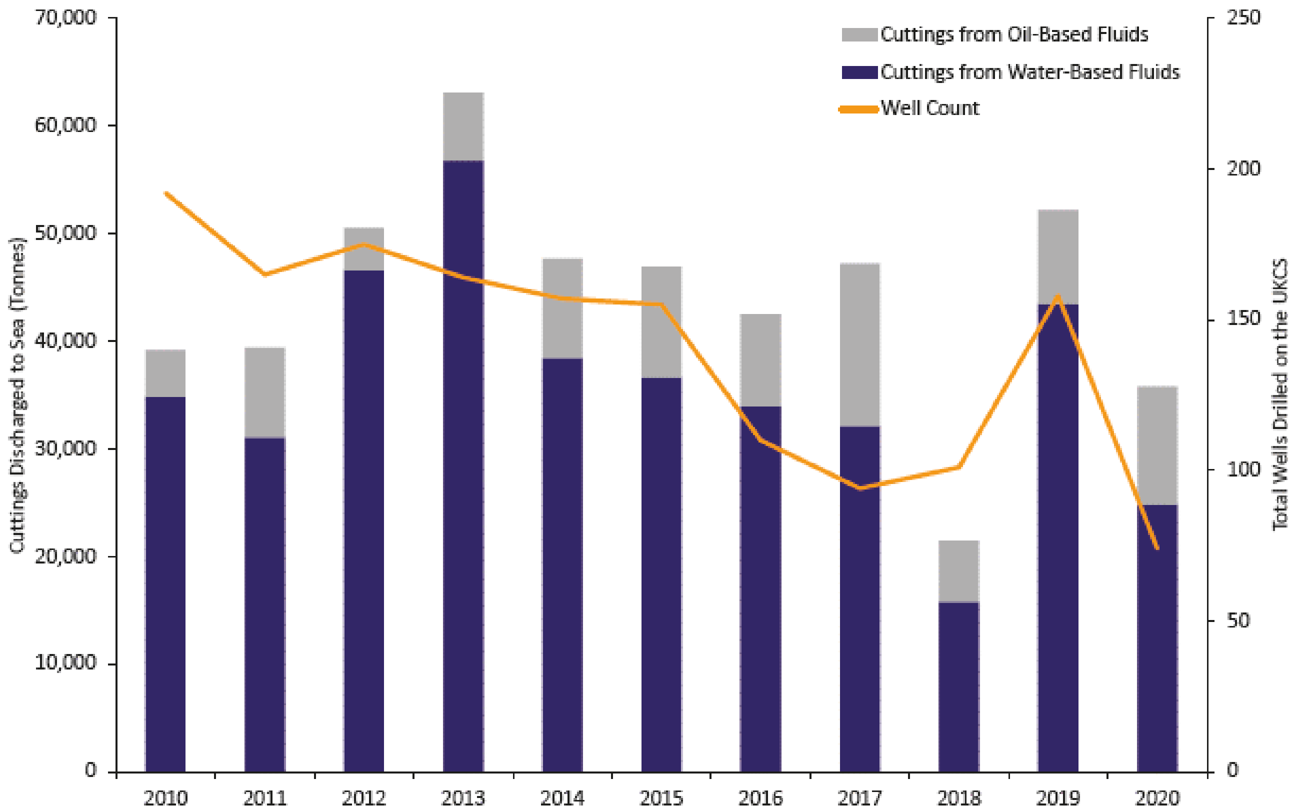
[237] OSPAR Decision 2000/3 on the Use of Organic-Phase Drilling Fluids (OPF) and the Discharge of OPF-Contaminated Cuttings

[238] Thermal processing of cuttings whereby these are heated to a temperature at which hydrocarbons are released from the solid, leaving solids with <1% oil in cuttings content

Used drilling muds and cuttings can also be ground and disposed of by reinjection into deep rock formations rather than discharged to sea or returned to land. The reinjection of wastes at source is an alternative disposal route avoiding the requirement for onshore disposal and landfill space, and relevant approvals for the re-injection of cuttings need to be secured from BEIS.. However, the process of reinjection can be energy intensive and thus result in increased atmospheric emissions from the installation. Suitable geological formation(s) for reinjection of such materials is not always available. Where it is, the target is selected on the basis of geological understanding from previous drilling in the area, with performance monitored over time. In 2020, some 2,800 tonnes of oil-based fluid cuttings were injected into offshore formations (OGUK 2021).

Figure 5.65: Drill cuttings discharged to sea, 2010-2020



Notes: Cuttings from OBM discharged to sea are treated cuttings from oil based fluids, Source: OGUK (2021)

In 2018, some 222 million tonnes of total waste was generated by the UK as a whole, compared to 218 million tonnes in 2016. Over half of this (62%) was generated by construction; ~19% was from commercial and industrial activities, with 11% from households (see Table 5.31). All activities saw an increase in waste since 2016 except households: the biggest increase since 2016 was from commercial/industrial (7%), while household waste decreased by over 3% compared to 2016.

Table 5.31: Waste generation split by responsible economic activity, UK, 2016-2018 comparision[1]

Year & change	Commercial & Industrial (million tonnes) & % change	Construction[2] (million tonnes) & % change	Household (million tonnes) & % change	Other[3] (million tonnes) & % change	Total (million tonnes) & % change
2016	39.8	136.2	27.3	15.0	218.3
2018	42.6	137.8	26.4[4]	15.4	222.2
Change	7%	1.2%	-3.3%	2.8%	1.8%

Notes: [1] Includes waste that may go for export, but excludes waste imported from outside the UK. [2] Construction includes dredging spoils. [3] Other consists of agriculture, forestry and fishing and mining. 4. 2019 figures available for this, was also 26.4. Sources: Waste Statistics Regulation return, in Defra (2021c)

Waste generated offshore in 2018 amounted to 120,000 tonnes (OGUK 2019) and represented 0.05% of the UK total for that year. The waste generated offshore in 2020 (180,995 tonnes) would represent 0.08% of the UK total for 2018 (OGUK 2021). In 2018, of the ~214 million tonnes of UK total waste that entered final treatment, just over 50% was recycled/recovered, with ~23% landfilled (Defra 2021c) (see Table 5.32).

Table 5.32: UK waste entering final treatment, split by final treatment method, 2016-2018 comparison[1] (million tonnes and % change)

Year & change	Recycling & other recovery	Incineration, with energy recovery[2]	Incineration[3]	Backfilling	Landfill	Land treatment & release into water bodies	Total
2016	103.9	7.3	5.7	16.8	52.3	25.5	211.5
2018	108.4	8.5	7.3	14.2	50.8	25.7	214.8
Change	4.3%	15.5%	28.3%	-15.8%	-2.8%	1.1%	1.6%

Notes: Percentages calculated may not exactly sum to totals due to rounding [1] Includes waste that may have been imported but excludes waste exported for treatment outside the UK. [2].Where formal R1[239] accreditation has been awarded. [3].Excluding R1, where this has not been awarded. Sources: Waste Statistics Regulation return, in Defra (2021c)

5.10.3.2 Renewable energy

Operational waste from offshore renewable developments is limited; wastes are generated from construction and maintenance activities, including vessel waste, these subject to the same regulation as waste coming onshore from oil & gas activity, and waste will also be generated at decommissioning. There is a requirement to include a description of decommissioning within development applications, and the requirements to complete (and get

[239] The R1 status of an Energy from Waste (EfW) facility classifies it as an Energy Recovery Facility rather than as a disposal operation.

approval of) a decommissioning programme at end of operational life, is also included in the Development Consent Order granted for each project.

There is the potential for substantial waste to be generated from the decommissioning of offshore renewable infrastructure and the end of life stage is becoming increasingly important as the rapid rise in developments and installations, could result in an equally rapid rise in decommissioning as infrastructures reach the end of their (25-30) year operational lifetime (Tota-Maharaj & McMahon 2020). There are studies of the potential scale of waste likely to be generated (e.g. Tota-Maharaj & McMahon 2020, Liu & Barlow 2017), options for life extension (e.g. Spyroudi 2021), and challenges to decommissioning and recycling (e.g. Topham *et al*. 2019, Bennet 2021, Net Zero Technology Centre 2021). Turbine blades are constructed from composite layers of stiff carbon or glass fibres in a resin matrix, and are currently difficult and costly to reprocess. Globally, there is an estimated 2.5 million tonnes of composite material in use in the wind energy sector, with glass fibre reinforced plastic (GFRP) representing the majority of the composites, whilst the demand for carbon fibre reinforced plastic (CFRP) has tripled between 2010 and 2020 (Burnett 2021). An estimated 60,000 tonnes of GFRP is expected to be decommissioned from the wind industry globally by 2023, with the sector expected to be the second biggest consumer of CFRP in the next decade (other consumers being aerospace, sports and automotive sectors) (Burnett 2021, Net Zero Technology Centre 2021). Currently, the end of life fate for both GFRP and CFRP is largely landfill or incineration, with technologies being developed to recover fibres and reduce this waste, these are at varying levels of maturity. Research and collaborations on a circular economy approach for the wind sector includes the University of Leeds[240], the Circular Economy for the Wind Sector (CEWS)[241] and the Carbo4Power project[242].

5.10.4 Carbon Transport and Storage, Gas Storage and Hydrogen Production

Drilling rig and drilling wastes from carbon dioxide injection wells will be similar to those from oil and gas operations, and similarly, hazardous and non-hazardous waste will be strictly segregated for onshore disposal.

During construction and operation of CO_2 injection and gas storage facilities, a number of wastes will be generated. Scrap metal and other solid operational wastes are segregated and stored for onshore disposal. Galley, domestic and liquid wastes are stored in bags/tanks/drums for onshore disposal and food waste is macerated prior to disposal and sewage is treated.

Wastes generated during construction of hydrogen production and transport facilities are expected to be minimal based on the potential scale of development in the near term, with limited wastes expected to be produced during operation.

Carbon dioxide storage, gas storage and hydrogen production facilities will be subject to requirements for decommissioning plans, with a range of wastes produced at the end of operational life. The nature of most of these wastes is anticipated to be similar to those from the oil and gas and offshore wind industries, i.e. a high proportion of metals, particularly steel, in addition to smaller quantities of plastics and other materials, with much being re-used or recycled.

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[240] https://www.leeds.ac.uk/info/130564/energy/929/new_research_on_circular_economy_and_offshore_wind
[241] https://ore.catapult.org.uk/stories/cews/
[242] https://www.carbo4power.net/

5.10.5 Controls and mitigation

The Merchant Shipping (Prevention of Pollution by Sewage from Ships) Regulations 2020 implement Annex V of MARPOL 73/78 (Regulations for the Prevention of Pollution by Garbage from Ships – revised Annex V entered into force in 2013[243]). Annex V, which applies to fixed and floating offshore installations, including rigs, their support vessels, and vessels involved in installation and operational maintenance of offshore renewables, operating on the UKCS, prohibits the discharge of all garbage into the sea (except ground food wastes where the installation is more than 12 miles from the nearest land), requires facilities/ships to have a waste (garbage) management plan and display placards to notify all persons on board that the over-board disposal of waste is prohibited, and to maintain waste records. Because the offshore disposal of garbage is prohibited, then all such waste must be transferred to shore for disposal and must therefore be managed in accordance with the Duty of Care for waste and the requirements of all relevant UK waste legislation. Carbon capture for the purposes of geological storage would be subject to similar waste management and reporting regulations, including for support vessels.

There are strict controls on the trans-frontier shipment of waste. Waste from decommissioning activities can be transported to locations outside of the UK for processing (e.g. Netherlands); this movement of waste is regulated and controlled (requiring approval from regulators in both the sending (i.e. UK) and receiving (e.g. Netherlands) countries) and receiving ports and yards must be suitably licensed to receive and process such waste.

Other controls and mitigation applied include annual waste reporting requirements (records quantities and disposal routes i.e. through the Environmental and Emissions Monitoring System, EEMS), waste segregation and the use of waste hierarchy whereby opportunities for waste prevention, re-use or recycling of equipment and materials is maximised, yard selection and regular contractor audit, use of licensed contractors and sites. The BEIS Guidance Notes for Decommissioning of Offshore Oil and Gas Installations and Pipelines under the Petroleum Act 1998, (BEIS 2018[244]) states that decommissioning of facilities will be regarded as the last option, after reuse for energy or other projects has been ruled out, and decommissioning decisions are consistent with waste hierarchy principles. Regulatory controls over decommissioning are in place and will continue to require a detailed assessment of waste processing prior to end of life.

5.10.6 Likelihood of significant effects

There are regulatory controls of waste management on- and offshore and significant effects from waste treatment and disposal are not expected.

Waste produced from offshore energy activities makes a minor contribution to waste volumes at a national scale and significant transboundary effects are not envisaged from the movement of decommissioning waste to licensed sites outside the UK.

5.10.7 Summary of findings and recommendations

At around 0.05% of total UK (based on 2018 figures) waste generation arises from offshore energy industry and is expected to remain, minor. Established waste management procedures

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[243] Annex V is considered a living document
; https://www.imo.org/en/OurWork/Environment/Pages/Garbage-Default.aspx
[244] This guidance is currently under review and an draft is expected to be issued for consultation in Q1/Q2 2022

comparable with those onshore and effective regulatory controls have minimised the generation of hazardous and other waste materials offshore.

In view of the volumes of material (drilling wastes and general waste) likely from the drilling or operations that could follow adoption of the draft plan/programme, together with the stringent control of waste disposal activities it is considered that any effects on land will be negligible.

Offshore decommissioning activity is expected to rise in the coming years, not just from the oil and gas sector, but from all offshore energy sectors, as projects reach the end of economic or operational life. This will increase the volume of waste generated from a range of offshore energy developments, with challenges remaining for the re-use and recycling of this waste. An increase in decommissioning waste for the oil and gas sector is already evident from the 2019 and 2020 returns and, at present, much of the waste returned to shore is recycled, and a high proportion of materials (especially structural steel, copper, cabling and other metals) can be expected to be recycled in the future. While effort is made to identify re-use opportunities for materials and equipment at the time of decommissioning, generally options are limited due to age and conditions of structures.

5.11 Air quality

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Local air quality effects resulting from vessel and power generation exhaust emissions, flaring and venting	X	X	X	X	X	X	X	X
Air quality effects of a major gas release or volatile oil spill	X	X	X					X
Potential for effects on human health associated with reduced local air quality resulting from atmospheric emissions associated with plan activities	X	X	X					

5.11.1 Introduction

Poor air quality may result in effects on human health, the wider environment and infrastructure. Atmospheric acid gases include sulphur dioxide (SO_2) and oxides of nitrogen (NO_X). These gases can react with water vapour forming acids, increasing the acidity of clouds and rain which can result in vegetation damage, acidification of surface waters and land, and damage to buildings and infrastructure. In addition, these gases can transfer directly to surfaces through dry deposition (close to the source) causing similar damage to acid rain (UKTERG 1988). Reduction in local air quality through inputs of contaminants such as oxides of nitrogen (NO_X), volatile organic compounds (VOCs) and particulates, may contribute to the formation of local tropospheric ozone and photochemical smogs, which in turn can result in human health effects (see for example, Bradley *et al*. 2019, Carnell *et al.* 2019, COMEAP 2018). Ozone is known to impair lung function and NO_X causes irritation of the airways and can be particularly problematic for asthma sufferers (see WHO 2014, Defra 2019a). In addition to potential human health effects, habitats may be sensitive to acid deposition, and in the UK many such habitats still exceed critical loads[245]. An overview of recent UK pollutant emissions and trends is provided in Appendix 1e. The potential sources of emissions from activities associated with each of the draft plan elements is discussed below.

5.11.1.1 Offshore wind farms

Offshore wind farm (OWF) development will result in emissions during the construction, commissioning and decommissioning phases of the project, principally through gaseous emissions from vessel power generation. The operational stage of OWF development has minimal energy requirements, principally associated with maintenance activities involving small wind farm service vessels, often involving high speed light craft.

The installation sequence of a turbine will vary depending on the type of foundation structure: gravity base will require initial preparation of the seabed, then placement and infill, however the

[245] Defined as the exposure level below which effects do not occur, according to present knowledge. See: https://uk-air.defra.gov.uk/data/ceh-map and https://uk-air.defra.gov.uk/data/critical-load

structure can be constructed onshore thereby reducing offshore operations. Other foundation types (monopile, jacket and bucket) only require placement and pile drive/suction installation. The installation of tethered turbines will differ depending on the type of foundation and mooring system, however analogous to gravity base-type foundations; construction of floating devices can largely take place onshore. The Hywind project utilised a series of pre-installed steel suction caissons followed by cable installation and the towing of the pre-assembled ballasted wind turbine to site to be moored (Statoil 2015). Similarly, both tension-leg platform (TLP)-type foundations and semi-submersible-type foundations can be substantially constructed at an assembly yard and then towed to site (see DNV GL 2015 for explanation of different foundation types). Time in the field of installation/support vessels may therefore vary depending on foundation structure design. Turbines are most likely to be taken to site on a barge and installed from either a jack-up barge or a floating (semi-submersible) vessel/crane, depending on water depth, vessel/crane capability/availability. Positioning of barges/crane vessels will likely be by tugs, and other vessels could include survey vessels, guard vessels and support vessels for equipment/supply transfer and air support for crew changes. During the operational phase of the wind farm, there may also be the requirement for maintenance trips, which will require supply vessels and support of variable size depending on the nature of the maintenance.

Emissions to atmosphere from individual projects will vary depending on the number of vessels required and the time these vessels are in the field. These assessments will be undertaken at a project specific level, however those undertaken for the majority of offshore wind farms to date have concluded negligible to no effect offshore, and have in most instances, in applications made under the *Planning Act 2008*, scoped out the issue entirely from EIA, with the scoping opinion in agreement (e.g. The Planning Inspectorate 2016[246], 2017[247]). For example, the scoping reports for Norfolk Boreas and Vanguard considered that the number of vessels (up to *ca*.12 during construction) and the associated atmospheric emissions would be small in comparison to the total shipping activity in the southern North Sea. It also noted that, marine exhaust emissions were limited in line with the provisions of International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78. Similarly, the issue was scoped out for Hornsea Project Three on the grounds that aerial emissions would be rapidly dispersed offshore, the proposed wind farm would be a long way from any static sources of emissions and aerial emissions from vessel and helicopter movements associated with the development were small compared with total emissions for the southern North Sea[248].

5.11.1.2 Wave and tidal developments

The effects on air quality identified above for offshore wind farms also apply to wave and tidal stream technologies and predominantly relate to atmospheric emissions from the vessels used for installation, decommissioning and maintenance of installations.

Atmospheric emissions and therefore air quality associated with tidal range schemes are skewed heavily by the long construction times (e.g. 7 years for La Rance, estimated to be 3 years for the Swansea Bay tidal lagoon), with high cumulative levels of emissions from construction and dredging vessels and vehicles on the landward side during this project phase.

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[246] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010079/EN010079-000018-Scoping%20Opinion.pdf
[247] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010087/EN010087-000860-6.5%20Scoping%20Opinion.pdf
[248] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-000570-HOW03_6.4.5.5_Volume%204%20-%205.5%20-%20Scoping%20Report%20and%20Secretary%20of%20State's%20Scoping%20Opinion.pdf

There are few Air Quality Management Areas (AQMAs) in the tidal range resource area (see Figure 2.9 and Figure A1e.1), with those in the Cardiff, Swansea and Liverpool areas being in closest proximity to the coast. Previous studies of barrage and lagoon options (DECC 2010f) noted that despite a significant rise in the air pollutant concentrations above background levels during construction, these would likely be localised (e.g. along main routes to the site and construction site itself). DECC (2010f, e) also noted the potential for changes to emissions from shipping should re-routeing be required, particularly for barrage options. Measures to reduce or prevent such re-routeing were identified (e.g. improved logistics to locks, coordination of transiting vessels, and dredging approaches and navigation channels), but an increase in transit times was generally expected but could not be quantified.

5.11.1.3 Oil and gas

The major sources of emissions to atmosphere from offshore oil and gas exploration and production are internal combustion for power generation by installations, terminals, vessels and aircraft, flaring for pressure relief and gas disposal, flaring from well clean-up and testing, cold venting from storage and loading operations and fugitive emissions. Power requirements for the UK offshore industry are dominated by oil production installations (typically >50MW per platform), with smaller contributions from gas platforms and mobile drilling units (typically 10MW per unit) and support vessels. The major energy requirement for production is compression for injection and export, with power generated by gas or dual-fuel turbine. Incidental emissions may also be associated with refrigeration and fire-fighting equipment. Additionally, any new installations will generate emissions through the transport of fixed or floating infrastructure to site and commissioning, with any effect being relative to the time spent in the field.

As indicated in Appendix A1e, UK offshore oil and gas installation emissions are reported annually to OSPAR and can be used to show trends in UK offshore oil and gas activity emissions (e.g. Figure 5.66). Noting the different units for CO_2 (million tonnes) compared to kilotonnes for the other emissions, CO_2 clearly accounts for the greatest proportion of emissions to air from UKCS offshore installations, primarily generated from fuel consumed by combustion equipment to provide electrical power and drive compressors for oil and gas export (Oil & Gas UK 2018). The climatic implications of CO_2 and methane emissions associated with the draft plan are described in Section 5.12. Whilst emissions have generally declined alongside production over the last twenty years, there is considerable variation between years, particularly for NO_x, CH_4 and nmVOC; noting that on an individual asset level, overall power demand and, therefore, emissions stay relatively stable, even as oil and gas production falls (OGA 2021a).

NAEI emissions data for 2020 will be released in 2022. Utilising European Union Emissions Trading Scheme (EU ETS), BEIS Environmental Emissions and Monitoring System (EEMS) and the Office for National Statistics GHG data, ONS (2021) indicate a reduction of between 10% and 14%, in industry emissions from 2019 to 2020, put down to a mixture of proactive emissions abatement initiatives, as well as reduction in industry activity driven by the COVID-19 pandemic and a commodity price crash, and end-of-life shutdown for a handful of large emitters. EEMS data show a reduction in all emission source categories between 2019 and 2020, with flaring emissions experiencing the greatest decrease. Diesel fuel emissions and venting emissions fell for the second consecutive year, and gas fuel consumption emissions fell after an increase in 2019. Methane emissions, between 2019 and 2020, fell by 20%, due to reductions in flaring and venting emissions (OGA 2021a).

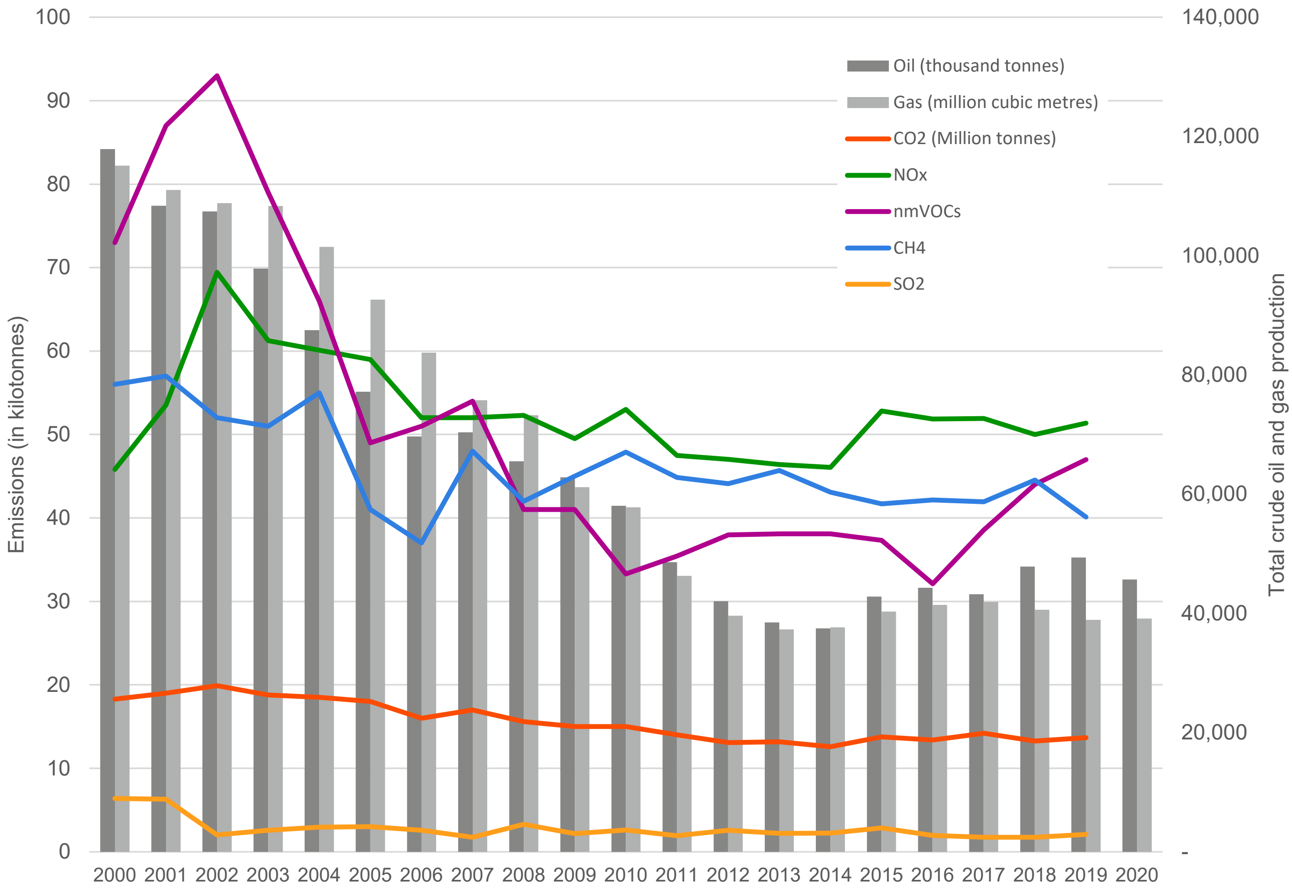
OGA analysis of EEMS data for 2020 indicates that nearly 70% of industry emissions were associated with on-site power generation, with electrification of energy intensive equipment offshore seen as a critical mechanism for emissions abatement (OGA 2021a, see also Section 5.12). The remainder of the CO_2 emissions from the industry are due to flaring at production sites, terminals and from rigs testing exploration and appraisal wells. A very small amount of CO_2 is vented from some production facilities (OGA 2021a). Methane (CH_4) emissions comprise around 10% of industry emissions on a CO_2 equivalent basis. Roughly half of these are associated with venting of natural gas. Most of the remaining methane emissions come from flaring, due to combustion inefficiency or cold flaring, where gas passes through the flare without ignition. Ninety percent of NO_x emissions are from fuel combustion with the remainder due to gas flaring (OGA 2021a). It is noted that new OGA guidance[249] sets an expectation that all facilities should have zero routine flaring and venting by 2030 or sooner (i.e. in advance of that covered by the World Bank Zero Routing Flaring Initiative), with industry taking action through its Methane Action Plan. Flaring and venting will still occur as these are important safety critical systems for offshore installations, however, these will only be for process upsets, planned events and safety critical purposes.

In general, the number of exploration wells drilled on the UKCS shows a decline over time (Figure 2.11). Trends in emissions from well testing, if taken as one of the most emissions intensive aspects of exploratory and appraisal drilling, have remained largely constant since 2000 (NAEI data). If current trends continue, and in view of the contribution of emissions reductions measures (including of that for ships, see Section 5.11.2), then emissions from future licensing rounds are not expected to be appreciably greater than any past round.

As fields cease production, emissions associated with their removal will be analogous to that of their installation, possibly involving the use of rigs to abandon wells, shipping including the use of heavy lift vessels to remove installation components and to transport them to licensed disposal yards onshore.

[249] https://www.ogauthority.co.uk/news-publications/publications/2021/flaring-and-venting-guidance/

Figure 5.66: UK offshore atmospheric emissions and total offshore oil and gas production, 2000-2020



Note: Emission figures for CO_2 are in million tonnes. Sources: OSPAR emissions to air, 2010-2019 (https://odims.ospar.org/en/submissions/ospar_discharges_offshore_2019_01/). OSPAR (2012). Discharges, spills and emissions from offshore oil and gas installations in 2010. Oil production (DUKES F.1 - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1006618/DUKES_F.1.xls Gas production (DUKES F.2 - https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1025455/DUKES_F.2.xls

5.11.1.4 Gas storage including hydrogen

Atmospheric emissions associated with gas storage can be split into similar phases to those for oil and gas exploration and production, including the use of survey vessels, rigs to drill exploration and appraisal wells, vessels used to install facilities and drill injection wells, as well as operational emissions resulting from power requirements for compression. Types of compression machinery used in gas storage applications will depend on the operating conditions, but can include centrifugal compressor units (usually used for medium and high volumetric rates), driven by gas turbines or electric motors, or reciprocating compressors (usually used for lower flow rates) driven by electric motors or gas engines.

As indicated in Section 5.12, there are presently no active offshore gas storage facilities operational on the UKCS. Gas demand will reduce as part of the transition away from fossil fuel use, but in the short to medium-term gas demand will remain and may be combined with CCS for power generation, or hydrogen production (blue hydrogen). Additional offshore storage capacity has the potential to come forward in the future to enhance the security of supply. Air quality effects associated with the installation and operation of these new facilities are likely to be small in a national context.

It should be noted that hydrogen is a reactive gas in the atmosphere that has the potential to generate ozone on regional scales. Like methane, leakage from the gas network would be a critical factor in managing the impacts of fugitive losses to the atmosphere (Air Quality Expert Group 2020). The transport of hydrogen from offshore generation facilities may be via new or existing pipelines, however the possibility of ship transfer cannot be entirely excluded, with the latter having associated shipping emissions (though note that such emissions are likely to decline over time as the sector decarbonises, see Section 5.12).

5.11.1.5 Carbon dioxide storage

Atmospheric emissions associated with carbon dioxide storage can be split into similar phases to those for oil and gas exploration and production and natural gas storage, including the use of survey vessels (including for operational monitoring), rigs to drill exploration and appraisal wells, vessels used to install facilities and drill injection wells, as well as operational emissions resulting from power requirements for compression. Transport of carbon dioxide to offshore facilities will most likely be delivered via new or existing pipelines (and possibly be used in enhanced oil recovery for partially depleted hydrocarbon fields), however the possibility of ship transfer cannot be entirely excluded. The use of existing facilities through storage in depleted hydrocarbon reservoirs (where practical) could reduce installation emissions. In general, minimal operational emissions and distance from shore is likely to mean that routine atmospheric emissions are not a source of likely significant effect for carbon dioxide transport and storage.

From an air quality perspective, a general assumption is that efficient large-scale CCS would have effective emissions abatement included within the plant infrastructure and be regulated, permitted and monitored in a similar manner to large combustion plant infrastructure at present. The most well reported area of intersection between CCS greenhouse gas reduction and air quality is around unintentional solvent (and by-product) emissions and this can be associated with both pre- and post-combustion CCS. Pilot scale CCS activities have shown the potential for the co-emission of trace amounts of organic amine as a by-product, including some highly toxic species such as nitrosamines. To address this, alternative novel CCS solvents with lower toxicity (for example oxygenated organic compounds) are emerging. There remains a general principle that by-product emissions from the solvent stripping process require careful evaluation, for both overall mass of VOC emissions and specific direct chemical toxicity. Existing regulatory mechanisms would be expected to address this hazard through the permitting process (Air Quality Expert Group 2020).

The *Energy Act 2008* makes provisions for the carrying out of carbon dioxide storage with a view to its permanent disposal. Regulations (e.g. *The Storage of Carbon Dioxide(Licensing etc.) Regulations 2010* (as amended)), require sufficient information on a proposed storage structure to understand, *inter alia*, the geology and flow properties of the reservoir overburden (caprock, seals, porous and permeable horizons) and surrounding formations, including fracture characterisation and any man-made pathways (e.g. wells). Any application for a storage permit must also include a monitoring plan to confirm that the carbon dioxide remains in storage and to validate any modelling, or whether unintended migration and leakage is occurring and that corrective measures must be taken using an approved “corrective measures plan”. Under Article 1(2) of the CCS Directive, which was transposed into, and is part of, retained EU law, states that, “*The purpose of environmentally safe geological storage of CO_2 is permanent containment of CO_2 in such a way as to prevent and, where this is not possible,* *eliminate as far as possible negative effects and any risk to the environment and human health*." In view of this central purpose, and for this section the human health aspect, a short consideration of potential leak effects on human health and the mitigation measures available is given below.

The Health and Safety Executive (HSE) are responsible for regulating the full CCS chain under the *Health and Safety at Work etc. Act 1974*, under which employers are required to ensure the health and safety of workers and members of the public, so far as is reasonably practicable. At present, carbon dioxide is not defined as a dangerous substance under the *Control of Major Accident Hazards Regulations 1999*. It should be noted that HSE (2009, 2011) concluded that CCS developments have the potential to introduce a major accident hazard, as hazard ranges modelled for instantaneous releases (50-100m) are in line with other regulated hazardous substances, but that the risk posed by a pipeline rupture is likely to be similar to natural gas, but for toxicity rather than it being a flammable gas. Though behaviour of an instantaneous release of dense phase CO_2 is still not well understood, and can introduce other hazards such as cryogenic burns, HSE (2009) suggest that the hazard ranges may be substantially higher for CO_2 transported in this manner. With regards to offshore elements of the risk, good project design, including the use of existing guidelines on pipeline design (BS PD 8010: 2004 Part 2, DNV RP-J202: Design and Operation of CO_2 Pipelines) and any future modifications to these with regards to specific CO_2 requirements should provide for suitable mitigation at a project level.

Low release concentrations would have minimal effect beyond associated climate impacts and possibly small localised acidification of adjacent waters (see Phelps *et al.* 2015), but high concentrations could affect human life, ecology and other organisms, and potentially have transboundary implications depending on the storage site/release location (see Section 5.13). CO_2 is denser than air and therefore can displace it causing a suffocating effect; however it is also toxic to the cardiovascular system at concentrations exceeding 3%, with symptoms notable at exposure for 1 hour, or largely fatal at 15% for 1 minute (HSE 2011) – note that CO_2 is naturally present in the atmosphere at a concentration of ~0.037%. Catastrophic releases are not the only concern, for instance IPCC (2005) reports that chronic effects of CO_2 exposure at atmospheric concentrations of between 0.5 and 1% can result in metabolic acidosis (an increase in blood acidity) and increased calcium deposits in soft skin. Examples from real world exposure are few, but include a very large natural release of CO_2 from the Lake Nyos volcanic crater in Cameroon which caused 1,700 human deaths and loss of livestock at a distance of up to 25km. HSE (2011) note that this release was in the order of 1.6 million tonnes CO_2, and very large when compared with the potential scale of commercial CCS in the UK: a pipeline from source to injection facility might hold 10,000 tonnes or a large pipeline cluster 100,000 tonnes, although likely sectionalised into smaller inventories upon detection of a leak through the use of isolation or block valves.

Significant survey work would need to be undertaken to avoid formations and storage areas with faults or other features that could cause loss of containment and long term monitoring would need to be carried out on any storage site to make sure that leakages do not occur during operation and once the site is full and in its post-closure phase. The requirement for the site operator to monitor and take any corrective actions following the closure of a site should be for at least 20 years unless the competent authority (presently OGA) are convinced that the CO_2 will be completely and permanently contained. Once this is proven, the responsibility for the site is transferred to the state. A wider range of considerations with regard to carbon dioxide transport and storage and accidental release is provided in Section 5.13 Accidental events.

5.11.2 Controls and mitigation

The potential sources of effects identified above are largely from routine combustion emissions, much of which are associated with shipping (e.g. in development installation, operation (including maintenance) and decommissioning). For all the draft plan related activities, it should be noted that the *Merchant Shipping (Prevention of Air Pollution from Ships) and Motor Fuel (Composition and Content) (Amendment) Regulations 2014* which came into force in December 2014, partly implements EU Directive 2012/33/EU on the sulphur content of marine fuel. The Regulations include limits to the sulphur content of fuel oil used or intended to be used in sulphur oxide emission control areas (defined by Annex VI of the MARPOL Convention and including the North Sea and English Channel), to not more than 0.1% by mass from January 2015. Similarly, the emissions of NO_x from shipping are being controlled through the requirements of MARPOL Annex VI, whereby different "tiers" of emissions are permitted depending on vessel construction date and whether it operates within an emissions control area (as defined for the UK above). The UK Government has supported this approach and relevant regulations (*The Merchant Shipping (Prevention of Air Pollution from Ships) (Amendment) Regulations 2021*) came into force October 2021. Emissions and deposition is higher around major shipping routes such as the Southwest Approaches and English Channel (see Appendix 1e). Routine emissions are also made on offshore oil and gas installations (and also any for gas storage including carbon dioxide) for general power generation (e.g. lighting) and compression (e.g. for injection of water or gas).

Following the publication of Maritime 2050 (Department for Transport 2019[250]), the Clean Maritime Plan[251] sets out in more detail how the UK Government plans to transition the industry towards net zero by 2050. Individual operators typically contract all shipping-related activities associated with their operations, and it is anticipated that the fleets of vessels that will be used for future activity will reflect the transition towards low carbon shipping. As part of this, large ports (handling cargo in excess of 1mt per year) in England are being asked to produce Port Air Quality Strategies[252], to establish a minimum level of understanding of air quality in ports, and to reflect actions that the port is taking to address emissions under their control.

At a wider UK level, the Government's Air Quality Strategy for England, Scotland, Wales and Northern Ireland (2007) set national air quality standards with the objective of protecting human health, vegetation and ecosystems. The UK Government's Clean Air Strategy (2019) outlines how the UK and devolved administrations are to tackle issues related to air quality including those relevant to human health, the environment, clean growth, transport, household and farming emissions. The Clean Air Strategy, along with the provisions of the *Environment Act 2021* and a number of other recent UK Government strategies and plans, set out how the UK's air quality issues are to be addressed. Of most direct relevance are the air quality plan for nitrogen dioxide (NO_2), and the UK National Air Pollution Control Programme (2019), but also includes the Industrial Decarbonisation Strategy (2021) and the 25 Year Environment Plan

250 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/872194/Maritime_2050_Report.pdf

251 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815664/clean-maritime-plan.pdf

252 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815665/port-air-quality-strategies.pdf

(2018), Aviation 2050 (2018) and Maritime 2050 (2019), all of which in part address emissions to air of pollutants and greenhouse gases.

AQMAs have been declared to deal with problem areas in the UK, mainly for NO_2 which is largely derived from transport sources, predominantly from road transport (see Appendix 1e). Where these are in coastal areas, they could be influenced by activities associated with the draft plan/programme where there is an increase in port related activity, or particularly in the case of tidal range developments, ancillary development and shore-based construction. Any development will need to consider how their estimated emissions could affect air quality limit values, particularly where these could affect AQMAs. A high degree of coordination between marine and terrestrial planning may there therefore be required, as indicated the Marine Policy Statement which requires marine plan authorities to take account of any relevant statutory air quality limits or how air quality may be improved, particularly within, or adjacent to, AQMAs. The National Policy Statement (NPS) for ports, though largely set within the thresholds set out in the *Planning Act 2008*, provides further guidance and potential mitigation, for instance the provision by ports of shore-side electrical connections to eliminate emissions from ship generators when in port where ships can utilise such supplies, and the use of systems to reduce acting cumulatively on existing air quality issues, for instance HGV booking systems to avoid peak times.

Improvements in efficiency and other measures have been taken by operators to reduce fugitive emissions (gas escapes, for example, from leaks or processes), and the use of vapour recovery systems at off-loading facilities to reduce emissions of methane and other volatile organic compounds (OSPAR 2010).

For offshore oil and gas installations with gas combustion installations (power generation, turbines, fired heaters etc.) that have a combined total rated thermal input exceeding 50MW and a Pollution Prevention and Control (PPC) permit is required. Conditions on approved PPC permits include provisions based on best available techniques, emission limits, energy efficiency and monitoring requirements. There are a number of exclusions including mobile drilling rigs, which do not require a PPC permit. Any flaring and venting at offshore installations is subject to flare and vent consents. OGA guidance[253] on flaring and venting indicates that flaring and venting and associated emissions should be at the lowest possible levels in the circumstances; consents should be based on the highest performance standards of operation and maintenance for the installation, and operators much demonstrate they have explored all options to remain in consented quantities, and must strive for continuous reduction. These should be included in flare and vent management plans as part of their Greenhouse Gas Emissions Reduction Action Plans. Additionally, all operators should work towards net zero routine flaring and venting by 2030, and all new development should be planned and developed on the basis of zero routine flaring and venting. Specifically with regards to carbon dioxide equivalent emissions (see Section 5.12), combustion installations with a rated thermal input of more than 20MWth were required to have a permit under the *Greenhouse Gas Emissions Trading Scheme Regulations 2012* to discharge CO_2 as part of the implementation of the EU Emissions Trading Scheme (EUETS). This has since been replaced by the UK ETS (established by *The Greenhouse Gas Emissions Trading Scheme Order 2020*)[254]. CCS activities are also covered by these Regulations such that any

[253] https://www.ogauthority.co.uk/licensing-consents/consents/flaring-and-venting/
[254] https://www.gov.uk/government/publications/participating-in-the-uk-ets/participating-in-the-uk-ets

leaked/fugitive carbon dioxide emissions would be subject to the surrender of emissions trading allowances, in the same way as combustion emissions.

5.11.3 Summary of findings and recommendations

Offshore wind farm, wave and tidal stream development will result in atmospheric emissions during the construction, commissioning and decommissioning phases of each project, principally through gaseous emissions from power generation of vessels. Emissions from flaring and venting from offshore oil and gas installations have substantially reduced in recent years and OGA guidance sets an expectation that all facilities should have zero routine flaring and venting by 2030 or sooner. Similarly, regulation of combustion equipment and inclusion within UK ETS requirements promotes efficient use of equipment and fuel. These savings may in part be reduced in future due to increased energy requirements of mature fields, however in the medium-term, decommissioning of facilities will also lead to an overall reduction in emissions from the sector. The OGA also see electrification of energy intensive equipment offshore as a critical mechanism for emissions abatement.

Major sources of emissions to atmosphere from offshore gas storage and carbon dioxide storage, are internal combustion for power generation by installations (e.g. for compression and injection), vessels and aircraft. Significant combustion emissions from flaring are not expected from potential development in the proposed licence areas, given the availability of existing gas process and export infrastructure. Though the use of carbon dioxide storage may alter the emissions portfolio of a given coal or gas power plant (e.g. see an increase in the emissions of ammonia, NH_3), it is not a consideration of this SEA and would need to be considered at the project specific level.

Potential environmental effects of acid gas and greenhouse emissions are, respectively, regional and global in nature. Given the distance of most prospective areas for oil and gas from the coastline, local air quality effects from atmospheric emissions are not expected. Few new effects are expected in terms of the siting of gas storage and carbon dioxide storage facilities in existing hydrocarbon reservoirs. However, the use of vessels for construction and maintenance and the potential transportation of liquid CO_2 by ship to some carbon dioxide storage reservoirs make shipping the greatest potential source of routine atmospheric emissions from these technologies.

Emissions to air from plan activities will be incremental to those from a range of other terrestrial and marine sources, and those transboundary sources from other countries. Cumulative effects are more likely to be significant where plan related activities affect problem areas, such as air quality management areas. For offshore oil and gas, emissions have progressively reduced through reduced flaring and more efficient plant, and the point sources of such emissions are generally too far from shore to significantly contribute to cumulative effects at a local level. Any further exploration and development would be expected make a minor increment to such emissions, with the overall scale of offshore activity (in view of decommissioning) not appreciably changing in the currency of this SEA. Significant emissions from renewables technologies are limited to the manufacturing, construction and decommissioning phases, which could produce temporary cumulative effects (e.g. through enhanced shipping and port use), but in the long-term are likely to contribute to overall emissions reductions, and so are broadly not considered likely to act cumulatively. Construction of tidal range devices could produce significant cumulative effects at a local level through emissions from shipping and road haulage transport, or production of dust. Compared to other forms of renewables construction takes place over extended time periods (5+ years) and is coastal in nature. Any emission of pollutants adds to existing elevated levels in the atmosphere. Where activities could take place close to a boundary with adjacent states or administrations and where they have land masses which are also close proximity (e.g. France, the Isle of Man), there is greater potential for transboundary issues, but given the nature and scale of most activities, these are considered to represent a minor increment with limited scope for significant transboundary effects.

Emissions will also be associated with the construction of any infrastructure to be installed, and the choice of construction materials can make substantial differences to the emissions generated for this part of a project lifecycle, and in many cases, these emissions may take place outside of the UK. The potential expansion of ports to facilitate mainly OWF, but possibly also other renewables development, may have implications for local air quality in these areas. In keeping with national terrestrial and marine policy, and regional policies where applicable, any effect on AQMAs must be considered. Where UK port expansion or significant changes in use occur as a result of plan activities, mitigation measures including those set out in the NPS for ports should be considered to avoid impacting AQMAs or exceeding national limit levels such that new problems are created.

Tidal range developments are shore connected, and therefore emissions may be generated through terrestrial and marine sources, and are associated with long construction times. There is the potential that individually or cumulatively, alterations in ship movement through construction of barrages or lagoons (e.g. see DECC 2010f) could alter the nature of emissions from shipping in these areas.

Operational effects of offshore renewables are expected to be negligible, and effects at the strategic level are not considered to be significant.

In view of regulatory controls and commercial considerations, combustion emissions from power generation are unlikely to represent a major contribution to industry or national totals.

5.12 Climatic factors

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Contributions to net greenhouse gas emissions	X	X						
Reduction in net greenhouse gas emissions			X	X	X	X	X	X
Effects on blue carbon	X	X	X	X	X	X	X	X
Positive socio-economic effects of contributing to greenhouse gas reduction			X	X	X	X	X	X

5.12.1 Introduction

This section considers the aspects of the current draft plan/programme (see Section 2.3) in relation to anthropogenically augmented climate change and the international and national policy context, along with their related commitments, which have developed in recent years. The draft plan/programme is complementary to current policy and legislation (as set out in Section 2 and Appendix 2), e.g. specifically of relevance to this topic, renewable energy generation targets and greenhouse gas reduction commitments. Certain aspects of the plan (oil and gas licensing, gas storage leasing/licensing) also complement activities that contribute to security of energy supply. Though their associated operations may be regarded as deleterious to climate change mitigation efforts, projections of the likely demand and supply of UK hydrocarbons as part of a transition to net zero suggest a continued demand in the context of a declining UKCS supply (e.g. CCC 2020b).

5.12.2 Consideration of the evidence

5.12.2.1 Climate change

Evidence for human influenced climate change is now unequivocal (IPPC 2018). Over the last century anthropogenic sources of greenhouses gases (GHGs) have amplified the natural greenhouse effect[255] and are estimated to have caused approximately 1.09°C of global surface warming above pre-industrial levels (likely range of 0.95°C to 1.2°C), with there being a greater than 50% likelihood that this will reach 1.5°C in the near term[256] (IPCC 2021). Carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and the “F-gases”, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) are termed “direct” greenhouse gases as they have a direct effect on radiative forcing (RF)[257] within the atmosphere. Other gases including carbon monoxide (CO), volatile organic compounds (VOC), oxides of nitrogen (NO

[255] The absorption of thermal radiation by water vapour and “greenhouse gases” in the atmosphere and the subsequent re-radiation of this heat back into the atmosphere..

[256] This likelihood is relevant to all five scenarios assessed by the IPCC Working Group I, with this being the case even for the very low emissions scenario (SSP1-1.9). See Section 15.12.3 for an explanation of SSPs. Near term covers 2021-2040.

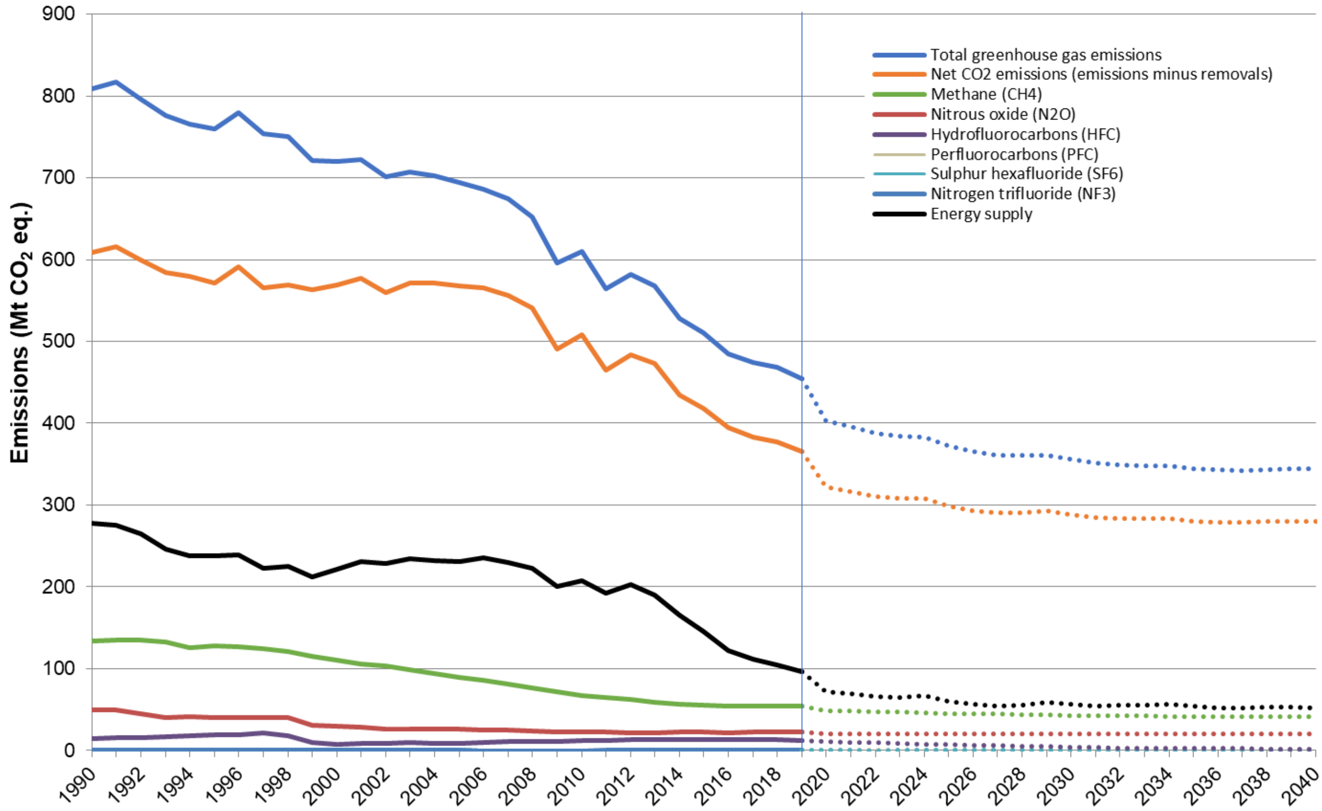
[257] Radiative forcing is a change in the net radiative thermal energy available to the global Earth-atmosphere system. Positive radiative forcing tends to warm the Earth’s surface and lower atmosphere. Negative radiative forcing tends to cool the Earth’s surface and lower atmosphere.

and NO_2) and sulphur dioxide (SO_2) although not significant direct greenhouse gases, are reactive and impact upon the abundance of the direct greenhouse gases through atmospheric chemistry.

CO_2 is the principal GHG of concern as it constitutes the largest component of combustion emissions (~80% of UK GHG sources in 2019 at 365 million tonnes (Mt), (BEIS 2021a, see Figure 5.67)) and has a potentially long atmospheric residence time (5-200 to ~1,000 years have been reported[258], see Houghton *et al*. 2001 and Archer 2005). Greenhouse gas residence times are an important metric as a greenhouse gases with a long residence time is irreversible in the short-term and will result in sustained radiative forcing over decades or centuries before natural processes can remove the quantities emitted. The residence times of such gases are therefore a key component of metrics used to estimate CO_2 equivalent (CO_2 eq.) emissions, that is, the radiative forcing provided by the emissions of a unit of a particular greenhouse gas species relative to CO_2, referred to as the Global Warming Potential (GWP), see Myhre *et al*. (2013). The result is a value in tonnes of CO_2 eq. incorporating the "basket" of GHGs listed above (i.e. those covered by the Kyoto Protocol). As atmospheric residence time influences this metric, GWP values differ depending on what "time horizon" is considered (see IPCC 2001, 2007, Myhre *et al*. 2013, and Shine 2009 for a synthesis and critical review). For example; CH_4 has a GWP of 82.5 ±25.8 times that of CO_2 at 20 years, and 29.8 ±11 times that of CO_2 at 100 years, reflecting its residence time in the atmosphere of ~11.8 ±1.8 years; N_2O has a GWP of 273 ±118 times that of CO_2 at 20 years, and 273 ±130 times that of CO_2 at 50 years, and 130 ±64 times that of CO_2 at 100 years, reflecting its residence time in the atmosphere of 109 ±10 years (IPCC 2021). A high degree of uncertainty in the GWP factors for some gases (CO and NOx), due to their short residence time in the atmosphere (1-4 months and hours-days respectively) and regional variability in abundance, means that they are generally not calculated. The IPCC (2021) indicate that it is virtually certain that CO and NOx have induced a positive RF and a net negative RF respectively. There is no scientific argument for the choice of a particular timescale to use for GWP metrics, but the 100 year time horizon was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) and is used in the Kyoto Protocol (Myhre *et al*. 2013), and is also used nationally for the calculation of carbon dioxide equivalent emissions (Shine 2009).

[258] No single lifetime / residence time can be defined for carbon dioxide because of the different rates of uptake by different removal processes.

Figure 5.67: UK greenhouse gas emissions, 1990-2019 and emissions projections 2020-2040 based on the reference scenario



Source: BEIS (2020a, 2021a). Notes: Final figures 1990-2019. “Reference scenario” projections based on central estimates of economic growth and fossil fuel prices. Contains all agreed government policies which have been implemented, adopted, or planned - where decisions on policy design are sufficiently advanced to allow robust estimates of impact (i.e. including "planned" policies).

Cumulatively, it is the concentration of such gases in the atmosphere globally, augmented by anthropogenic emissions, which are leading to global warming. Global concentrations of CO_2 (420ppm), CH_4 (1,866ppb) and N_2O (332ppb) have increased substantially due to human activity since 1750, exceeding pre-industrial levels in 2011 by 47%, 156% and 23% respectively, and considerably exceed levels recorded between 2 million and 800,000 years of reconstructed atmospheric records from ice core data (IPCC 2021). There is a high level of scientific understanding of the effects of anthropogenically enhanced levels of GHGs and ozone on global radiative forcing (IPCC 2013, IPCC 2018, IPCC 2021), with greater uncertainty about some important factors including aerosols (which partly offset the radiative forcing of GHGs) and predicting future forcing by solar irradiance (i.e. the influence of cyclic solar activity on the Earth’s climate). Predicted effects include *inter alia* an increase in global temperature (Kirtman *et al*. 2013, Collins *et al*. 2013), hot extremes in most inhabited regions, heavy precipitation in several regions, the probability of drought and precipitation deficits in some regions, rising sea-levels (Lowe *et al*. 2009, Church *et al*. 2013, Horsburgh *et al.* 2020), changes in ocean circulation (Collins *et al*. 2013, McCarthy *et al.* 2020) and potentially more frequent extreme weather events (see Woolf *et al.* 2020 for a UK specific discussion), and other effects including ocean acidification generated by enhanced atmospheric acid gas loading, deposition and exchange (see Bates *et al*. 2012). These effects, most recently summarised in the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report (IPCC 2013); Special Report: Global Warming of 1.5° (IPCC 2018) and the 6th Assessment Report Working Group I report (IPCC 2021), are the rationale on which global and national greenhouse gas reduction commitments are made.

The UK Climate Projections (UKCP) provides medium- to long-term projections (to 2100) for climate change specific to the UK. Projections for marine related impacts of climate change within the latest report, UKCP18, indicate future sea-level rise attributable to a low emission scenario in the ranges 0.29-0.70m in London and 0.08-0.90m in Edinburgh by the end of 2100, and for a high emission scenario in the ranges 0.53m-1.15m in London and 0.30m-0.9m in Edinburgh. The spatial variation in the rate of sea-level rise around the UK is related to different rates of land uplift, subsidence and oceanic processes resulting in greater projected sea-level rise in the south and less in the north. The Marine Climate Change Impacts Partnership (MCCIP) has close ties with UKCP, and these programmes help to provide climate change evidence and advice which may be used to inform policy and decision-makers. For example, a consideration of UK Climate Projections is recommended in the Marine Policy Statement (MPS) and also in terrestrial plans which may involve coastal elements (see the NPPF) and now also regional marine plans.

5.12.2.2 Energy and climate change policy context

The policy context relating to climate and climate change is summarised in Section 2 and discussed in greater detail in Appendix 1f and Appendix 2. The following provides an overview of the policy and legislation and its global context of relevance to the draft plan/programme considered in this SEA.

Human activities are estimated to have already led to approximately 1.09°C of global warming above pre-industrial levels, and the IPCC Special Report concluded that global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate (IPCC 2018). Given the potentially long residence time of CO_2 in the atmosphere, it is clear that current policy decisions with regards to climate change could have far reaching effects for the medium and long-term trajectory of changes. In 2006 the Stern Review concluded that the economic costs of not attempting to avoid the worst effects of climate change at the earliest opportunity would outweigh any subsequent cost of climate change mitigation (The Stern Review 2006). The recent HM Treasury review of the UK Government's Net Zero Policy (2021) upholds the economic conclusions of the Stern Review. In the absence of mitigation, impacts including sea-level rise, coastal flooding and coastal squeeze would occur at a faster rate than if efforts to reduce emissions were realised. Access to water, food and also the health effects of climate change will all have a socio-economic impact in the UK and elsewhere.

Reducing emissions of GHGs, and therefore the concentration of such gases in the atmosphere, is the principal means by which anthropogenic influences on the global climate system and related effects can be avoided. It is widely regarded that maintaining any rise below 2°C above pre-industrial will assist in avoiding the worst of these effects, and it is likely that if CO_2 concentrations of 450ppm or lower are achieved by 2100, that warming below this can be maintained (IPCC 2014). The Paris Agreement, an international legally binding treaty on climate change, was adopted in 2015 by 196 parties and provides a framework to strengthen the global response to the threat of climate change by (Article 2):

- Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change
- Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production

- Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development

Nationally determined contributions (NDCs) are the key mechanism through which the Paris Agreement commitments will be achieved. All Parties are required to submit successive and increasingly ambitious NDCs, in the form of targets or actions to reduce their emissions, on a 5 yearly basis. The initial NDCs were submitted in 2016 when Parties ratified the Paris Agreement with the start of the NDC cycle commencing in 2021 (delayed from 2020 as a result of the Covid pandemic). Ahead of the COP26 meeting in November 2021, Glasgow, the UNFCCC prepared a synthesis report on the latest NDCs under the Paris Agreement. The findings of the report concluded that, taking in account implementation of the latest NDCs, global greenhouse gas emissions would exceed levels required to limit global warming to both 1.5°C and to below 2°C scenarios. Thus either a significant increase in the level of ambition of NDCs between now and 2030, or a significant overachievement of the latest NDCs would be required to mitigate the worst impacts of global warming (UNFCCC 2021). COP26 marked the first ambition raising milestone of the Paris NDC cycle. An updated synthesis of 2030 NDCs and sectoral pledges following COP26 indicates that the measures would be expected to reduce warming to 2.4°C by the end of the century (CCC 2021b). However, policies are not yet in place to deliver on these targets, and based on current policies a temperature rise of around 2.7°C could be expected by the end of the century (CCC 2021b). In addition to the NDCs, which are legally binding short-term targets, Net Zero is being widely adopted as the standard long-term goal and in some cases has been set into national legislation. Estimates of the effect the Net Zero targets would have on global warming, in addition to the 2030 NDCs indicates that if these ambitions are delivered global warming could be limited to just below the 2°C scenario (CCC 2021b).

The UK *Climate Change Act 2008* provides the legal basis for the UK's approach to tackling and responding to climate change. At its inception, it set out a legally binding climate change mitigation target for the UK to reduce its greenhouse gas emissions by 80% by 2050 (excluding international shipping and aviation), compared to 1990 levels. The Act also established the Committee on Climate Change (CCC), an independent body to provide evidence-based advice to the UK Government and Parliament on setting mandatory five-yearly carbon budgets to meet the overall 2050 target. Under the Act the government has powers to introduce a domestic emissions trading scheme to support carbon management, and is required to publish regular risk reports and establish National Adaptation Programmes. The CCC provides an annual report to government on progress made in reducing greenhouse gas emissions and reviews the current climate change science, economic and policy evidence base for setting targets, and the pathways for meeting them. The UK met both its first and second carbon budgets and is currently on track to meet its third budget (2018-2022) (CCC 2020a). The fourth carbon budget (2023-2027) is consistent with the Balanced Net Zero Pathway, however, the fifth carbon budget (2028-2032) is not, and is also not consistent with the UK's NDC. The CCC (2020b) does not consider it necessary to amend the budget, but they indicate a budget of 1,585MtCO_2e would be needed (currently 1,725MtCO_2e), including international aviation and shipping.

Following publication of the IPCC Special Report on Global Warming on 1.5°C (2018), the CCC recommended a new UK climate change mitigation target for the UK to reach net-zero emissions of greenhouse gases by 2050 (compared to 1990 levels), and this was legislated for in July 2019. The CCC subsequently set its sixth carbon budget (running from 2033-2037) which will require a 78% reduction in emissions from 1990 to 2035 and sets the pathway for the UK to achieve net zero emissions (CCC 2020b). The government set the sixth carbon budget into UK law in April 2021.

In response to the CCC's Net Zero recommendations the UK Government published a Ten Point Plan for a Green Industrial Revolution, which sets out a framework for policy and investment in ten key areas to achieve: provision of clean energy across sectors; reduced energy demand through energy efficiency improvements in buildings and supporting low carbon travel such are walking, cycling and public transport; deployment of carbon removal technologies and nature based solutions such as tree planting; and development of cuttings edge technologies in support of Net Zero. Specific targets outlined in the Ten Point Plan of relevance to this OESEA include provision of 40 GW of offshore wind including 1GW of floating offshore wind by 2030; review of the offshore electricity transmission network, and establishing four industrial cluster and Carbon Capture, Usage and Storage (CCUS) sites capturing 10Mt of CO_2 per year (this target was subsequently revised by the UK Government Net Zero Strategy 2021 to 23-30 Mt of CO_2 per year – described below). The Ten Point Plan was supported by the UK Government Energy White Paper (HM Government 2020) which builds on the energy-related measures outlined in the Plan with a long-term strategic vision for the energy system underpinned by a series of actions and commitments. Ahead of the COP26 meeting in November 2021, the UK Government released its Net Zero Strategy: Build Back Greener in October 2021, which sets out a delivery pathway for Net Zero emissions showing indicative emissions reductions across sectors to meet the targets up to the UK's sixth carbon budget.

The deployment of renewable energy in the UK was initially (2002-2014) incentivised through the Renewables Obligation (see the *Renewables Obligation Order 2009*, as amended), where renewable electricity generators sold their Renewables Obligation Certificates (ROCs) to suppliers which guaranteed a premium above wholesale market prices. This was eventually closed to new renewable developments under the *Renewables Obligation Closure Order 2014* (as amended). The *Energy Act 2013* contains provisions for the UK Government's Electricity Market Reform (ERM) including the introduction of a new financial support mechanism for renewable energy developments under the "Contracts for Difference" (CfDs) scheme which replaced the ROCs. The CfDs incentivise renewable developments by guaranteeing developers a flat (indexed) rate for the electricity they produce over a 15 year period which protects them from volatile wholesale energy prices. The CfD also caps the cost of electricity to the consumer by requiring the operator to pay back any difference if the wholesale electricity prices exceed the CfD flat rate. To date three allocation rounds of CfD have been run between 2015 and 2019, with the fourth opened on 13^{th} December 2021. The UK Government and the offshore wind sector agreed the Offshore Wind Sector Deal in 2019 which set key commitments and actions from the UK Government to support offshore wind development, including the delivery of up to 30GW of energy from offshore wind by 2030. The subsequent UK Government Ten Point Plan, Energy White Paper and Net Zero Strategy commits to increase this target to 40GW.

Deployment of CCUS at a scale that will capture 20-30Mt of carbon dioxide a year by 2030 and produce 5GW of CCUS-enabled hydrogen is one of the critical greenhouse gas reduction mechanisms in the Government's Net Zero strategy. The Government have identified two Industrial Clusters in Phase 1 Track 1 for delivery by the mid-2020s, these are: HyNet which will produce low carbon hydrogen and capture carbon dioxide from industries across north west England and north Wales; and the East Coast Cluster which will capture carbon dioxide from industries across the Humber and Teesside to secure in offshore storage in the Southern North Sea (BEIS 2021b). A further reserve cluster, the Scottish Cluster based at the St Fergus gas terminal in NE Scotland, could be taken forward during Phase 1 (should the government discontinue engagement with a cluster in Track 1) or potentially as a Track 2 cluster. These projects will benefit from the £1 billion CCUS Infrastructure Fund through a variety of funding mechanisms including the Industrial Decarbonisation and Hydrogen Revenue Support (IDHRS) scheme, and the £240 million Net Zero Hydrogen Fund (supporting both CCS-enabled 'blue' and electrolytic 'green' hydrogen) to fast track their delivery. In August 2021, BEIS launched the CCUS Innovation 2.0 programme to fund CCUS projects in the mid- and late-stages of development to help accelerate the deployment of CCUS technology at scale by 2030.

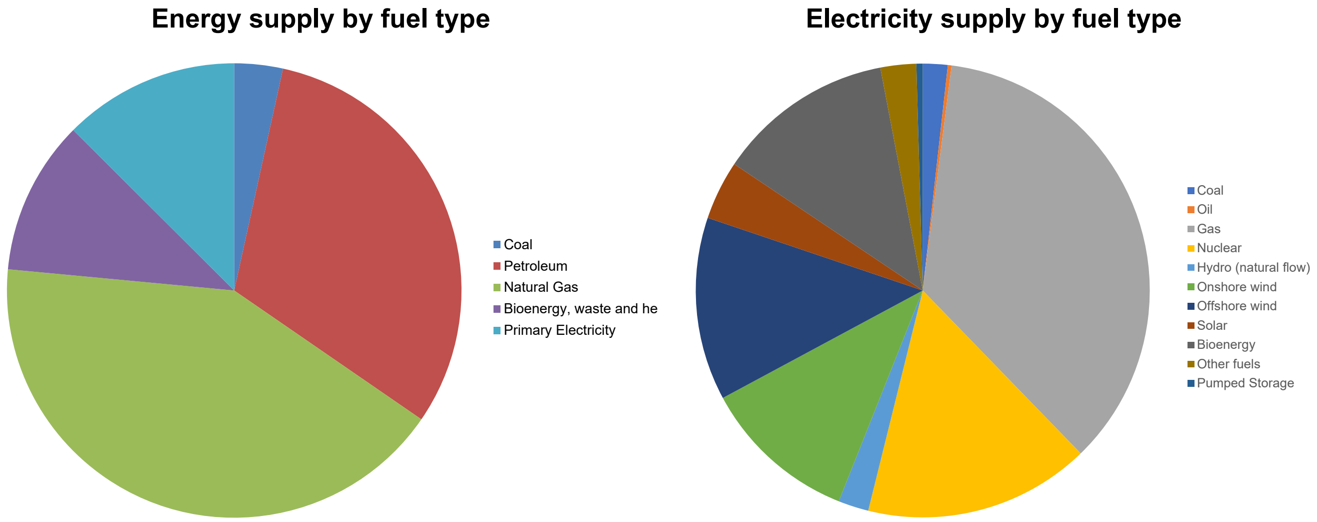
In addition to incentivising and investing in renewable and CCUS technologies, the Net Zero Strategy also aims to reduce energy demand and emissions sources. In support of Net Zero the OGA renewed its Strategy to incorporate a range of Net Zero obligations for the UK upstream oil and gas industry including reducing greenhouse gas emissions from sources such as flaring and venting, and power generation. Under the OGA Asset Stewardship Strategy a new Stewardship Expectation, SE11 Net Zero, was also introduced to clearly define the actions and behaviours required to manage both existing operations and new developments in line with the overarching Net Zero target. The OGA strengthened its position on flaring and venting in July 2021 to further assist the UK Government Net Zero strategy by requiring all new developments to be designed on the basis of zero routine flaring and venting, and for zero routine flaring and venting to apply to all assets by 2030, which is consistent with the World Bank's Zero Flaring by 2030 initiative.

Recognising the infrastructure and skills within the North Sea oil and gas industry and the future decline in demand, the UK Government agreed the North Sea Transition Deal with the industry in March 2021. The deal supports the industry's transition to clean energy by securing commitment from the oil and gas industry to reduce greenhouse gases arising from production activities by 60Mt by 2030 (equivalent to 50% on 2018 emissions), provides funding for offshore electrification, invests in technologies to deliver CCUS and hydrogen and aims to secure a future for the supply chain by requiring a 50% UK content across the lifecycle, energy transition and decommissioning activities.

5.12.2.3 Energy consumption, the energy mix, and the draft plan/programme

Primary energy in the UK is derived from a number of sources, but principally comes from hydrocarbons (gas and oil), bioenergy, solid fuels (e.g. coal), and electricity (a mix of hydrocarbon, solid fuel nuclear and renewable sources) – see Figure 5.68 for an overview of the proportions of these making up the present UK energy mix. Of primary relevance to this OESEA are oil and natural gas production, and electricity generation from renewable sources.

Figure 5.68: Energy mix displayed as supply by fuel type, 2020



Source: BEIS (2021c)

Energy consumption is partly a function of weather conditions, though when these are factored into the calculation of energy consumption the broad trend remains the same (Figure 5.69). Use of coal, coke and breeze to produce energy declined substantially through the 1980s and 1990s, being substituted with natural gas and primary electricity sources (see DECC 2015a). The increase in the total consumption figures through the 1980s and 1990s can be linked to the growing output of goods and services associated with economic growth, increasing travel, rising numbers of households and the gradual increase in population, with the more recent decline attributed to a reduced use of gas and petroleum, though economic recession is another relevant factor. Consumption in 2020 was significantly affected by the Covid-19 pandemic, with the transport sector accounting for the majority of the reduction due to the restrictions put in place in response to the pandemic (BEIS 2021c).

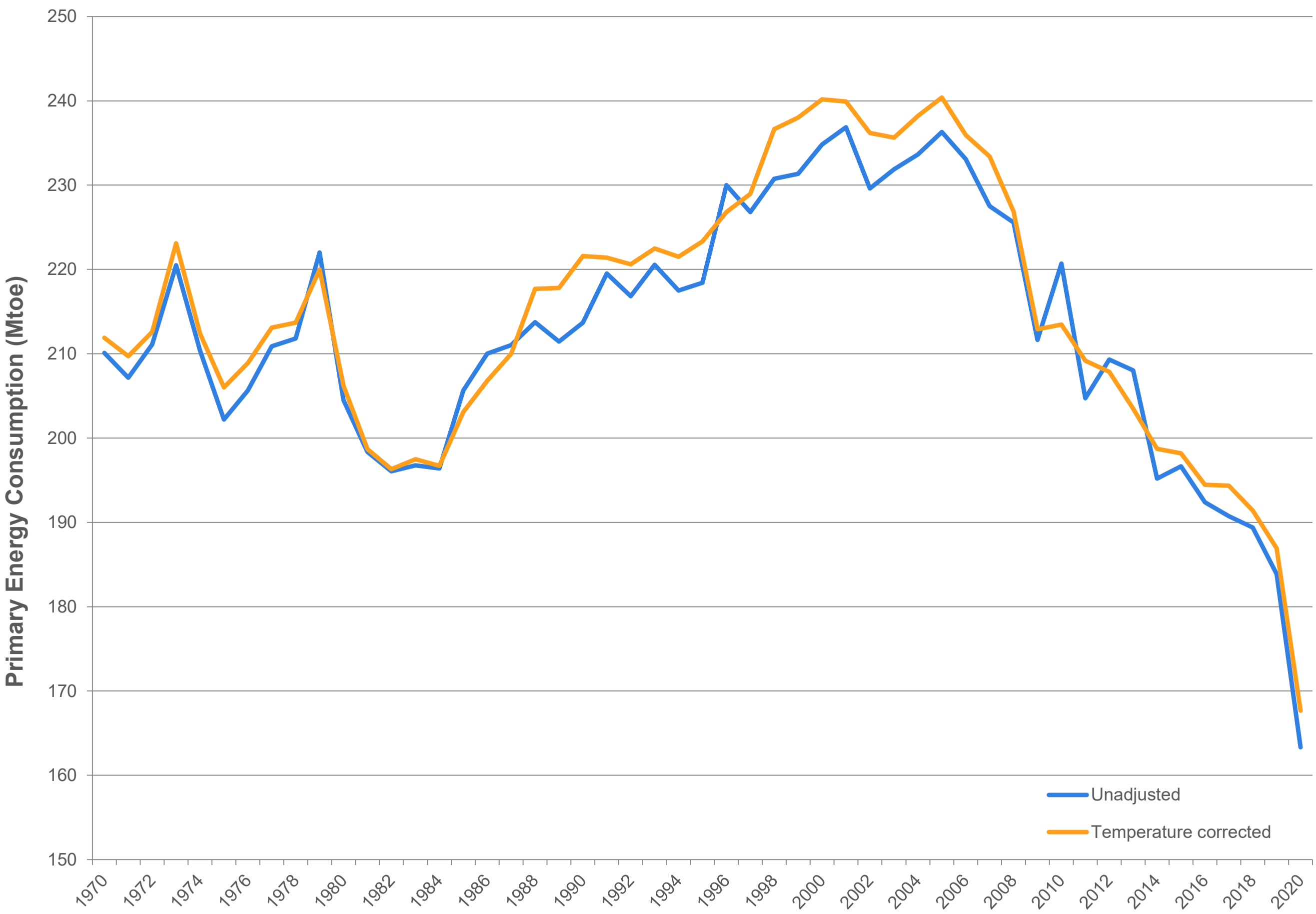
For context, annual primary energy consumption in the UK averaged about 197Mtoe (2010-2020), with the share of fossil fuel used in energy consumption standing at an average of ~72% over the same period (derived from data in BEIS 2021b). The final consumers of energy in the UK can be divided into four groups: industry, domestic sector, transport and services. Table 5.1 shows final energy consumption for the main sectors, and indicates a small decline in energy consumption in the industry sector over the last six years, while other sectors have remained relatively constant. Consumption within the transport sector was also relatively constant with the exception of during 2020 where there was a significant decline, attributed to the restrictions associated with Covid-19.

Table 5.33: Final energy consumption by sector (Mtoe)

	2015	2016	2017	2018	2019	2020
Industry[1]	24.3	22.5	22.8	23.1	22.4	21.0
Domestic sector	38.9	39.7	38.5	39.5	38.4	39.3
Transport	55.0	56.0	57.0	56.9	56.7	40.5
Other final users[2]	19.7	21.8	21.5	21.6	21.4	20.2
Total final energy consumption	137.9	140.0	139.8	141.1	138.9	121.0

Source: BEIS (2021d), Notes:[1] Includes the iron and steel industry, but excludes iron and steel use of fuels for transformation and energy industry own use purposes. [2] Mainly agriculture, public administration and commerce.

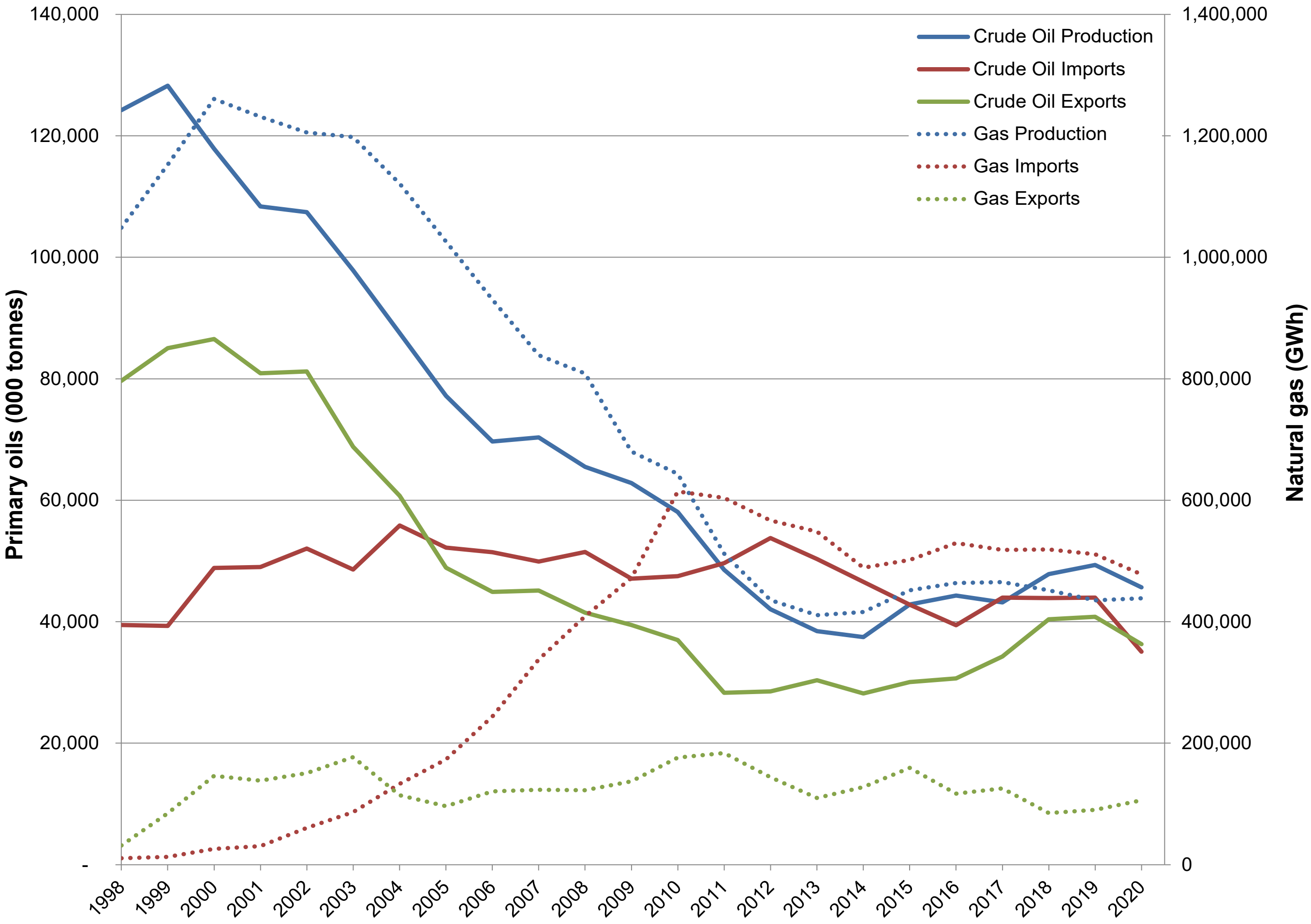
Figure 5.69: Total Primary Energy Consumption (Mtoe), 1970-2020



Source: BEIS (2021d)

In 2020 the UK was the fifth largest exporter of oil among OECD countries (BEIS 2021e). In the 1990s, the UK changed from an energy net importer to a net exporter, with government policy designed to maximise production from domestic reserves. To achieve this end, the licensing system was reformed with the introduction of two new licences: i) the 'promote' licence and ii) the 'frontier' licence. UK oil & gas production peaked in 1999 with an overall decline thereafter resulting in the UK becoming a net importer of gas in 2003 and of oil in 2004 (Figure 5.70). Reductions in production levels and exploration activities on the UKCS in the early 2000s led to the Wood Review in 2013 which set out a number of recommendations that were accepted by government, including maximising economic recovery, and the creation of the Oil & Gas Authority (OGA). Net imports of crude oil have generally declined since 2012, with the exception of 2017 which saw an increase. The UK became a net exporter of crude oil again in 2020, for the first time since 2014, following a sharp decline in demand and also in crude oil imports (Figure 5.70).

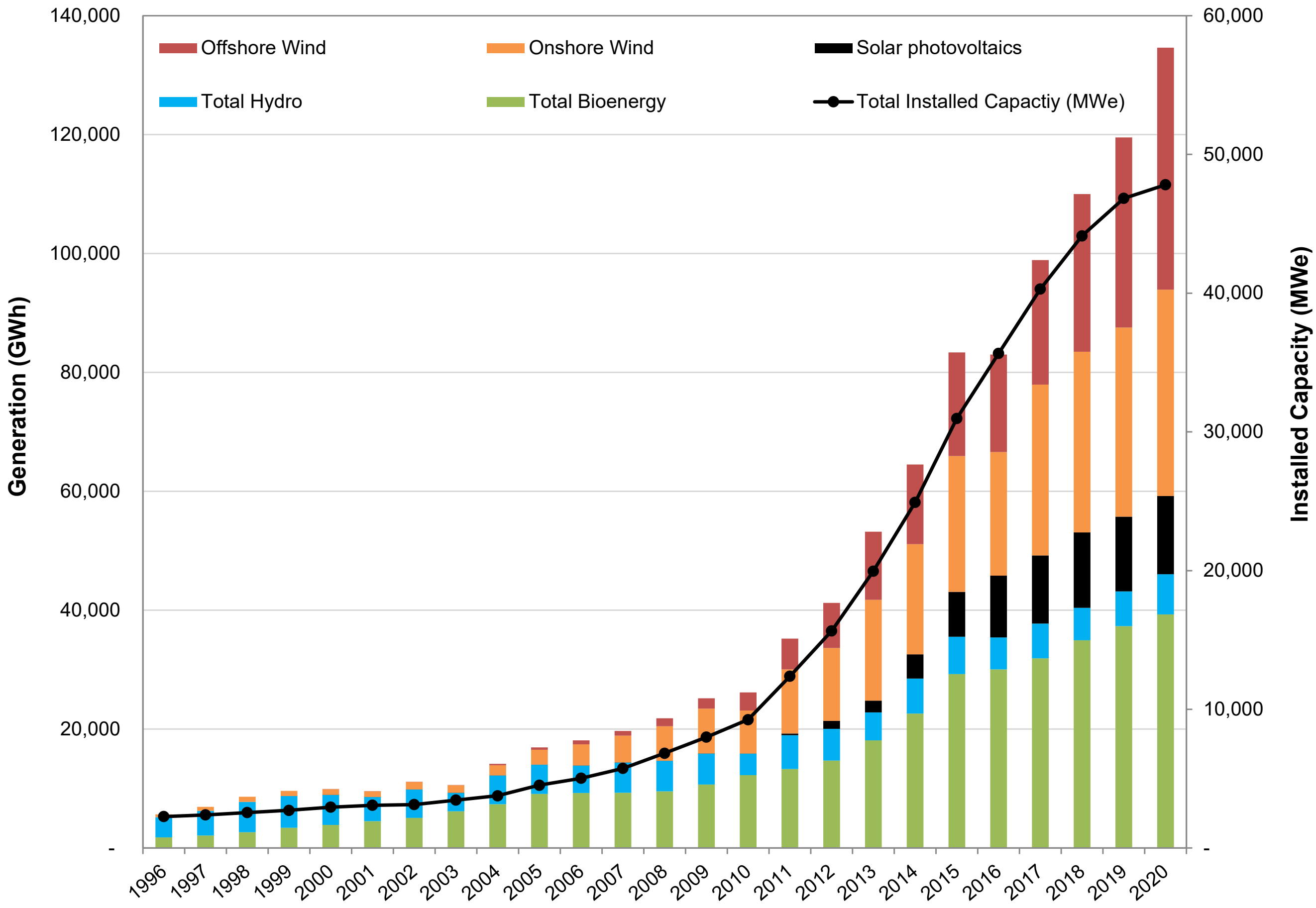
Figure 5.70: Commodity balance of crude oil and natural gas, 1998-2020



Source: BEIS (2020b)

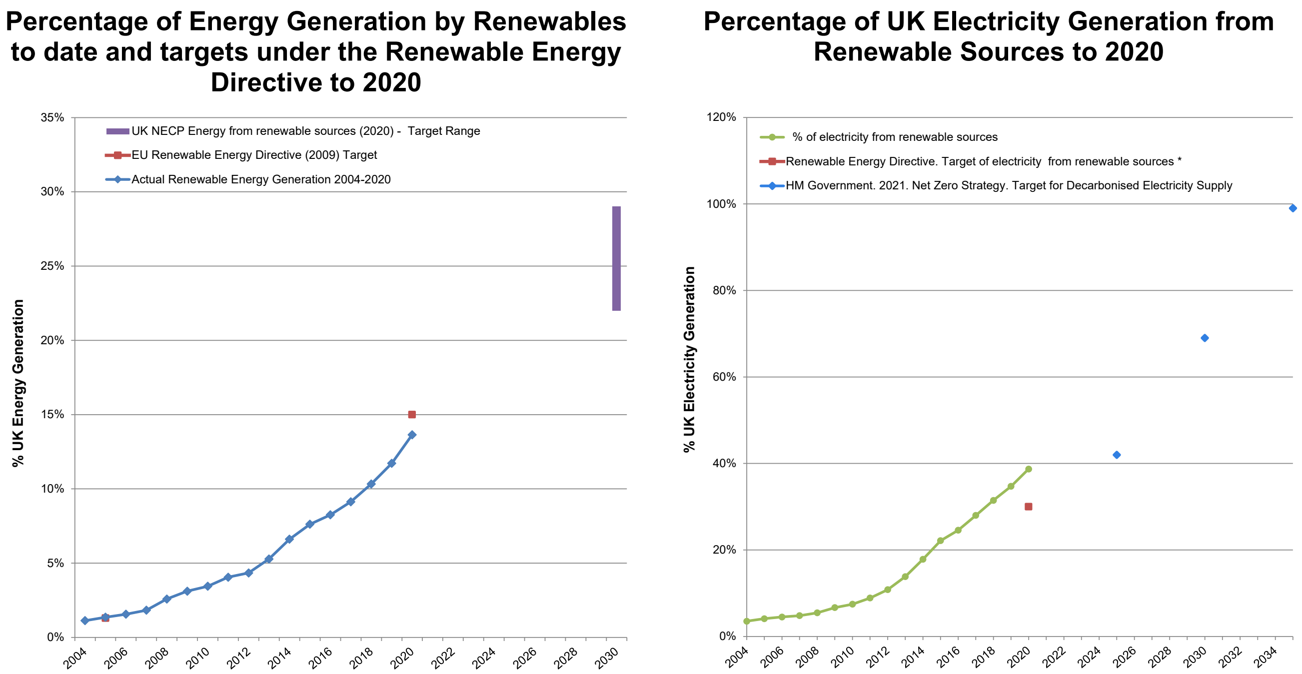
The supply of renewable energy has substantially increased in recent years from a total of 5,685GWh in 1996 to 134,603GWh in 2020, accounting for 38.7% of electricity generation from renewable sources in 2020 and 13.6% of total energy demand (energy demand also includes heating and transport as well as electricity). As a result, the UK successfully met and exceeded the Renewable Energy Directive target of 30% electricity generation from renewable sources by 2020 (see Figure 5.6). In addition, the proportion of renewable electricity produced exceeded that generated from fossil fuels for the first time in 2020 (BEIS 2021f). All renewable technologies, including bioenergy, saw an increase in generation shares in 2020, with the largest being a 3.7% increase in wind generation. Wind energy has increased substantially up to 2020, when it accounted for ~24% of energy generation from renewable sources. Figure 5.71 shows the change in energy generation from various renewable sources, and the total installed capacity for all renewable technologies up to 2020. The increased deployment of renewables is multifaceted, both aiding reductions in greenhouse gas emissions while contributing to domestic energy supplies and therefore energy security. The Government's Net Zero Strategy (2021) sets out a series of ambitious targets for increasing renewable electricity generation up to 99% by 2035 (see Figure 5.72).

Figure 5.71: Renewable energy generation (GWh) and installed capacity (MWe), 1996-2020



Source: BEIS (2021f) Digest of UK Energy Statistics (DUKES). Chapter 6: renewable sources of energy (6.4).

Figure 5.72: Renewable energy and electricity generation in relation to relevant targets



Source: BEIS (2021f) Digest of UK Energy Statistics (DUKES): Renewable Sources of Energy. Chapter 6. [Digest of UK Energy Statistics (DUKES): renewable sources of energy - GOV.UK (www.gov.uk)]

The elements of the UK Government's Net Zero plan of relevance to this OESEA primarily relate to renewable energy developments and emissions reductions, for example offshore wind, tidal energy, CCUS and electrification of the oil and gas industry, and will contribute to the overall decarbonisation of the power sector. In its Net Zero Strategy, the UK Government signalled its intent to fully decarbonise the power system by 2035, subject to security of supply. As all sectors work towards reducing and eliminating emissions of greenhouse gases the demand for clean electricity will increase, for example as zero emissions vehicles are phased in and electric heat pumps replace domestic heating systems. This could mean that electricity demand doubles by 2050 (from today's 345 TWh), and that electricity supply could provide more than half of the UK's overall energy demand by that date (HM Government 2020).

In preparing the UK's 6th Carbon Budget the CCC developed four exploratory economy-wide scenarios to achieve Net Zero by 2050, and to inform the development of a 'Balanced Pathway' that maintains a range of ways of reaching that target (CCC 2020c). The scenarios illustrate the range of ways to achieve Net Zero and explore how the pace of emissions reductions can vary between sectors. As a general principle, the pathways prioritise emissions reductions where known solutions exist and minimise the need for the use of greenhouse gas removals. The UK's ability to reach Net Zero will in part rely on the extent of societal / behavioural changes and progress in innovation, the success or depth of which are unknown. The four exploratory scenarios modelled by the CCC assume varying levels of success with regards to these changes, and can be summarised as follows (CCC 2020c; Figure 5.73):

- **Balanced Pathway** – the recommended scenario to meet Net Zero by 2050, by driving progress through the 2020's while creating options that seek to keep the other four exploratory scenarios open until 2035.

- **Headwinds** – policies bring forward societal and behavioural changes at the lesser extent of the scale, such that they do not significantly reduce the cost of green technologies ahead of the current projections. This limits the scope of electrification and consequently results in a lower electricity demand in 2050. This scenario relies on the lowest contribution of offshore wind to reach Net Zero and higher levels of solar, nuclear, gas and bioenergy with CCS.

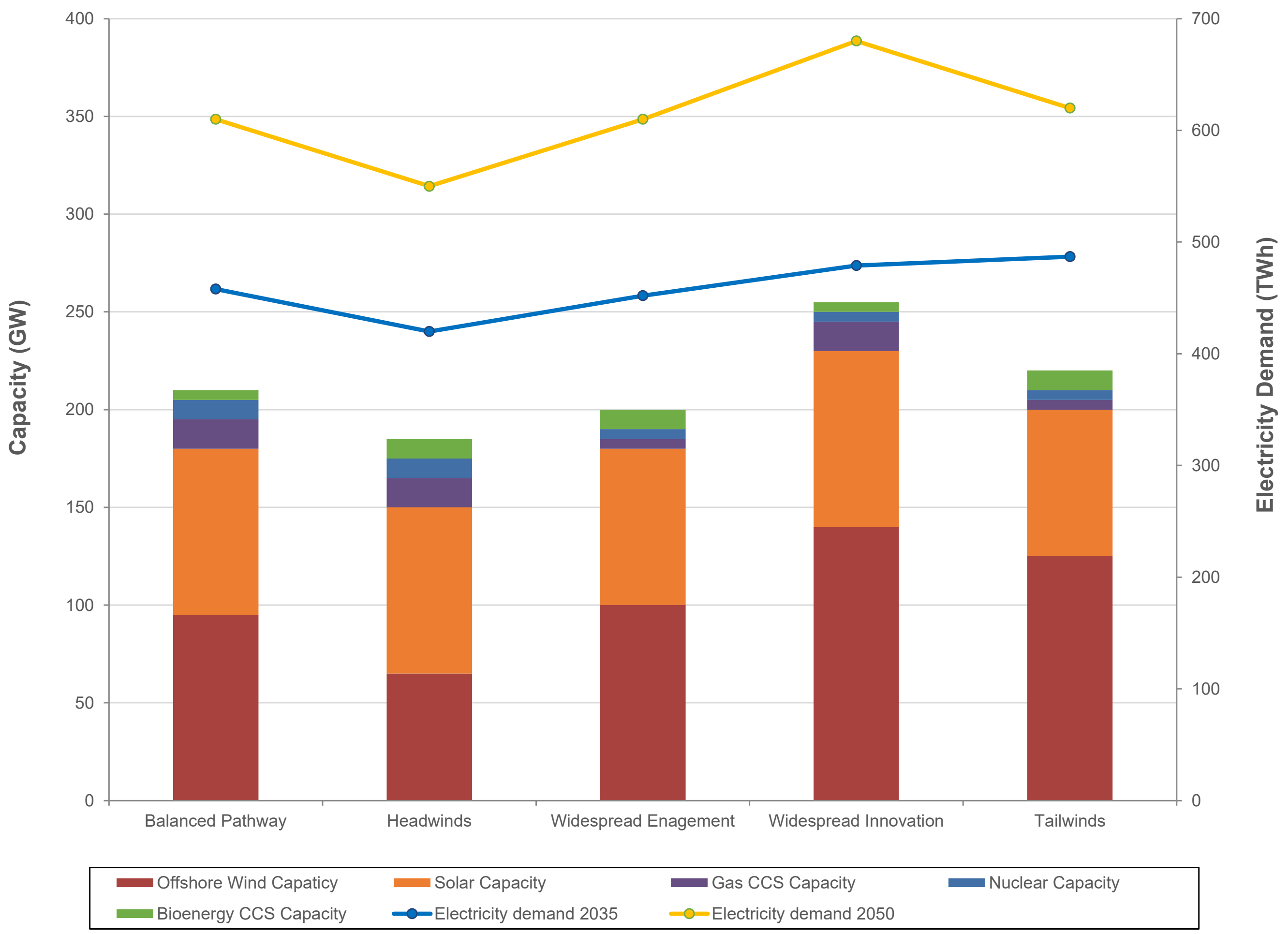
- **Widespread engagement** – assumes higher levels of societal and behavioural changes, which reduce the demand for high-carbon activities and increase the uptake of some climate mitigation measures. This scenario results in a moderate electricity demand when compared to other scenarios, with offshore wind then solar providing the majority of the capacity.

- **Widespread innovation** – assumes greater success in reducing the costs of low-carbon technologies utilising high levels of offshore wind, and enabling more widespread electrification. This scenario consequently results in the highest electricity demand in 2050.

- **Tailwinds** – assumes higher levels of success in both societal / behavioural changes and in innovation, such that this scenario out-performs the 'Balanced Net Zero Pathway' to achieve Net Zero before 2050. This scenario relies on the highest levels of offshore wind development and the lowest levels of nuclear and gas with CCS. Electricity demand is moderate compared to the other scenarios as it achieves widespread electrification whilst simultaneously reducing demand through behavioural changes.

All scenarios rely on almost doubling onshore wind capacity by 2050. Technologies such as tidal and wave that have not been commercialised at large scale could provide predictable power to a variable renewables-driven system, however, costs would need to decrease substantially to be competitive against other technologies (CCC 2020c). Pumped hydro could be further developed in the UK, which would be beneficial as a source of storage.

Figure 5.73: Role of Electricity Generation Technologies for the CCC's Sixth Carbon Budget Scenarios



Source: CCC (2020a)

The CCC's exploratory scenarios informed the development of the balanced pathway to achieve Net Zero in 2050. These scenarios build on the nearer-term target set out in the UK's 6th Carbon Budget for a reduction in greenhouse gas emissions of 78% by 2035 (CCC 2020b) and demonstrate a range of credible pathways for the UK to meet it longer-term goal.

The Ten Point Plan and Net Zero Strategy set a range of targets within the energy sector to enable the UK to meet the 6th Carbon Budget. An initial evaluation by the CCC (2021a) indicated that the commitments set out in the Net Zero Strategy match those of the 6th Carbon Budget's Balanced Pathway for the period 2025-2035. Policies to deliver on these commitments and targets are in part under development and their individual contribution to emissions reductions have not been quantified. Moreover, the commitments will need to move at pace to ensure sufficient progress is made.

5.12.3 Sources of potentially significant effect

5.12.3.1 Renewables

As indicated above, in the coming years offshore renewable energy generation will contribute to a reduction in the overall carbon intensity of UK energy supply, and sufficient capacity would appear to be in planning (see Section 2.6.1), or could possibly be deployed (see Section 5.15), to make a substantial contribution from this sector to the energy mix required to reduce energy supply carbon intensity as indicated above in the CCC scenarios.

Offshore renewable energy will not assist the decline of GHG emissions from the UK power sector in isolation (e.g. refer to the Net Zero Strategy). However, further renewables leasing will provide for reductions in emissions in combination with other energy sources including abated gas-fired power stations (via proving CCS at a commercial scale), those other energy supply sources with a lower carbon intensity such as new nuclear, and also energy efficiency measures. Despite the overall contribution of the renewables aspects of this plan to energy supply decarbonisation, there will be emissions associated with the manufacture and installation of projects. Life Cycle Assessment (LCA) is a methodology used to estimate the likely impact of a device or development from its manufacture, deployment, operation, maintenance and eventual decommissioning, and has been variously applied to developments to assess both their environmental and economic impact and feasibility. The Energy Balance or Energy Payback Time (EPT) refers to the time it takes for a generating station to recover the energy used in its manufacture and installation. The EPT for a number of types of marine renewable technologies considered in the draft plan/programme is typically in the range of 4-24 months. A recent assessment for the Norfolk Boreas offshore wind farm (Royal Haskoning 2020b) concluded that for an operational lifetime of 30 years, the carbon intensity of produced electricity would be 7.48-7.8kgCO_2/MWh, and that the EPT for the whole project including onshore and offshore works (compared to a UK grid average of 181kgCO_2/MWh in 2020), operations and maintenance, and decommissioning, would be 12-24 months, such that the project will effectively generate zero emissions from this period onwards.

It is acknowledged that there is the potential for carbon dioxide release from seabed disturbance primarily associated with the installation of offshore renewables infrastructure (see Appendix 1b). The potential for such effects on blue carbon stores and sequestration, and their scale, is discussed in Section 5.4. In addition to potential effects on blue carbon stores, the landfall of export cables from wind farms need to be considered in the context of coastal change, and how this could accelerate in the coming years in response to increased storminess and sea-level rise (see Appendix 1b, 1f and below). Planning policy (e.g. Section 5.5. of EN-1, currently subject to review; policy CC1 in the East Inshore and Offshore Marine Plans, CC-2 of the other English Marine Plans) already requires the consideration of the effects of climate change and development on coastal change, and that the latest sea-level rise projections and other climate change-related data in planning applications (in particular outputs from UKCP) and relevant Shoreline Management Plans, which, when combined with coastal monitoring and project engineering, ensure that any landfall does not exacerbate existing and anticipated levels of coastal change. In the future, an offshore coordinated grid (e.g. as being investigated by the OTNR and is not covered in the draft plan/programme subject to OESEA4) may reduce the number of landfalls from offshore renewables.

5.12.3.2 Oil and gas exploration and production

Carbon dioxide accounts for the greatest proportion of emissions to air from offshore oil and gas installations with around 13.7Mt emitted in the UKCS in 2019, and 30Mt in the wider OSPAR area (OSPAR 2021). Approximately 84% of OSPAR emissions of CO_2 associated with upstream oil and gas production are from the UK and Norway. Emissions of CO_2

equivalent emissions from all UK upstream oil and gas activities including exploration, production and transport of hydrocarbons were approximately 17.8Mt[259] in 2019 with wider energy supply emissions being 95.8Mt (Figure 5.74), and that of all UK GHG sources being 454.8Mt. While representing a relatively moderate to small proportion of total energy supply emissions (18.5%) and wider UK GHG emissions (3.8%), upstream oil and gas emissions need to be reduced significantly to be consistent with the Net Zero Strategy, and related initiatives such as the North Sea Transition Deal (NSTD). It is noted that in response to the Net Zero Strategy, the CCC (2021b) indicates that the NSTD target of a 50% reduction by 2030 lacks ambition and falls short of their recommendation of 68% in the 6th carbon budget. Further recommendations (CCC 2022) encourage that in developing tests as part of the climate compatibility checkpoint, an assessment of the sector's emissions should be based on a reduction of 68% rather than the 50% under the NSTD. Work by the OGA has demonstrated the potential for electrification and flaring abatement in meeting the targets of the NSTD (below), but the commercial viability of this reduction was not considered, without which it may be challenging to fully understand the likelihood of this or more stringent targets to be met.

In addition to the NSTD, a new climate compatibility checkpoint for future oil & gas licensing on the UK Continental Shelf may be introduced[260] and the sector will be regulated in a way that minimises greenhouse gases through the revised Oil and Gas Authority Strategy. The main sources of emissions from upstream oil and gas exploration and production are power generation, and flaring and venting. The former may be from diesel or gas-fired sources, or a combination of these. Emissions intensity of platform power generation varies, but may be ~460kgCO_2/MWh for open cycle gas powered generation, or 602kgCO_2/MWh for diesel generation (OGA 2021a), compared with a current average UK grid intensity of 181kgCO_2/MWh[261]. As noted above, the carbon intensity of large wind farms using current technologies for installation may be in the range of 7-8kgCO_2/MWh, and the UK Government has committed to decarbonise the power sector by 2035 which should reduce the emissions intensity of UK electricity to very low levels. Figure 5.74 indicates that flaring and venting presently accounts for just over half of upstream oil and gas emissions and contributes significantly to emissions intensity for some installations (Figure 5.76). Whilst this has declined from a peak in the mid-1990s, annual emissions from these sources have remained around 4MtCO_2 eq. per year over the last decade. Routine flaring and venting will be driven down, going beyond the World Bank's "Zero routine flaring by 2030" initiative (to which the UK is a signatory). New OGA guidance[262] sets an expectation that all facilities should have zero routine flaring and venting by 2030 or sooner (i.e. in advance of the World Bank target), with industry taking action through its Methane Action Plan. Flaring and venting will still occur as these are important safety critical systems for offshore installations, however, these will only be for process upsets, planned events and safety critical purposes.

The OGA (2020) identified a number of decarbonisation options[263] associated with the integration of energy systems which largely rely on the electrification of offshore installations, for example, from integration with offshore wind farms. The technical feasibility of supporting

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[259] Includes CO_2eq. emissions from upstream activities: fuel combustion associated with oil and gas production, flaring and venting, offshore well testing, and fugitive emissions from loading/unloading and process emissions. Data collated from the National Atmospheric Emissions Inventory (NAEI), December 2021: https://naei.beis.gov.uk/data/

[260] https://www.gov.uk/government/consultations/designing-a-climate-compatibility-checkpoint-for-future-oil-and-gas-licensing-in-the-uk-continental-shelf

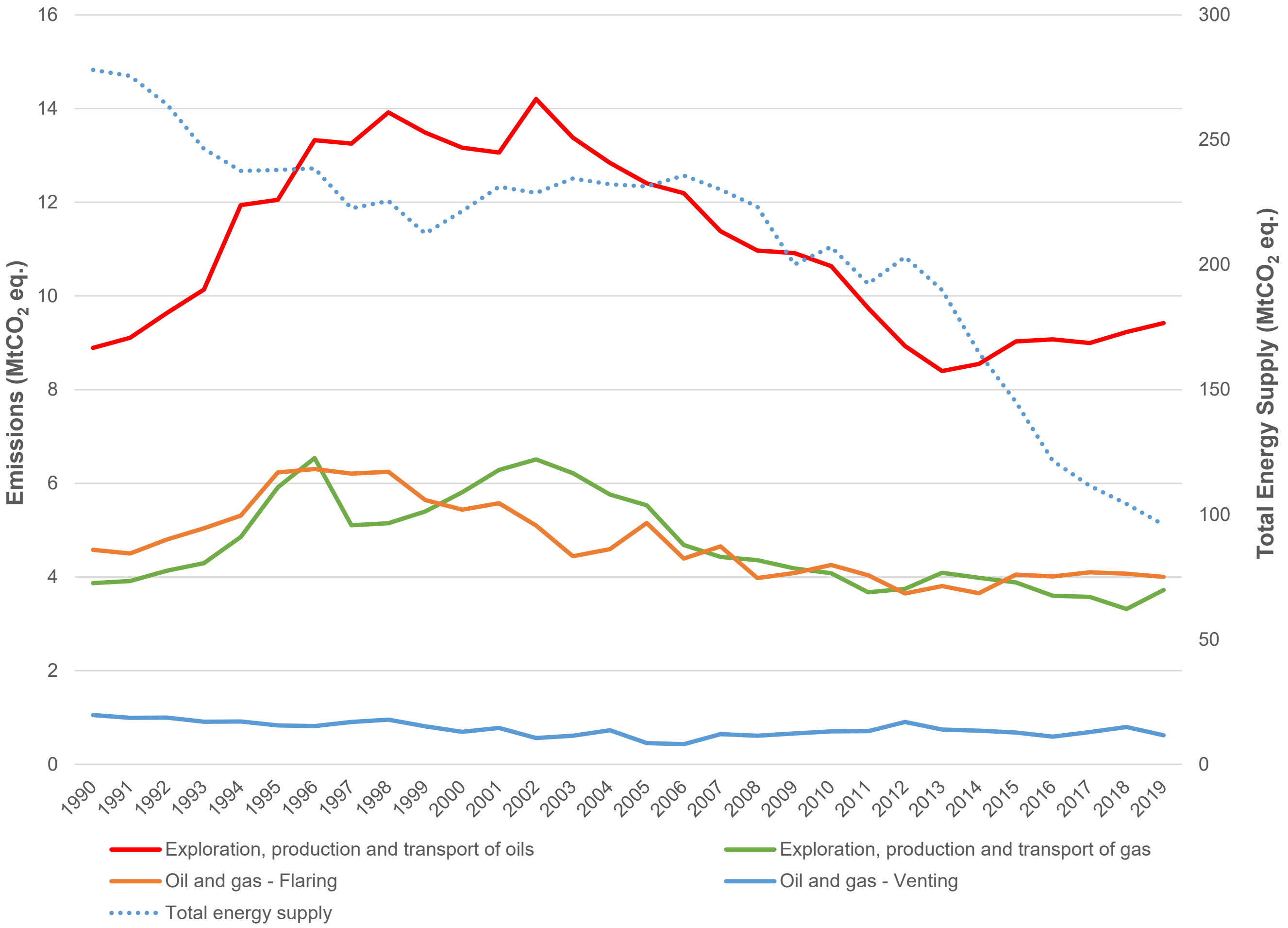
[261] See: https://www.nationalgrideso.com/news/introducing-our-carbon-intensity-app

[262] https://www.ogauthority.co.uk/news-publications/publications/2021/flaring-and-venting-guidance/

[263] https://www.ogauthority.co.uk/the-move-to-net-zero/energy-integration/

power generation on platforms using offshore wind has already been demonstrated (e.g. at Beatrice in the Moray Firth), and the cost reduction of offshore wind combined with developments in floating wind turbines may now make them more attractive for deeper-water locations[264]. The Scottish Government has announced an Innovation and Targeted Oil and Gas (INTOG) leasing round, whereby developers may apply for rights to build offshore wind farms to power oil and gas installations, within a number of areas identified by Marine Scotland as part of a sectoral plan[265]. The Scottish plan is subject to its own SEA, with renewables being a devolved matter, however, associated reductions in upstream emissions will assist in the achievement of the NSTD and the reduction in the carbon intensity of central and northern North Sea installations.

Figure 5.74: GHG emissions from exploration, production and transport in the context of total energy supply, 1990-2019



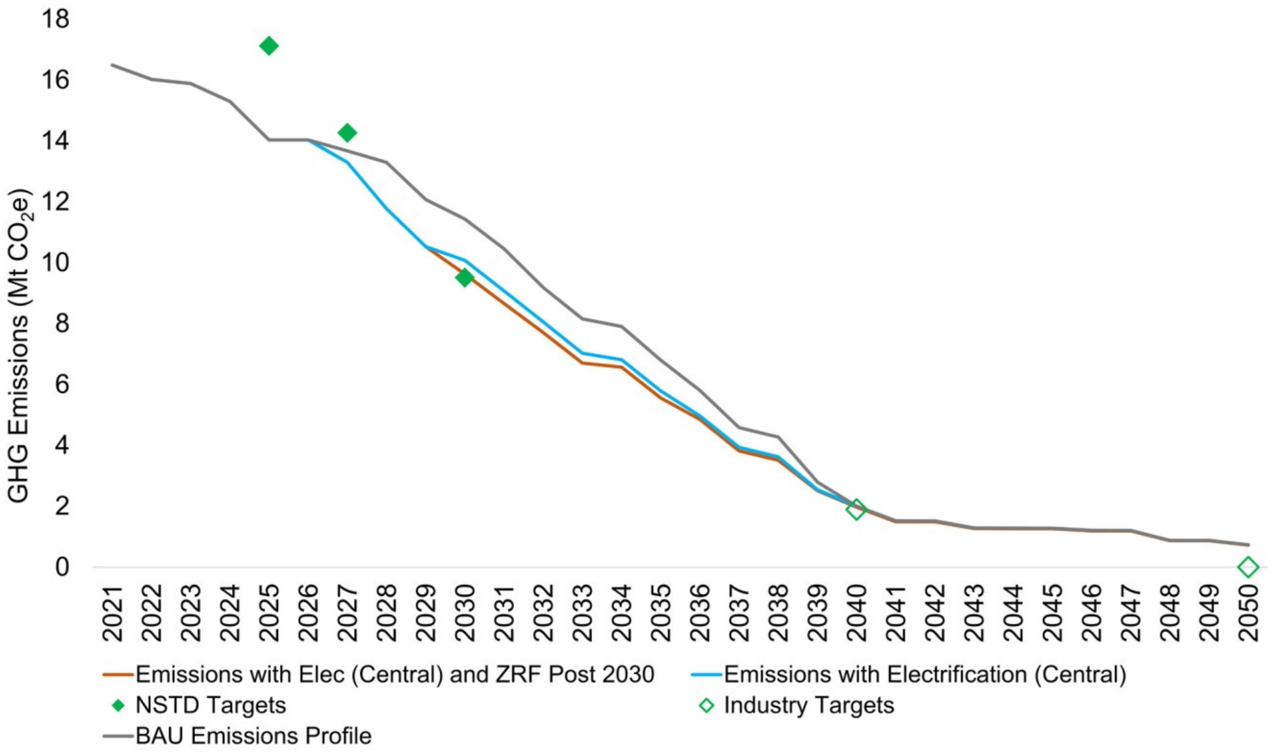
Source: NAEI, BEIS (2021g)

The OGA have projected GHG emissions from upstream oil and gas production based on recent industry emissions and expected field closures from the UKCS Stewardship survey[266]. Emissions associated with this "business as usual" (BAU) projection are estimated to fall by 2040 from current levels, by which time they will be ~1-2MtCO_2e/year, with current measures to reduce emissions projected to meet the NSTD targets for 2025 and 2027, but not 2030. The

[264] e.g. https://www.equinor.com/en/what-we-do/hywind-tampen.html
[265] https://marine.gov.scot/data/sectoral-marine-plan-offshore-wind-innovation-and-targeted-oil-and-gas-decarbonisation-intog
[266] https://www.ogauthority.co.uk/exploration-production/asset-stewardship/surveys/

potential for further abatement to meet the 2030 target could come from electrification and zero routine flaring and venting by 2030 (Figure 5.75). The emissions abatement potential from electrification and flaring shown in Figure 5.75 is based on installation data, knowledge of UKCS electrification projects and a range of other assumptions (e.g. recent emissions and flaring histories, abatement levels (e.g. full or partial), expected closure dates, emissions factors)[267], but the commercial viability of this abatement has not been considered (OGA 2021a).

Figure 5.75: UK upstream oil and gas emissions projections for the business as usual and abatement scenarios



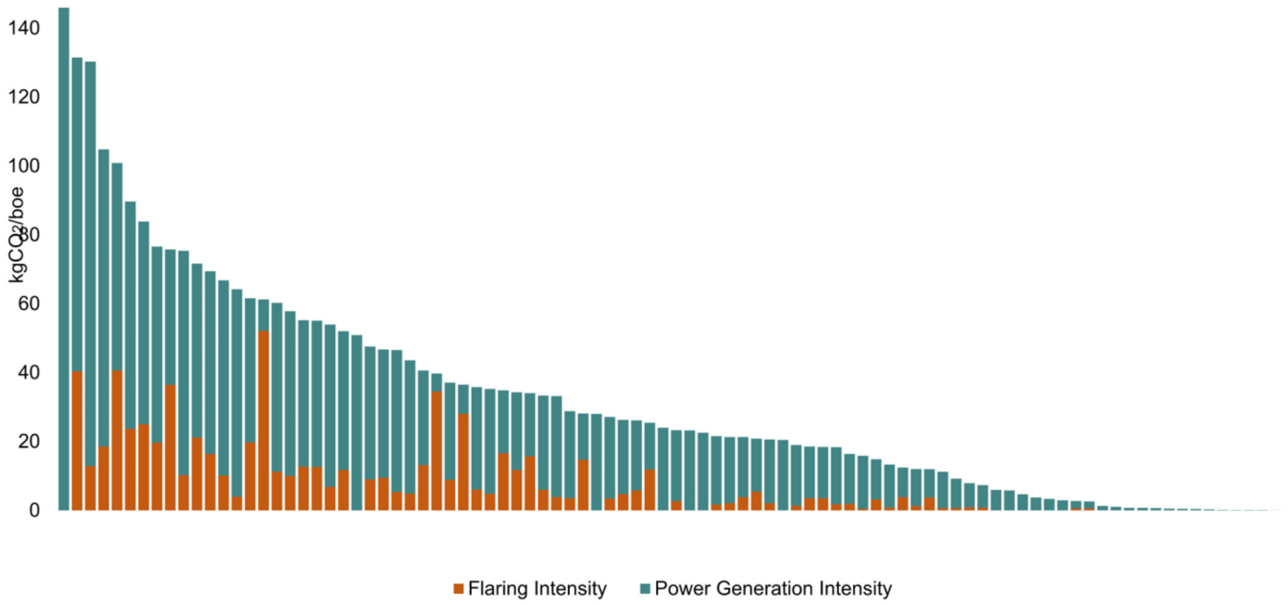
Source: OGA (2021a)

The carbon intensity of UK oil and gas production i.e. the volume of CO_2 emissions per unit of oil or gas produced, is a function of a number of factors including installation age, size, location, hydrocarbon type, availability of native gas for energy production, and the nature of the process required to produce a given field's hydrocarbons etc.; this was an average of 20kgCO_2/boe in 2020. This average ranges considerably, with some installations having an intensity in excess of 100kgCO_2/boe (Figure 5.76); those older and larger installations have a particularly high intensity, with small southern North Sea gas field NUIs producing a few hundred tonnes of CO_2 per year, with an intensity of <1kgCO_2/boe (OGA 2021b)[268]. Analysis by Rystad Energy (2018 figures) provides the carbon intensity of upstream oil and gas emissions for the top ten hydrocarbon producing countries[269]. The UK imports hydrocarbons from several of these countries which include Norway (7kgCO_2/boe), the United States

[267] https://www.ogauthority.co.uk/media/7813/annex.pdf
[268] Also see the OGA carbon intensity tracker: https://app.powerbi.com/view?r=eyJrIjoiZjdjYjA3NWQtNTU2OC00NDZiLTgwMTItNDVlODVlNzdkMTNmIiwidCI6ImU2ODFjNTlkLTg2OGUtNDg4Ny04MGZhLWNlMzZmMWYyMWIwZiJ9
[269] https://www.rystadenergy.com/newsevents/news/press-releases/us-tops-upstream-oilgas-co2-emitters-list-canada-has-highest-intensity-norway-lowest/

(12kgCO_2/boe), Russia (14kgCO_2/boe) and Canada (39kgCO_2/boe). However, these upstream emissions intensities do not account for transport and so are not directly comparable to UKCS production. For example in relation to the UK's gas supply, analysis by the OGA[270] indicates that LNG imports generally have twice the carbon intensity (average 55kgCO_2/boe) of that of UK domestic gas production (22kgCO_2/boe), with pipeline imports from Norway having a slightly lower intensity (19kgCO_2/boe). In 2020, the UK's LNG imports were primarily from Qatar (60-80kgCO_2/boe), the United States (140-160kgCO_2/boe), Russia, and Trinidad & Tobago (both ~40-50kgCO_2/boe), all of which are significantly greater than from domestic sources.

Figure 5.76: UK offshore installation carbon intensity, 2020

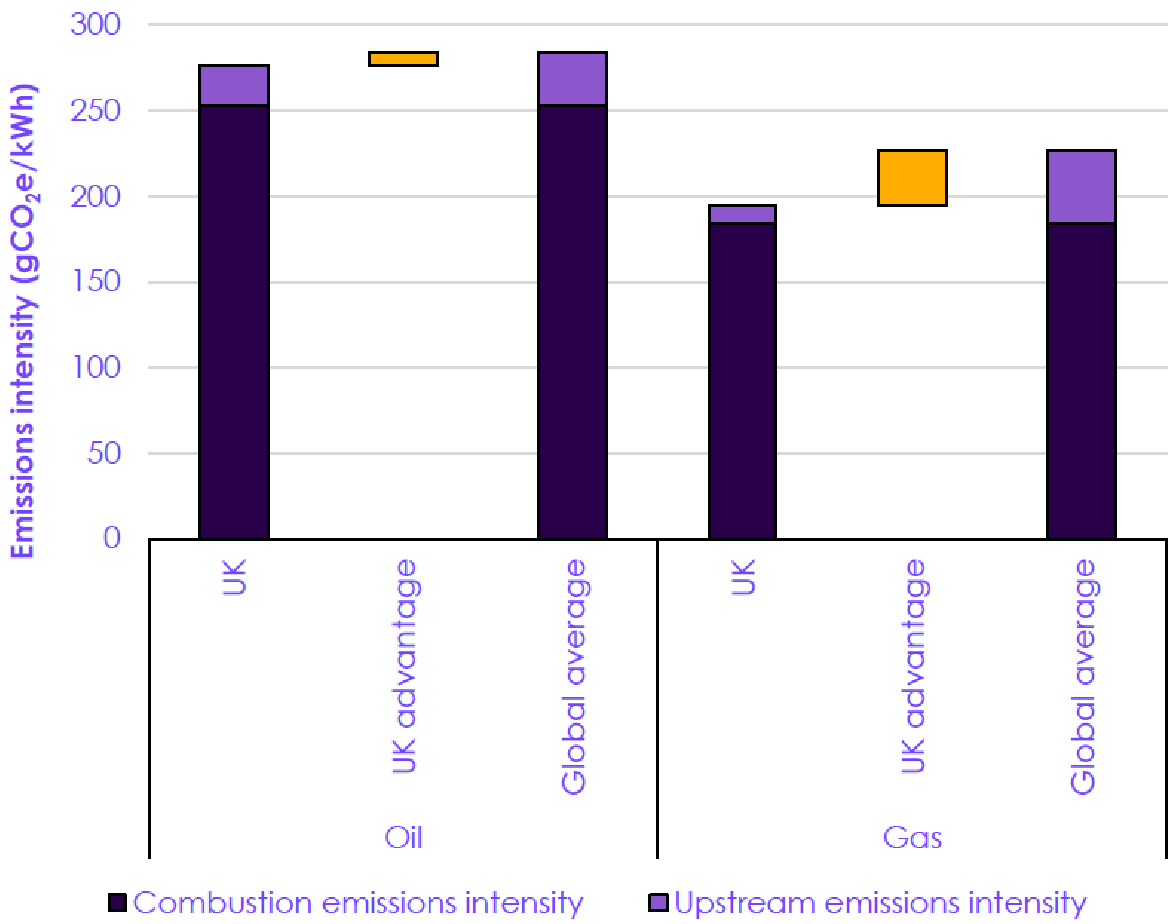


Source: OGA (2021b)

The CCC (2022) provides further analysis (Figure 5.77, note the different units to those elsewhere in this section), which demonstrates the current "advantage" in emissions intensity from UKCS production. Any consideration of this current advantage in future licensing round decisions should assess the potential for decarbonisation in the wider market as other countries seek to meet their NDCs and as part of other international initiatives, including, zero flaring by 2030 and the Global Methane Pledge. These other international initiatives may diminish the UK's advantage in the coming years, however, the timescales may not align with the UK's ambition, and a small advantage may remain, in part from transport related emissions.

[270] https://www.ogauthority.co.uk/the-move-to-net-zero/net-zero-benchmarking-and-analysis/natural-gas-carbon-footprint-analysis/

Figure 5.77: Comparison of oil and gas emissions intensity



Source: CCC (2022); CCC analysis; OGA 2021 Projections of oil and gas production and expenditure[271]; IEA (2018) World Energy Outlook. Notes: the values presented in this chart represent best estimates for 2018 emissions intensity based on publicly available data. They include upstream and combustion emissions and exclude downstream emissions (e.g. LNG or refining).

The projected supply of hydrocarbons (Figure 2.14) is consistent with a scenario in which the UK meets its net zero goal, largely achieved by a shift in the demand for hydrocarbons. The relationship is not clear, for example, a proportion of UKCS production, primarily oil, is not used domestically[272] but exported (Figure 5.70). Recent studies (SEI *et al.* 2021, Welsby *et al.* 2021, 2022) suggest that globally no new fields are needed to meet hydrocarbon demand or emission levels consistent with limiting global average temperature increases to 1.5°C, and that further fields, including in the UK, would only be consistent with this goal if the equivalent production was curtailed elsewhere. Welsby *et al.* (2022) note that for the UK to be aligned with a 50% chance of limiting warming to 1.5°C, oil and gas extraction would need to respectively decline at rates of 6% and 7% on average per year. Based on the projections of OGA (see Section 2.5.3), the daily oil and gross gas production rates from UK fields are

[271] https://www.ogauthority.co.uk/data-centre/data-downloads-and-publications/production-projections/

[272] Not all oil is traded equally, and some of the UK's import and export of oil involves exporting light crudes and importing heavier crudes to get the balance of hydrocarbons used by the UK. The nature of this trade, and the end use of these hydrocarbons is beyond the scope of this assessment.

assumed to decline by 6% and 9% per year respectively after 2026. These studies, and CCC (2022), do not account for the effects on security of supply should no further seaward licensing rounds take place[273]. The UK's projected production has been accounted for in its carbon budget, and the CCC's (2022) analysis notes that it cannot be concluded whether further UK seaward licensing would result in higher emissions, as it is not clear that this production would lead to more consumption, also noting the discussion above in relation to carbon intensity of domestic production. They do however suggest that there are risks to achieving the Paris Agreement Targets in the absence of a supply-side policy.

The climate compatibility checkpoint was proposed as a means to test whether further seaward licensing would be consistent with net zero. In view of the length of the licences issued (which may be up to nine years for the initial exploration term, see Section 2.4.3) and subsequent field development timelines, other tests towards the point of production must also be consistent with the net zero target. These could be delivered by the NSTD (noting above and elsewhere the recommendations of the CCC on the ambition of this), the OGA strategy and through EIA, however, strategic targets for the licensing round may also be required. While the NSTD will reduce emissions in the immediate term, the upstream emissions from licensing associated with this draft plan/programme (other than exploration) are likely to be made after 2030 beyond which explicit targets have not been set. For example, assuming a licensing round proceeded in 2023, projects may not have completed the initial term until 2032 at the latest, with development and operation potentially coming later. Ideally, further targets (aligned with or in addition to industry targets, see Figure 5.75) would be set soon for 2040 and 2050 to place further production from licensing rounds in the 2030s in the context of the scale of emissions abatement necessary to achieving net zero. Additionally, in view of the potential timescale from licence to production, it is recommended that there should be a presumption that all future developments arising from further licensing rounds must have their upstream emissions (power generation, flare and vent) fully abated.

In view of the above, any further consideration of licensing rounds in "frontier" areas should assess the need for licensing in underexplored areas if known reserves in more mature areas (particularly in relinquished areas of known proven reserves) are considered both sufficient to meet the supply consistent with the net zero target. Further developments in mature areas are also likely to use existing infrastructure that would in effect reduce the carbon footprint, either acting as host facilities or through complete re-use. Previous SEAs have recommended that blocks west of 14 degrees west should be withheld along with the deeper parts of the Southwest Approaches, beyond the shelf break, in waters >200m deep. This is in view of the paucity of information on many potentially vulnerable components of the marine environment, and other considerations. Once further information becomes available, the possible licensing in these areas can be revisited. The potential for collaborative investigations in the areas is recognised reflecting the cost and difficulty of studies in distant, deep waters. However, the potential for future licensing in these (and other) areas may be contingent on the outcome of periodic climate compatibility checkpoints.

Drilling rigs, support (e.g. supply vessels, construction vessels and tankers) for future oil and gas exploration, appraisal, production and operation, and decommissioning, is dependent upon shipping. Emissions associated with such vessels are a significant proportion of those associated with the offshore oil and gas sector.

[273] Oil and gas import dependency is due to increase from 48% in 2021 to 69% in 2050.

Shipping is presently the source of about 2.89% (~1,076Mt) of global carbon dioxide equivalent emissions (IMO 2020). Though these were excluded from reduction targets in the Kyoto Protocol, the IMO is progressing measures to reduce them, and the Initial IMO Strategy on reduction of GHG emissions from ships was adopted in April 2018. The strategy identifies that the energy efficiency of international shipping must decline by at least 40% by 2030, pursuing efforts towards 70% by 2050, relative to 2008, and that greenhouse gas emissions from international shipping peak and decline as soon as possible by at least 50% by 2050 en route to phasing them out completely, consistent with the Paris Agreement goals. To achieve the goals of the Initial IMO GHG Strategy the design of all new vessels must implement further phases of the energy efficiency design index (EEDI) to reduce carbon intensity during operation. Similarly, at the national level, international shipping (and aviation) emissions were not specified within the 2050 Climate Change Act target, but have since been included (along with international aviation) in the *Carbon Budget Order 2021*[274]. The CCC's advice to Government is that it should aim for net zero in the sector by 2050, which will likely require some form of greenhouse gas removal, amongst other means of reducing emissions such as alternative fuels. Following the publication of Maritime 2050 (2019), the Clean Maritime Plan sets out in more detail how the UK Government plans to transition the industry towards net zero by 2050. Individual operators typically contract all shipping-related activities associated with their operations, and it is anticipated that the fleets of vessels that will be used for future activity will reflect the transition towards low carbon shipping.

Improvements in efficiency and other measures have been taken by operators to reduce fugitive emissions (gas escapes, for example, from leaks or processes), and the use of vapour recovery systems at off-loading facilities to reduce emissions of methane and other volatile organic compounds (OSPAR 2010).

The scale of previous licensing rounds (19th to 32nd) is indicated in Figure 2.11. It is typical that each licence issued will have a commitment to drill a well and potentially to conduct other exploratory work (e.g. seismic survey) within a stipulated time period, after which the licence must be relinquished in whole or part (see Section 2.6 for an overview of licence types). Based on previous experience, typically less than half of exploration wells drilled reveal hydrocarbons, and of that half, less than half again will yield an amount significant enough to warrant development. Therefore, the number of projects resulting in the extraction of hydrocarbons from each round has typically been small. As noted in Section 2.6, the likely scale of future licensing will reflect the maturity of the UKCS and continued interest in exploration. Future licensing may be subject to periodic climate compatibility checkpoints, and individual projects would be subject to EIA, part of which will consider the contribution of each project to upstream emissions.

This SEA considers the implications further licensing and potential activities and developments on the UKCS. It is expected that emissions associated with existing mature fields may increase due to greater power demands e.g. for water injection, and the possible use of diesel generation for such activities where native fuel gas supply is in deficit, and alternatives such as electrification are not economically viable. The decommissioning of fields in the coming years may generate emissions of a scale similar to production installations, however, following these temporary activities, operational emissions would cease at these locations.

[274] See the explanatory memorandum to the 2021 Order: https://www.legislation.gov.uk/uksi/2021/750/memorandum/contents

It is acknowledged that there is the potential for carbon dioxide release from seabed disturbance primarily associated with the installation of oil and gas infrastructure (see Appendix 1b). The potential for such effects on blue carbon stores and sequestration, and their scale, is discussed in Section 5.4.

Gas storage

Greenhouse gas emissions associated with gas storage may emanate from the consumption of fuel gas and diesel, flaring and venting, fugitive and other emissions. As an example, CO_2 emissions from the Rough gas storage facility were 106,172 tonnes in 2002, declining to 17,783 tonnes in 2017 just prior to closure, reflecting the reduced volumes of gas being injected over time. Gas compression power requirement can be the major fuel gas user on a facility. From a representative in-house Operator study, assuming plant was online for 365 days per year for 4 years and 349 days per year for 3 years (to allow for planned maintenance) a 20MW compressor would produce 270 t/d of CO_2, and a 40MW compressor would generate 540 t/d CO_2 (Bacton Storage Company Ltd 2009). Analogous to the reduction in power generation emissions associated with upstream offshore oil and gas production and export, electrification has the potential to substantially reduce the emissions associated with gas storage.

The construction of facilities for the transport and injection of gas will also have associated emissions. For salt cavern construction, Gateway Gas Storage (2007) estimated that for their East Irish Sea facility, 763 tonnes of CO_2 would be released during the drilling of each well (over 15 days), with a total of 20 wells to be drilled. Additional emissions come from the commissioning of the salt caverns and annual maintenance which is estimated to be some 25,776 and 83 tonnes CO_2 respectively. The Deborah gas storage project (ENI Hewett Ltd 2010) in the southern North Sea proposed to use depleted gas reservoirs, and was estimated to have installation emissions (i.e. those associated with power generation for the drilling rig and support vessels) of 94,704 tonnes CO_2. If future offshore gas storage projects are proposed, the short-term emissions from vessels and drilling rigs would still take place (for well drilling and the installation infrastructure such as pipelines and platforms). However, the reduction in GHG emissions from vessels would be consistent with the decarbonisation initiatives at the international and national level, as outlined above for offshore oil and gas.

There are presently no offshore gas storage facilities operational in the UK, nor are there any active proposals for new sites. Gas demand will reduce as part of the transition away from fossil fuel use, but in the short to medium-term gas demand will remain and may be combined with CCS for power generation, or hydrogen production (blue hydrogen). Additional offshore storage capacity has the potential to come forward in the future to enhance the security of supply. Emissions associated with the installation and operation of these new facilities are likely to be small in a national context, and any future development would be expected to minimise related operational emissions consistent with the aim of achieving net zero by 2050.

It is acknowledged that there is the potential for carbon dioxide release from seabed disturbance primarily associated with the installation of gas storage infrastructure (see Appendix 1b). The potential for such effects on blue carbon stores and sequestration, and their scale, is discussed in Section 5.4.

5.12.3.3 Carbon dioxide transport and storage

Carbon dioxide capture and storage is a key component to reducing CO_2 emissions associated with the power sector and industries which are hard to decarbonise, such as steel production, as well as storing carbon from other potential sources such as direct air capture (DACCS).

While these technologies are yet to be deployed at a commercial scale in the UK, the majority of scenarios which achieve net zero emissions (CCC 2020b), or limit temperature rises to 1.5°C with and without overshoot (IPCC 2018, 2021) require CCS to do so. Global temperature is expected to remain approximately constant if GHG emissions were to cease such that reductions in mean surface temperature can only be achieved with net negative emissions. An overshoot would require Carbon Dioxide Removal (CDR) even under the very low emissions scenario (SSP1-1.9[275], see 5.12.3.4 below), which, amongst others, would include BECCS and DACCS. The UK Government has a target to store 20-30MtCO_2/year by 2030 (see above and Section 2.6.5 for more details), and it is likely that the majority, or all of this, will be stored in offshore geological formations. The CCC's (2021b) Balanced Pathway scenario published as part of the 6th Carbon Budget report includes a capacity of 22MtCO_2/year by 2030, with which Government targets are broadly consistent) increasing to 104MtCO_2/year by 2050. This storage comprises CO_2 emissions from electricity supply, manufacturing and greenhouse gas removals (e.g. BECCS and direct air capture).

The most prospective types of geological formation for storage are depleted or partially depleted oil and gas reservoirs or saline aquifers (see Appendix 1b for an overview). A theoretical P50[276] storage capacity of 78Gt has been estimated collectively for UKCS hydrocarbon fields and saline aquifers (Bentham *et al.* 2014). Based on the GHG emissions associated with energy supply in the UK (98Mt in 2019 and averaging 194Mt 2000-2019) and projected declines through carbon reduction measures (above, also see BEIS 2020a[277]), there is likely to be sufficient capacity available on the UKCS to support storage for UK emissions for some time but the extent and nature of storage options requires further appraisal. Offshore transport and storage of CO_2 would not in itself reduce UK emissions, but will facilitate the long-term storage of CO_2 in geological formations and therefore contribute to UK decarbonisation.

For effective transport and storage, CO_2 is captured as a gas and compressed or cooled for transport for subsequent injection into a storage reservoir, requiring power which will, unless also abated, have associated atmospheric emissions. The capture process can add significantly to the overall energy needs and the fuel used to generate electricity is termed the "energy penalty". The CCS cost reduction task force (2013) estimated energy penalties to be in the range 19-25% but with reductions expected as technology improvements are made. Budinis *et al.* (2018) summarised other estimates of the energy penalty, with ranges of 15-28% for pulverised coal, 15-16% for natural gas combined cycle plants, and 4.9-20% for integrated gasification combined cycle plants. Bulk transport is either by pipeline or tanker, with pipelines favoured for large and near shore installations and shipping for long distances and areas that cannot be accessed easily by pipeline, or are unlikely to be operational for long enough to justify infrastructure investment. For offshore sites, with distances greater than 1,000km ship transport may be economically viable (IPCC 2005), contingent on various factors controlling the technical and economic feasibility of pipelines compared to shipping, with installation and operational costs dominating these forms respectively (Weihs *et al.* 2014). The latest LNG ships have a capacity of 200,000m^3 and could potentially carry 230kt of liquid CO_2 with estimations of losses to the atmosphere from both boil-off (although technical options may be available to reduce this loss) and exhaust from the ships engines of 3-4% for 1,000km (IPCC 2005). Energy requirements for CO_2 injection sites is broadly analogous to that of natural gas storage. National Grid (2015) estimated operational emissions of ~9,000tCO_2e/year would be

[275] SSP1-1.9 assumes a rapid reduction in CO_2 emissions to net zero by 2050 followed by net negative emissions to 2100.
[276] that is, having a 50% certainty of being achieved
[277] https://www.gov.uk/government/collections/energy-and-emissions-projections

generated from an NUI injecting 2.68MtCO_2/year, resulting primarily from diesel power generation. Like further licensing for oil and gas exploration and production, and leasing/licensing for gas storage, such power may come from electrification in future proposals, but any diesel generation emissions would be small in the context of volumes of CO_2 stored.

Significant atmospheric emissions associated with carbon transport and storage could result from potential accidental releases from shipping, pipelines or the storage areas themselves. These are not likely. While limited to one site, monitoring evidence from the Sleipner project suggests that all the gas injected into the formation has remained *in situ*, spreading throughout the formation with no leakage to the surface. Requirements of the CCS Directive, as transposed into retained EU law, are such that extensive site characterisation and monitoring are required to ensure any storage structure is suitable, prior to injection (see Section 5.11 and 5.13). The most probable risk source is from abandoned wells, but likely rates of any such leaks are regarded to be low (Jewell & Senior 2012).

It is acknowledged that there is the potential for carbon dioxide release from seabed disturbance primarily associated with the installation of carbon dioxide storage infrastructure (see Appendix 1b). The potential for such effects on blue carbon stores and sequestration, and their scale, is discussed in Section 5.4.

5.12.3.4 Impacts of relevance to climate change

The IPCC 5th assessment report (AR5) has a number of principal findings which indicate that it is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century, through anthropogenic inputs of CO_2 and other greenhouse gases. A draft of the physical science basis for AR6 was published in 2021 (IPCC 2021) and it is anticipated that AR6 will be published in full in 2022. Some initial reference is made to this Working Group I report, but as it is draft the following also makes use of AR5 and the IPCC (2018) 1.5°C Special Report on the on the impacts of global warming of 1.5°C above pre-industrial levels. IPCC (2021) notes that the increase in GHGs are unequivocally linked to human activity, with atmospheric concentrations having reached 410ppm, 1,866ppb and 332ppb for CO_2, CH_4 and N_2O respectively in 2019, levels which have not been higher in at least the last 2 million years for CO_2, and 800,000 years for CH_4 and N_2O. The likely range of anthropogenic global surface temperature rise is 0.8-1.3°C (best estimate of 1.07°C) between the periods of 1850-1900 and 2010-2019, with temperature rise over land being greater than that over the ocean. Consequences of this temperature rise include changes in precipitation over land and patterns of near-surface ocean salinity, alterations to mid-latitude storm tracks, the retreat of glaciers and ice mass loss from the Greenland Ice Sheet and Antarctic Ice Sheet, global heating of the upper ocean with greater upper ocean stratification, ocean acidification, reduced oxygen levels, ocean circulation changes including a weakening of the Atlantic Meridional Overturning Circulation (AMOC) and more extreme and frequent El Niño and La Niña events (medium confidence) and, an increase in global mean sea level (mostly through thermal expansion, and loss of ice from glaciers and ice sheets), see IPCC (2019) and related chapters in Pörtner *et al.* (2019). These impacts are occurring at present, and there is high confidence that scale and intensity of changes, for example Greenland and Antarctic Ice Sheet mass losses and sea-level change, will increase in the near term (2031-2050) and will increase further from 2050 onwards unless there are significant reductions in GHG emissions.

The scale of the continued rise in global mean surface temperature through the rest of this century, and beyond, depends on how quickly the global economy can reduce its GHG emissions. AR6 uses five illustrative scenarios called Shared Socioeconomic Pathways

(SSP)[278] to understand potential temperature trajectories based on the radiative forcing (1.9-8.5Wm^{-2}) associated with a range of GHG emissions. In the near-term (2021-2040), 1.5°C is very likely to be met under the high emissions scenario (SPP5-8.5), likely to be met under the high and intermediate scenarios (SSP3-7, SPP2-4.5 and SPP1-2.6), and more likely than not under the very low emissions scenario (SSP1-1.9). IPCC (2018) notes that overshoot trajectories result in greater impacts and challenges compared to those with no overshoot, with the scale and duration of overshoot affecting the risks and impacts from climate change. Even under the very low emissions scenario (SSP1-1.9), there is likely to be some overshoot of 1.5°C, and only under this scenario would temperatures decline to below 1.5°C by the end of the century, consistent with the Paris Agreement. Under all other scenarios the best estimate for the long-term (2081-2100) ranges from 1.8-4.4°C (range 1.3-5.7°C). Specific to the UK, UKCP18 and subsequent updates indicate that under the high emissions scenario (equivalent to RCP8.5[279]), temperatures in the 10-90% range 0.9-5.4°C in summer and 0.7-4.2°C in winter are projected.

Physical environment (refer to Appendix 1b and 1d)

A secondary effect of climate change is the increase of coastal erosion and flooding from rises in sea-level, which may be exacerbated by storminess and wave height changes, though there is some uncertainty in projections of the North Atlantic storm track which UK climate model projects are sensitive to (Wong *et al.* 2014, Sayers *et al.* 2020, Masselink *et al.* 2020, Wolf *et al.* 2020). Modelling of future significant wave heights project a decrease in the North Atlantic, though mean annual maximum and extreme significant wave heights are both projected to increase, with sea ice retreat a causal factor (Wolf *et al.* 2020, Aarnes *et al.* 2017). There has been no recent significant observed change in storm surge frequency or magnitude (Horsburgh & Lowe 2013, Wong *et al.* 2014, also see Haigh *et al.* 2016). Though a high level of confidence in the recent MCCIP report card (Masselink *et al.* 2020) is attached to the current knowledge of coastal processes and erosion, a medium level of confidence is applied to what could happen, mainly due to uncertainties about the effect of climate change, rate of sea-level rise and changes in the wave climate, and their interactions with a complex coastal system. It can be expected that the pattern of UK coastal erosion which is linked to the variation in geological resistance and geomorphology (see Clayton & Shamoon 2008) will continue, with coasts on the east and south of the UK generally eroding more quickly than elsewhere. However, the rate of erosion is likely to increase with sea-level rise, with coastal management a key aspect in understanding the long-term response of coastlines to climate change (Masselink *et al.* 2020). Certain areas of low elevation or those geographically constrained by defence works (which includes numerous estuaries) and infrastructure will be unable to respond to sea-level rise in the longer term without intervention and adaptation and will therefore be subject to coastal squeeze (Masselink *et al.* 2020).

Ecosystems (refer to Appendix 1a and 1d)

Climate change can impact marine ecosystems through ocean warming, by increasing thermal stratification and reducing upwelling, sea level rise, through increases in wave height and frequency, loss of sea ice, increased risk of diseases in marine biota, and decreases in the pH

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[278] AR4 used Representative Concentration Pathways (RCPs). SSPs differ in that they include socioeconomic narratives that are considered to represent major socioeconomic, demographic, technological, lifestyle, policy, institutional and other trends (O'Neill *et al.* 2017, Riahi *et al.* 2017), matched with mitigation targets representing the radiative forcings (Wm^{-2}) in 2100.

[279] Representative Concentration Pathways (RCPs) represent a value of radiative forcing in Wm-2 at 2100 for a range of plausible future emissions scenarios. Like SSPs (above), these pathways are distinguished by the value of radiative forcing, which are RCP2.6, 4.5, 6.0 and 8.5. RCPs were used in AR5 and, in part, in UKCP18. See van Vuuren *et al.* (2011), Cubasch *et al*. (2013) and Appendix 1c in this report.

and carbonate ion concentration of the surface oceans (see MCCIP report card and Pörtner *et al.* (2019). The Working Group II Report (IPCC 2014) in contribution to the IPCC AR5 considers impacts, adaptation and vulnerability in relation to climate change. Chapters 5 and 6 (Wong *et al.* 2014, Pörtner *et al.* 2014, also see the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate; Pörtner *et al.* 2019) consider the impacts of climate change on coastal and ocean systems respectively, including on ecosystem properties, goods and services. Particularly relevant conclusions of Wong *et al.* (2014) and Pörtner *et al.* (2019) are provided below, including confidence in them:

- Ocean acidification has occurred through absorption of CO_2 and this will continue through the 21st century (virtually certain). Levels have declined in the range 0.017-0.027 pH units per decade since the 1980s (very likely) and is project to decrease by 0.3 pH units by 2081-2100 relative to 2006-2015 under RCP8.5 (high emissions scenario), with higher risks for aragonite shell forming species.
- The global ocean has warmed since 1970 and will continue to do so through the 21st century (virtually certain), with heat uptake more than doubling since 1993 (likely), with this uptake being attributed to anthropogenic forcing (very likely). Heat uptake is projected to increase for the upper 2,000m under RCP8.5 (5-7 times) and RCP2.6 (2-4 times) than that observed since 1970 (very likely). Marine heatwaves doubling in frequency since 1982 with 84-90% of heatwaves in the period 2006-2015 being attributable to anthropogenic ocean temperature increases (very likely), and these will continue to increase in frequency (very high confidence).
- Stratification has increased in the upper 200m of the ocean since 1970 and is expected to increase 12-30% under RCP8.5 and 1-9% under RCP2.6 for 2081-2100 relative to 1986-2005 (very likely).
- Oxygen in the upper ocean (1,000m) has reduced in the range 0.5-3.3% for data spanning 1970-2000 (very likely), with an expansion of hypoxic regions termed Oxygen Minimum Zones (OMZs) (likely). Oxygen loss is primarily related to increased stratification, changing ventilation and biogeochemistry (high confidence). Oxygen is projected to decrease between 100m and 600m depth over 59-80% of the ocean by 2031-2050 under RCP8.5 (very likely).
- The AMOC has weakened relative to 1850-1900 (medium confidence) but the scale of this change and its attribution to anthropogenic forcing cannot yet be supported by available data, but projections in model simulations show a weakening through the 21st century under all RCPs (very likely) but low confidence in the magnitude of change. There will not be an abrupt collapse in the AMOC before 2100 (medium confidence), but any such collapse would cause abrupt and widespread changes in regional weather patterns and the water cycle (very likely).
- There have been warming-induced shifts in the abundance, geographic distribution, migration patterns, and timing of seasonal activities of species in response to other effects of anthropogenic forcing noted above, including ocean warming and oxygen loss (high confidence).
- Ocean warming has resulted in a decrease in catch potential and species composition of catches (medium confidence). Suitable habitat/abundance has increased for some species due to changing ocean conditions (high confidence). The biomass of marine animals is projected to decrease by 15±5.9% (very likely range) and the catch potential of fisheries by 20.5-24.1% by 2100 relative to 1986-2005 under RCP8.5 (medium confidence); these changes are three to four times greater under RCP8.5 than RCP2.6 (very likely). Reduced organic carbon flux from the ocean surface to the deep, along with

ocean warming and acidification, as projected to harm cold water corals, with related effects on biodiversity (medium confidence).

- Coastal ecosystems are also affected by the above anthropogenically induced changes in ocean temperature, acidification and reduced oxygen, but are also subject to salinity intrusion and sea-level rise, compounding other terrestrial anthropogenic effects (high confidence), adversely affecting coastal communities (high confidence). Such risks are moderate to high under RCP2.6 and high to very high under RCP8.5 (medium confidence). Kelp forests, seagrass meadows and saltmarsh are all at risk from further warming, with 20-90% of coastal wetlands projected to be lost by 2100 (regionally variable), especially where subject to coastal squeeze and constrained by sediment supply (high confidence).

Activities covered by the draft plan/programme can directly and indirectly impact the physical environment, for example tidal range developments have the ability to both reduce flood risk in impounded areas and increase the risk elsewhere (e.g. during fluvial flood events in tide-lock conditions – see DECC 2010a). Conversely, the deployment of renewables in successive leasing rounds will contribute to the reduction in global concentrations of atmospheric GHGs.

Population and human health (Appendix 1g)

Climate change is already generating alterations which have the potential to threaten ecological and social systems, and human health. Sources of impact are wide and include changes in crop yields, it is very likely that the seasonal activity of pests and plant diseases have increased in northern Europe, as well as vector-borne diseases in ruminants. Similarly, crop damage, reduced soil fertility and degradation, ground and surface water contamination, increased risk of death, injuries and infections and general disruption to infrastructure and loss of property are all increasing as a result of climate change related effects. Ecological impacts from changes in species distributions and phenological mismatch will constrain ecosystem functions and related services (Kovats *et al.* 2014).

Global warming is increasing the frequency of extreme events contributing to heat related death and changes in infectious disease vectors (e.g. malaria carrying mosquitoes); the reduction in GHGs that would limit such extreme events have a number of benefits including connected issues relating to air quality. Any form of disruption in the food supply due to precipitation events or a change in the growing season is likely to be negative for both local and imported food stocks. Industries and settlements in coastal locations may be disrupted due to changes in sea-level and coastal erosion and therefore will be more prone to flooding. Increased storminess at sea may also negatively affect offshore operations, with shorter weather windows and increased ‘down time’.

5.12.3.5 Controls and mitigation

Several elements to the draft plan/programme will contribute to the decarbonisation of UK energy supply, and to meeting Government targets and commitments to achieve net zero by 2050. The policy context to legally binding targets and international agreements provided above frames the principal high level control on emissions from UK sources. Project level controls will be variously delivered through requirements such as the need to reduce upstream oil and gas emissions, inclusion in the UK ETS, and generally through initiatives seeking to decarbonise the shipping sector which is fundamental to the installation, operation and maintenance, and decommissioning of all activities associated with the draft plan. Further seaward oil and gas licensing rounds may be subject to periodic climate compatibility checkpoints. National and regional level policy also contains objectives or policy wording relevant to the emissions of greenhouse gases and adaptation (e.g. the Marine Policy Statement, National and Regional Marine Plans), and all developments must take account of relevant programmes of measures which in whole or part have relevance to the potential influence of climate change, particularly on coastal environments (for example Shoreline Management Plans, flood risk management plans).

5.12.3.6 Summary of findings and recommendations

A summary of the above considerations is given below:

- There is clear scientific consensus that anthropogenic emission of carbon dioxide and other GHGs are having a direct effect on global temperature and related effects on ecosystems, and that such warming is, and will, impact society. Anthropogenic emissions of GHGs have resulted in a warming of ~1.0°C to date, with warming increasing at a rate of ~0.2°C per decade as a result of emissions which have taken place and which are ongoing. This trajectory results in a likely warming of 1.5°C between 2030 and 2052; a continued rise to 2°C by 2100 would result in significantly higher climate-related risks for the environment and people (IPCC 2018). In response, a number of international and national agreements, UK legislation and policy aim to a transition away from high carbon economies. However, at an international level, and despite the aim of the Paris Agreement, commitments still fall short of achieving a global average increase of 1.5°C, the temperature beyond which effects will be significantly greater; based on current policies a temperature rise of around 2.7°C could be expected by the end of the century. As noted following COP26, improved proposals to reduce emissions through Parties' NDCs will be required if temperature rises are to be limited.
- The offshore wind part of the draft plan/programme would contribute to the deployment of additional capacity up to and beyond the 2030 target of 40GW of fixed and 1GW of floating offshore wind. The deployment of ~3GW/year is estimated to be necessary to maintain pace with the capacities needed as part of the mix of technologies required to meet the 6th carbon budget and towards net zero by 2050. Further offshore renewables leasing as part of the draft plan/programme being assessed (including wind, wave and tidal energies) has the potential to contribute to other aspects of the draft plan, including the production of hydrogen offshore (green hydrogen) and the electrification of oil and gas installations in those relevant waters for which renewables consenting is reserved.
- The transport and storage of carbon dioxide offshore is highly likely to be a critical component of delivering on the UK Government target to store 20-30MtCO_2/year by 2030 and to decarbonise parts of the energy supply sector and industry, directly and through hydrogen production (blue hydrogen). Further leasing and licensing of prospective areas for carbon dioxide storage will maintain the level of exploration, appraisal and development of such areas to deliver required storage capacity beyond 2030.
- Oil and gas production on the UKCS is in long term decline, as is exploration activity (see Section 2.6.3). The CCC (2020b) and OGA have projected the estimated continued demand for oil and gas for fossil fuel and non-fossil fuel use to 2050. These projections indicate that even when following the CCC's "balanced pathway" to net zero there is a gap between hydrocarbon production from the UKCS and UK demand (Section 2.6.3), which would need to be filled by imports. Available current data indicates that such imports have a greater carbon intensity than natively produced hydrocarbons, and when taken in the context of the NSTD, the revised OGA strategy, and the requirement by operators (e.g. through the EIA process) to demonstrate how they propose to make new development's upstream emissions (flare, vent, power generation) compatible with net zero, the gap between native and imported product carbon intensity has the potential to widen,

particularly as upstream energy CO_2 abatement is likely to come in the form electrification from low carbon sources. However, assuming international markets decarbonise at pace as part of the global effort under the Paris Agreement, this gap should be kept under review. Accurate figures on international carbon intensity of upstream production and transport would assist understanding of the potential for further UKCS production to contribute to reducing the emissions associated with oil and gas production.

- Despite the anticipated decline in UKCS carbon intensity, future seaward licensing rounds may be subject to periodic climate compatibility checkpoints. There is a need for any future licensing, and related projects, to be consistent with scenarios (including levels of production) which achieve net zero and at least the upstream emissions targets associated with the NSTD including the contribution of upstream emissions to the relevant carbon budget periods. It is recommended that, in keeping with the CCC (2021a, 2022) that further licensing decisions are considered against a target of 68% emissions reductions by 2030, and that in view of the potentially long time period between licence issue and production, that by that time, there should be a presumption that upstream emissions from new developments are fully abated.
- The need for future “frontier” rounds should be considered in the context of production consistent with net zero commitments.

5.13 Accidental events

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Accidental events – major oil or chemical spill	X							
Accidental events – major release of carbon dioxide			X					
Accidental events – major release of hydrogen								X
Accidental events – risk of sediment contamination from oil spills	X							
Accidental events – blow out impacts on seabed	X	X	X					
Accidental events - contamination of the water column by dissolved and dispersed materials from oil and chemical spills or gas releases	X	X	X					?
Accidental events – potential food chain or other effects of major oil or chemical spills or gas release	X	X	X					?
Accidental events – socio-economic consequences of oil or chemical spills and gas releases	X	X	X					?

5.13.1 Introduction

The accidental release of oil is an issue of environmental and public concern in relation to the offshore oil and gas industry, although the majority of large spills in the UK have resulted from shipping casualties; these are relatively infrequent, but more likely to occur in coastal waters where environmental and economic sensitivities are highest. The risks of large oil spills resulting from hydrocarbon exploration and production (E&P) are associated with major incidents on production platforms, export (pipeline and tanker loading sources), with the additional potential for loss of well control and subsequent oil blowout during drilling or well intervention activities. Previous SEAs have reviewed hydrocarbon spill scenarios and risks associated with exploration and production facilities. The Deepwater Horizon accident in the Gulf of Mexico in 2010 resulted in significant re-examination of operational practices, regulation and contingency planning for E&P.

5.13.2 Sources of potentially significant effect

5.13.2.1 Accidental events related to exploration and production

Oil spills on the UKCS have been subject to statutory reporting since 1974 under Petroleum Operations Notice (PON) 1 (formerly under CSON7); annual summaries of which were initially published in the "Brown Book" series, now superseded by on-line data available from the BEIS website[280]. Discharges, spills and emissions data from offshore installations are also reported

[280] https://www.gov.uk/guidance/oil-and-gas-environmental-alerts-and-incident-reporting#pon-1

by OSPAR (e.g. OSPAR 2020, 2021) and are included in the annual environmental report by Oil and Gas UK (now Offshore Energies UK) for the UK (e.g. OGUK 2021). BEIS data indicates that the most frequent types of spill from mobile drilling rigs have been of chemicals, with fewer numbers of oil spills, which mainly relate to hydraulic fluid and diesel. Topsides couplings, valves and tank overflows are the most frequent sources of spills from production operations, with most spills being <1 tonne.

Since the mid-1990s, the reported number of oil spills has fluctuated, and there is more rigorous reporting of very minor incidents (e.g. the smallest reported crude release in 2020 was 4.5×10^{-8} tonnes). Since 2018, the number of accidental releases of oil has declined and the number of releases in 2020 (145 releases, compared with 215 in 2019), was the lowest for the ten-year period 2011-2020 (BEIS PON1 data[281]). However, the underlying trend in oil spill quantity (excluding specifically-identified large spills) suggests a consistent annual average of 30 tonnes or less (2015-2020 PON1 data), with 9.3 tonnes accidentally released in 2020. In comparison, oil discharged with produced water from the UKCS in 2020 totalled 2,234 tonnes (OGUK 2021), this represents operational discharges from a number of widely distributed sources, at an average dispersed oil concentration of 17.8 mg/l (OGUK 2021). Some of the spill data for 2020 (PON1 database) remains under review and due to ongoing investigation or enforcement is not yet included in the public database. The OGUK (2021) report includes spills in 2020 not yet reflected in the PON1 database which includes a diesel spill of 238 tonnes.

Analysis of oil types showed that 47% of reported releases in 2020 were lubricant and hydraulic oils (4.4 tonnes), followed by fuel oils at 38% (3.5 tonnes) and crude oils at 3% (0.3 tonnes), with the remaining 11% of spills being releases of unknown, weathered, waste and other oils (1 tonne). The majority of spills were small, with 72% of releases being less than 10kg, and 38% less than 1kg (BEIS PON1 data).

Previously, an annual review of reported oil and chemical spills in the UKCS was made on behalf of the Maritime and Coastguard Agency (MCA) by the Advisory Committee on Protection of the Sea (e.g. ACOPS 2017[282]). This included all spills reported by POLREP reports[283] by the MCA and PON1 reports to BEIS. The latest ACOPS report covered 2016 and it is unclear whether production of these reports has now ceased.

Well control incidents (i.e. "blowouts" involving uncontrolled flow of fluids from a wellbore or wellhead) have been too infrequent on the UKCS for a meaningful analysis of frequency based on UK data. A review of blowout frequencies cited in UKCS Environmental Statements as part of the OESEA2 gave occurrence values in the range 1/1,000-10,000 well-years. Analysis of the SINTEF Offshore Blowout Database which is based on blowout data from the US Gulf of Mexico, UKCS and Norwegian waters for period 1980 to 2014, provided blowout frequencies (per drilled well) for exploration drilling for North Sea standard operations, for exploration of normal oil (1.3×10^{-4}) and gas wells (1.6×10^{-4}), as well as deep high pressure high temperature oil (8.0×10^{-4}) and gas (9.8×10^{-4}) wells (IOGP 2019). Accident statistics for offshore units on the UKCS estimated an annual average frequency of blowouts[284] for mobile drilling units of 6.6×10^{-3} per unit year for the period between 2000 and 2007 (based on analysis of a total of 455 unit years, OGUK 2009).

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281 https://itportal.beis.gov.uk/eng/fox
282 https://www.acops.org.uk/wp-content/uploads/2020/08/ACOPS_Ann-Rep-2017-final.pdf
283 POLREP (pollution reports) relate to those issued in accordance with the Bonn Agreement, to alert Contracting Parties to relevant pollution events.
284 An uncontrolled flow of gas, oil or other fluids from the reservoir, i.e. loss of 1.barrier (i.e. hydrostatic head) or leak and loss of 2. barrier, i.e. BOP/ Down Hole Safety Valve (DHSV).

5.13.2.2 Accidental events related to gas storage including hydrogen

The main accidental risk associated with gas storage developments offshore is considered to be accidental hydrocarbon releases, mainly from spills of fuel oils from fixed installations and support vessels. Gas storage in depleted hydrocarbon reservoirs has an associated risk of reservoir fluid release during drilling operations (qualitatively similar to risk associated with E&P), and a theoretical risk of loss of containment through previously abandoned wells which may have penetrated the reservoir. The environmental risk is considered to be low given the geological and engineering understanding of the developments, and the (depleted gas) reservoirs likely to be developed for storage. Gas storage in salt caverns has a negligible risk of liquid hydrocarbon release from well operations. With respect to failure rates associated with underground gas storage (based primarily on onshore data), the HSE (Keeley 2008) indicated that the risk is dominated by a release from the well connecting the storage cavity to the surface, which had an estimated failure rate of the order of 10^{-5} per well year.

With respect to hydrogen storage, concerns exist over hydrogen-induced embrittlement of steel and other potential reactions that could degrade the production and transport system. The major hazard related to leakage of hydrogen relates to the possibility of explosive conditions (Hassanpouryouzband *et al*. 2021). Given the relative infancy of hydrogen storage in offshore depleted hydrocarbon reservoirs or salt caverns there is very little specific information available on the potential for accidental events. However, the potential sources of accidents are likely to be similar to gas and carbon dioxide (CO_2) storage. Similar to carbon dioxide storage below, the engineering of transportation systems and injection facilities for hydrogen will need to take due account of the physical properties of hydrogen gas and consenting of storage projects will require predictive assessment of the safety and environmental risks of a large-scale release.

5.13.2.3 Accidental events related to carbon dioxide storage

The principal sources of CO_2 leaks from carbon capture, usage and storage (CCUS) projects are either mechanical (e.g. from a pipeline rupture or loss of containment in injection or abandoned wells) or geological (e.g. through fractures and faults or cap rock seal failure (including through educed seismicity), seepage through porous structures) (Czernichowski-Lauriol *et al.* 2006, Blackford *et al*. 2008, Santra & Sweatman 2011, Dewar *et al.* 2013, Caramanna *et al.* 2014, Phelps *et al.* 2015, Williams *et al.* 2014, Verdon 2014).

The probability and consequence of a major accidental release of CO_2 from the transportation and offshore storage of CO_2 is difficult to assess, although the technology and risk sources (e.g. mechanical damage to a pipeline through impact or collision) are similar to those for gas production and transportation (but without the potential consequences of ignition of a gas release). To date, accidents associated with development of the UK's offshore gas reserves have been few and of limited environmental effect. Clearly, however, the engineering of transportation systems and injection facilities for carbon dioxide will need to take due account of the physical properties of CO_2 in various phases and consenting of CCS will require predictive assessment of the safety and environmental risks of a large-scale release.

Twenty years of monitoring of CO_2 storage in a subsea geological formation at the Sleipner platform in the Norwegian sector of the North Sea have shown the continued containment of the CO_2 and has gone towards improved reservoir understanding and optimisation of monitoring programmes (Furre *et al*. 2017). Generally, multiple natural barriers, including at least one non-permeable caprock layer and natural sealing processes, are expected to ensure that injected CO_2 stays in place (Blomberg *et al.* 2021). However, monitoring is required to verify long-term storage, and to detect and quantify leakage if it should occur (IPCC 2005). Techniques in monitoring the fate of injected carbon dioxide have developed over time; 4-D (repeated 3-D) seismic survey of the formation, vertical seismic profiling, multibeam echosounding, bubble stream detection, seawater geochemistry and various downhole measurements are some of a suite of techniques which may be applied to monitor CO_2 migration and anticipate and detect leakage. Evaluations of specific monitoring design details (e.g. selection of monitoring technology, timing and extent of monitoring surveys) should also be case/site specific and risk based (Furre *et al.* 2017, and reviewed in Blomberg *et al.* 2021). Time-lapsed seismic data from Sleipner has shown that the upper CO_2 layers tend to follow topographic highs, and, after accumulation underneath the topographic highs above the injection point, the CO_2 has spread in a relatively narrow corridor and started accumulating below a structural high approximately 3km north/north east of the injection point. Geological assumptions such as the number of feeder channels, permeability, topography and temperature distribution will all have a strong effect on final flow pattern; data from the Sleipner project provides ongoing insights, valuable for future CO_2 injection projects (Furre *et al*. 2017).

Alcalde *et al.* (2018) developed a model (the Storage Security Calculator, SSC) to address the knowledge gap that, as yet, no comprehensive case studies have been published that facilitate an industry-wide assessment of CO_2 storage security. A number of scenarios were used to investigate the injection and storage of a large cumulative tonnage of CO_2 (12 Gt), comparable to the 2050 storage target of the European Union. Injection was modelled between 2020 and 2050, and the SSC was run for 10,000 years into the future. Of the scenarios developed, the Offshore Scenario used the North Sea as an exemplar of a CO_2 storage environment. The assigned abandoned well density (0.44 wells km^{-2}) was based on well densities of the North Sea (4,400 wells per 10,000 km^2) (IPCC 2005). Abandoned well integrity and frequency of leaking wells were based on data from offshore hydrocarbon fields.

Even when applying conservative input parameters, results from the SSC model illustrated that CO_2 storage in regions with moderate abandoned well densities and, that are regulated using current best practice, will retain 98% of the injected CO_2 over 10,000 years in more than half of cases, and result in maximum leakage of 6.3% of the injected CO_2 in fewer than 5% of cases. The authors indicate that abandoned wells posed a significant leakage risk to the offshore scenario, if the wells leak even a small amount due to cement corrosion over hundreds to thousands of years. In addition, while corrosion is considered to be a significant long-term risk to well integrity in CO_2-rich reservoirs, other processes acting on the well may decrease permeability. Corrosion may be associated with carbonation and precipitation of minerals, effectively plugging defects. Furthermore, stress regimes in many sedimentary basins promote closure of vertical pathways, with observations of reduction in annulus size and narrowing of steel casing in active wells over decades, suggesting that many abandoned well leakage pathways may become self-sealing over time (Alcalde *et al*. 2018 and references therein).

5.13.2.4 Accidental events related to renewable energy developments

Offshore wind and wet renewable energy developments have a generally limited potential for accidental loss of containment of hydrocarbons and chemicals, due to the relatively small inventories contained on the installations (principally hydraulic, gearbox and other lubricating oils). As part of the BEIS SEA research programme, a review of chemical use and discharge in the construction, operation and decommissioning of OWFs was undertaken (Blake *et al*. 2021), which included identifying licence conditions related to loss or spills. Typically, conditions stipulated *the requirement for the prevention or and response to any marine pollution incident caused via loss or spill*. However, relatively few licences contained requirements regarding loss or spills, this contrasts with the oil and gas industry where there is a requirement to report spills, which are then publicly reported. However, in comparison to E&P developments, there is low anticipated frequency and consequence of spills occurring during fuel or oil transfers, maintenance operations etc associated with OWFs.

The major risk scenario for offshore renewable energy developments is collision between a vessel fixed and installation, resulting in loss of fuel or cargo from the former. Collision risk assessment is therefore a key aspect of site-specific planning and consenting. At a strategic level, it can be noted that the anticipated scale and geographical location of development (specifically of offshore wind) must result in some overall increase in vessel collision risk, either through direct collision with a fixed installation or through constriction of available routes for safe navigation, particularly of larger vessels. Provision of effective National Contingency Planning, and adequate response resources at a national level – including Emergency Towing Vessels (ETVs) – are therefore considered to be important mitigation measures to support long-term development of the UK's offshore renewable energy resources.

5.13.3 Consideration of the evidence

5.13.3.1 Fate and trajectory of accidental releases

Accidental events related to exploration and production

The fate of oil spills to the sea surface is relatively well understood. On the sea surface, there are eight main oil weathering processes: spreading, evaporation, dispersion, emulsification, dissolution, oxidation, sedimentation and biodegradation. The rates of individual processes are inter-dependent, and also influenced by hydrocarbon characteristics, temperature and turbulence. In general, oils with a large percentage of light and volatile compounds and low viscosity (such as diesel) will evaporate, disperse and dissolve more rapidly than oil predominantly composed of higher molecular weight compounds (e.g. crude oils).

Oil on the sea surface will move due to a combination of tidal currents and wind stress. Generally, the slick front will be wind-driven on a vector equivalent to current velocity plus approximately 3% of wind velocity.

To support environmental assessments of individual drilling or development of oil and gas projects, modelling is carried out for crude and condensate release resulting from blowouts, loss of containment, including pipelines[285], and for diesel oil releases where relevant. Representative modelling cases from various parts of the UKCS have been reviewed by successive SEAs.

A review of spill modelling completed for exploration and development projects within those Regional Seas which support the main oil and gas producing areas is summarised in Table 5.34. The OPEPs and ESs reviewed are grouped by quadrant (see Figure 5.78). It should be noted that the minimum time to beach estimates in Table 5.34 are from worst case scenarios of unconstrained blowouts and large diesel spills with no intervention, combined with constant winds from one direction over a significant period of time (deterministic modelling[286]), which is improbable. With respect to stochastic modelling[287] requirements, the most recent OPEP guidance (BEIS 2021i)[288] indicates that:

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[285] If a pipeline contains 100% dry gas, with no possibility of an oil pollution incident, then there is no requirement for an emergency response plan; justification for this still has to be provided to the Regulator, including a demonstration that there is no potential for an oil pollution incident from the pipeline

[286] Assumes that a continuous 30 knot onshore wind occurs throughout the spill event - – note that this type of modelling will no longer be a requirement of the latest OPEP guidance.

[287] Stochastic modelling utilises metocean and meteorological inputs to determine likelihood of beaching and possible areas affected

[288] Any applicable new OPEP submissions, five year reviews or new worst case scenario models submitted must comply with this Guidance - https://www.hse.gov.uk/osdr/assets/docs/opep-guidance-rev5-apr-2019.pdf

- A minimum two year data-set of hydrodynamic and meteorological parameters must be used.
- A minimum of 100 model runs should be performed (a lower number of runs may be acceptable when accompanied by sound scientific or statistical justification)
- The duration of the model period must be appropriate to the scenario. The duration of the release period must be justifiable and should consider any discrepancy between the duration of the modelling and identified time period required to stop the release
- For production operations, or operations extending over a year, modelling must be carried out for each season; Winter (Dec-Feb), Spring (Mar-May), Summer (Jun-Aug) and Autumn (Sept-Nov)
- For temporary operations e.g. drilling/well intervention; the season(s) during which the operation is to be undertaken must be used for modelling purposes. For operations which could be subject to change it is recommended that all four seasons are modelled.
- The model result must be displayed to an oil thickness of 0.3µm

Table 5.34: Review of OPEPs and Environmental Statements[1] for quadrants in the main oil and gas producing areas

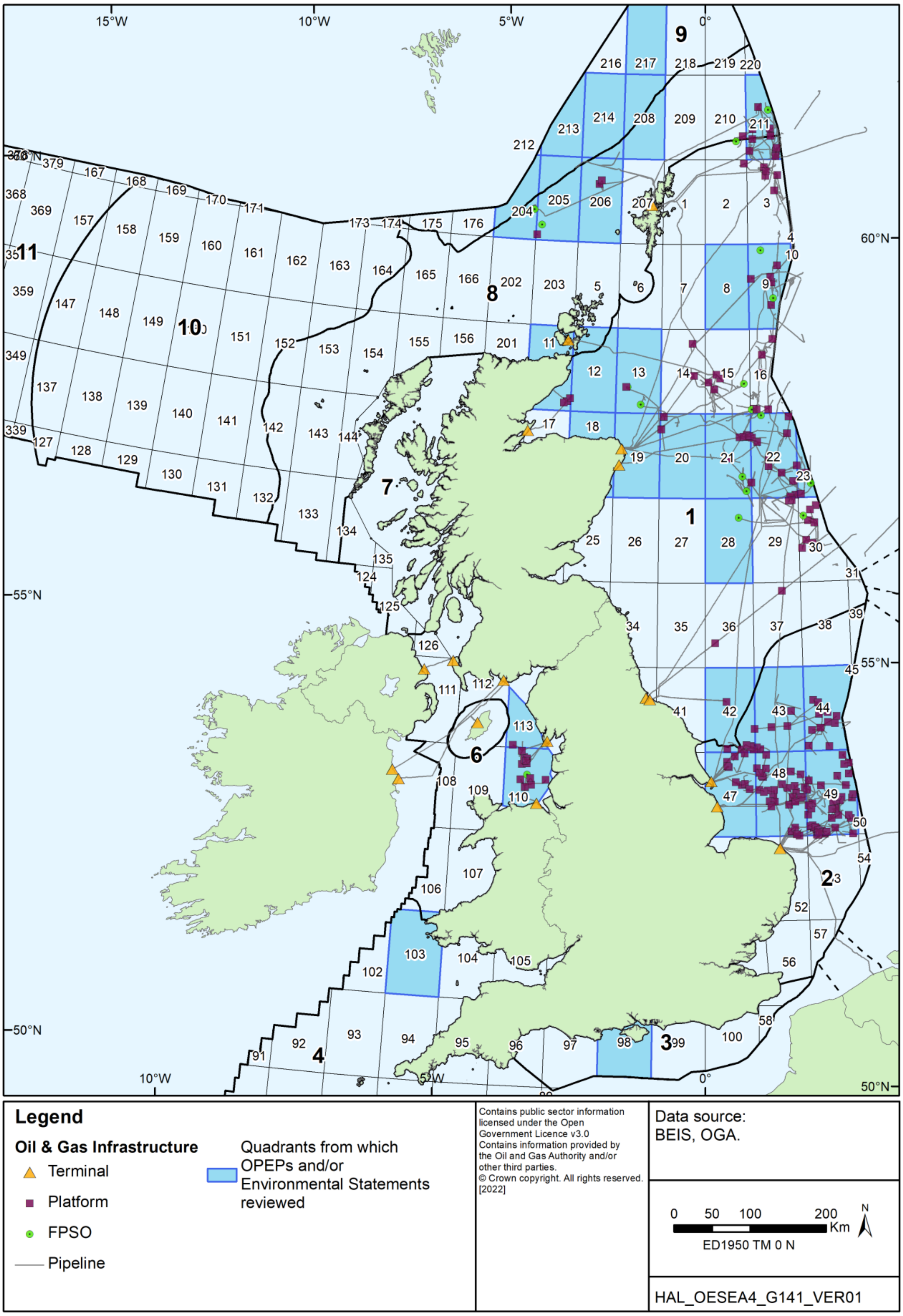
Quadrants Regional Sea 1	Number of OPEPs or ESs reviewed	Spill type & size	Minimum time to beach (hours)	Likelihood of beaching (%)
		Oil Pollution Emergency Plans		
12	1	Crude blowout 460m^3 per day (5 days)	14 (NE Scotland)	10 (Scotland)
13	2	Crude blowout 400-660m^3 per day (10 days)	30 (Fraserburgh)	<1 (Scotland, Norway)
18	1	Crude blowout 1,236m^3 per day (2 days)	8 (NE Scotland)	10 (Scotland)
19 & 20	2	Crude blowout 5,814-7,879m^3	26-39 (NE Scotland)	<10 (Scotland)
		Environmental Statements		
9	1	Crude blowout 283,322 m^3 (total)		30 (Shetland)
11	1	Crude blowout 161,250m^3 (total)	2	100 (north east coast Scotland)
13	3	Crude blowout 30,341m^3 (total)	48	70 (north east coast Scotland)
21	3	Crude blowout 1,420,560m^3 (total)	384	9 (Shetland)
22	1	Crude blowout 21,895m^3 (total)	480	25 (Aberdeenshire)
23	2	Crude blowout 271,649m^3 (total) Condensate blowout 95,400m^3 (total)	No UK beaching 596	0 6 (Shetland)
28	1	Crude blowout 238,288m^3 (total)	?	17 (north east England)

Quadrants	Number of OPEPs or ESs reviewed	Spill type & size	Minimum time to beach (hours)	Likelihood of beaching (%)
42	1	Condensate blowout 97,052m^3 (total)	?	100 (east coast of England)
Regional Sea 2				
Oil Pollution Emergency Plans				
42	1	Total rig inventory diesel loss 333m^3	Disperses within 8	0
44	3	Total rig inventory diesel loss 666-715m^3	Disperses within 8	0
44	1	Condensate blowout 17m^3 per day (28 days)	Does not beach	0
47	2	Total rig inventory diesel loss 371-715m^3	Disperses within 8-9	0
47	1	Condensate blowout 286m^3 per day (2 days)	17	7 (England)
49	1	Total rig inventory loss 889m^3 diesel, 150t low toxicity oil based mud	Disperses within 8	0
49	1	Condensate blowout 16m^3 per day (28 days)	Does not beach	0
Environmental Statements				
43	1	Condensate blowout 40,850m^3 (total)	288	28
48	2	Crude blowout 3006m^3 (total) Condensate blowout 39,373m^3 (total)	24 16	17 (Yorkshire and Lincolnshire coasts) 78
49	1	Condensate blowout 8,829m^3 (total)	No shoreline oiling	0
Regional Sea 3				
Environmental Statements				
98	1	Crude blowout 89,016m^3 (total)	2.5	100 (south coast of England)
Regional Sea 6				
Oil Pollution Emergency Plans				
103	1	Total rig inventory diesel loss 1,177m^3	Disperses within 8	0-<1 (Wales, Ireland)
110	6	Total rig inventory diesel loss 208-1,075m^3	3 for project adjacent to coast	0-50 (England) <5 (Wales)
110	1	Total loss of crude storage 146,242m^3	10 (England)	2-94 (England) Welsh 1-30 (Wales) 14 (N Ireland) 3-61 (Scotland) 2 (Ireland) 74 (Isle of Man)
110	2	Crude blowout 347m^3 per day (90 days)	18-24 (England)	34-100 (England) Welsh 2-100 (Wales)

Quadrants	Number of OPEPs or ESs reviewed	Spill type & size	Minimum time to beach (hours)	Likelihood of beaching (%)
				26 (N Ireland) 44-96 (Scotland) 10 (Ireland) 100 (Isle of Man)
113	5	Total rig inventory diesel loss 666-1,666m^3	Disperses within 8-9	0-0.7
113	1	Condensate blowout 21m^3 per day (28 days)	Does not beach	0
Regional Seas 8 & 9				
Oil Pollution Emergency Plans				
204	8	Crude blowout 720-287,280m^3 total spill	42-105 (Shetland)	5-60 (Shetland) 1-<5 (Orkney, Faroe, mainland Scotland) <10 (Norway)
205	2	Crude blowout 720-2,254m^3 total spill	40 (Shetland)	1-10 (Shetland) 1-42 (Orkney)
206	2	Crude blowout 35,000-287,280m^3 total spill	25-36 (Shetland)	3 (Shetland) 0 (Orkney, mainland Scotland, Faroe) 10-60 (Norway)
208	2	Crude blowout 57,652-169,175m^3 total spill	50-55 (Shetland)	2-10 (Shetland) 2 (Norway)
213	5	Crude blowout 1,000-1,100,822m^3 total spill	35-269 (Shetland)	1-21 (Shetland) 1-10 (Orkney, Faroe, Norway)
214	1	Condensate blowout 318m^3 total spill	Disperses within 10	0
217	1	Crude spill 1,400m^3 total spill	144 (Faroes) 146 (Shetland)	8
Environmental Statements				
205	1	Crude blowout 13,370m^3 per day (91 days)	40	100 (Shetland)
208	1	Condensate blowout 4,101m^3 (total)	96	4 (Shetland)
211	1	Crude blowout 429,094m^3 (total)	192	10 (Shetland)
213	1	Crude blowout 1,304,977m^3 (total)	80	98 (Shetland)
214	1	Condensate blowout 187,986m^3 (total)	42	6 (Shetland)

Notes: [1]Review of a selection of environmental statements for oil and gas industry since OESEA3 (2016). Source: BEIS website, Operator ESs

Figure 5.78: Quadrants from which OPEPs and/or Environmental Statements reviewed



Accidental events related to carbon dioxide storage

Modelling studies have informed the potential characteristics of fluid escape from a ruptured pipeline (Wareing *et al*. 2013, 2014) and related instantaneous releases of carbon dioxide from pipelines and longer term releases from geological stores (Blackford *et al*. 2008, Phelps *et al.* 2015). Releases of CO_2 at the seabed may be visible in the form of bubbles (see Blackford & Kita 2013, Li *et al.* 2021) or droplets with the phase determined by temperature and pressure, with bubbles likely to form in the shallow southern North Sea (Dewar *et al*. 2013). While the presence of natural gas seeps (e.g. through faults and from pockmarks) can provide useful data on bubble or droplet movement (typically of CO_2 and CH_4), the presence of a mixture of gases rather than pure CO_2 (Dewar *et al.* 2013) and the highly site specific nature of both natural (Kirk 2011) and storage site releases (Pearce *et al.* 2014a, b) makes them difficult to directly compare. The latter are more likely to provide insights into chronic, small-scale releases (maximum observed flux rate of a natural seep is up to 8,500t/m^2/year at Panarea, see Kirk 2011) rather than catastrophic or short-term releases.

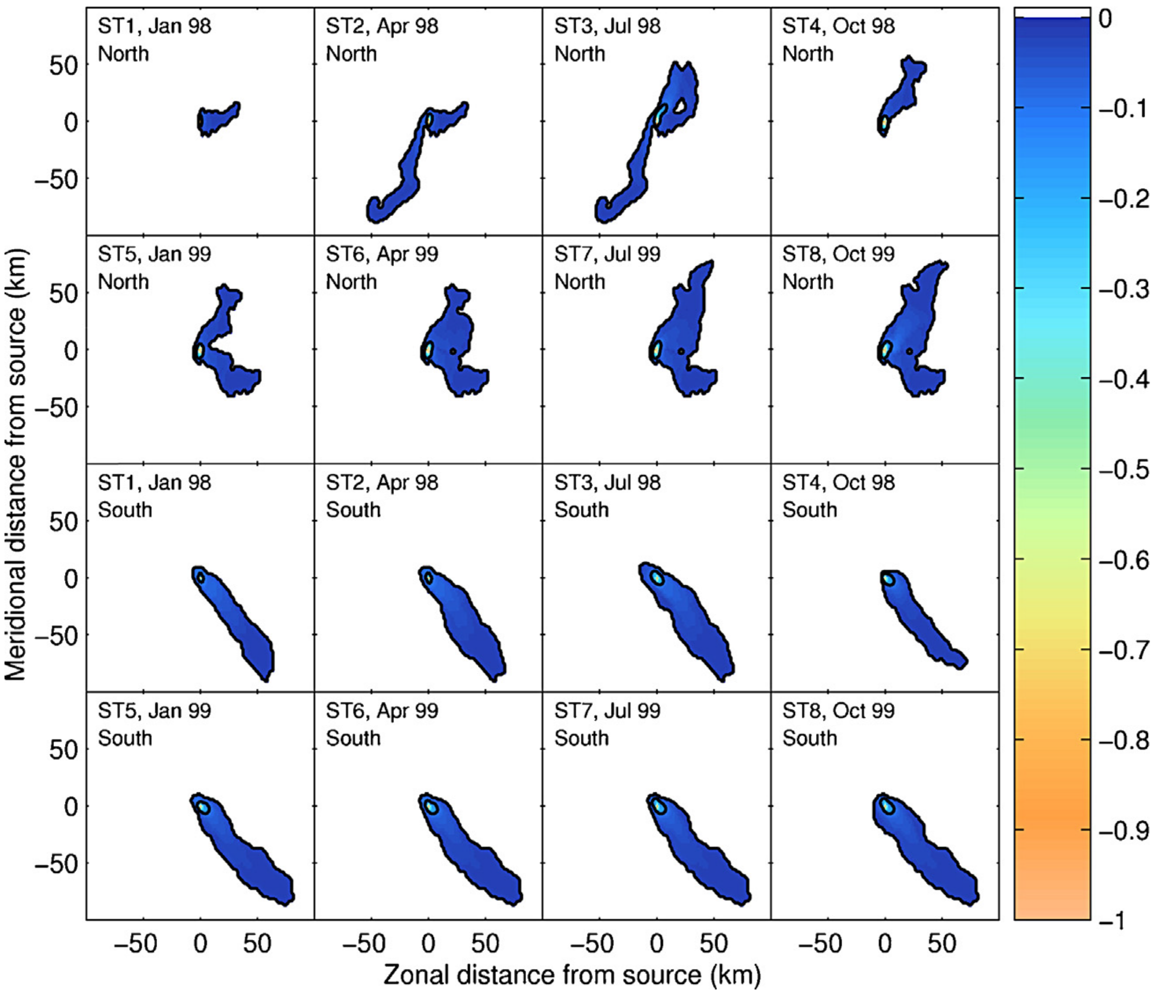
Blackford *et al*. (2015, 2017) note both the ability to discriminate small pH anomalies in the context of natural variability in marine carbon chemistry, and the need to understand local site characteristics for monitoring to reduce the potential for high numbers of false positive results to be investigated. Vielstäde *et al*. (2019) describe the limited ability to detect leaks from abandoned wells other than in close proximity to the well, in view of the rapid dissolution and dispersal noted in field experiments of releases in the order of 31 tonnes/year at Sleipner, and that such leaks could only be considered significant if there were many chronic releases. Monitoring approaches have also been subject to study (e.g. see Blackford *et al*. 2015, Furre *et al*. 2017, Wilkinson *et al*. 2017, Waarum *et al.* 2017, Dean & Tucker 2017, Blomberg *et al*. 2021, Flohr *et al*. 2021), which identify a number of potential monitoring techniques and strategies which could be used to detect leaks at storage sites.

For a short-term release thought to be representative of a pipeline rupture, Phelps *et al.* (2015) modelled a release over 1 day at two locations in the North Sea; a northern site corresponding to the approximate location of the Forties oil field characteristic of the relatively deep northern North Sea with a depth of 98m, and a southern site representing the approximate location of the Viking group of gas fields and typical of the shallow southern North Sea with a depth of 43m. The release rate was 5,000 tonnes of CO_2 per day (tCO_2/day), equivalent to twice the capacity of the current Sleipner pipeline and simulations were undertaken for each season (starting in each month of January, April, July and October for 1998 and 1999).

Significant changes in the marine carbonate system were observed in each of the short term leakage scenarios, but any perturbations were minimal outside the vicinity of the source. Across all eight simulations the largest recorded reductions to seawater pH were 1.92 and 1.22 pH units at the north and south site respectively, both occurring during the October simulation, yet reductions were typically weaker than 0.1 pH units beyond 10km from the release sites (Figure 5.79). Significant perturbations to pH were generally restricted to the bottom layer, even at the vertically mixed south site, and reductions to surface pH were typically weaker than 0.1 pH units. It is evident that any CO_2 plumes arising from leakages of this magnitude are highly localised in the context of the North Sea (Phelps *et al.* 2015).

The carbonate system at the leakage sites quickly returned to background values after the end of the CO_2 release period. This was primarily due to advection of CO_2 away from the leakage sites and tidal mixing rather than outgassing of CO_2 at the sea surface, and a rapid recovery was also observed at the north site during the summer months when outgassing was negligible. During the recovery period the greatest reduction in seawater pH was generally not found at the release sites but at nearby locations, as the CO_2 plumes were advected away from their point source. Significant changes in pH were restricted to the bottom layers of water with surface water changes typically of less than 0.1 units[289], despite the relatively well-mixed waters of the southern North Sea, consequently, there was no discernible seasonal signal in the behaviour of the release (note that northern North Sea waters showed distinct seasonal changes related to the presence of a thermocline). Dewar *et al.* (2013) noted that the largest changes in pH and dissolution of CO_2 were likely to be found near the base of the leak source due to the greater density of CO_2 compared to the surrounding seawater, which means plumes will tend to sink (McGinnis *et al.* 2011).

Figure 5.79: Maximum changes in pH at the seabed during short-term simulations



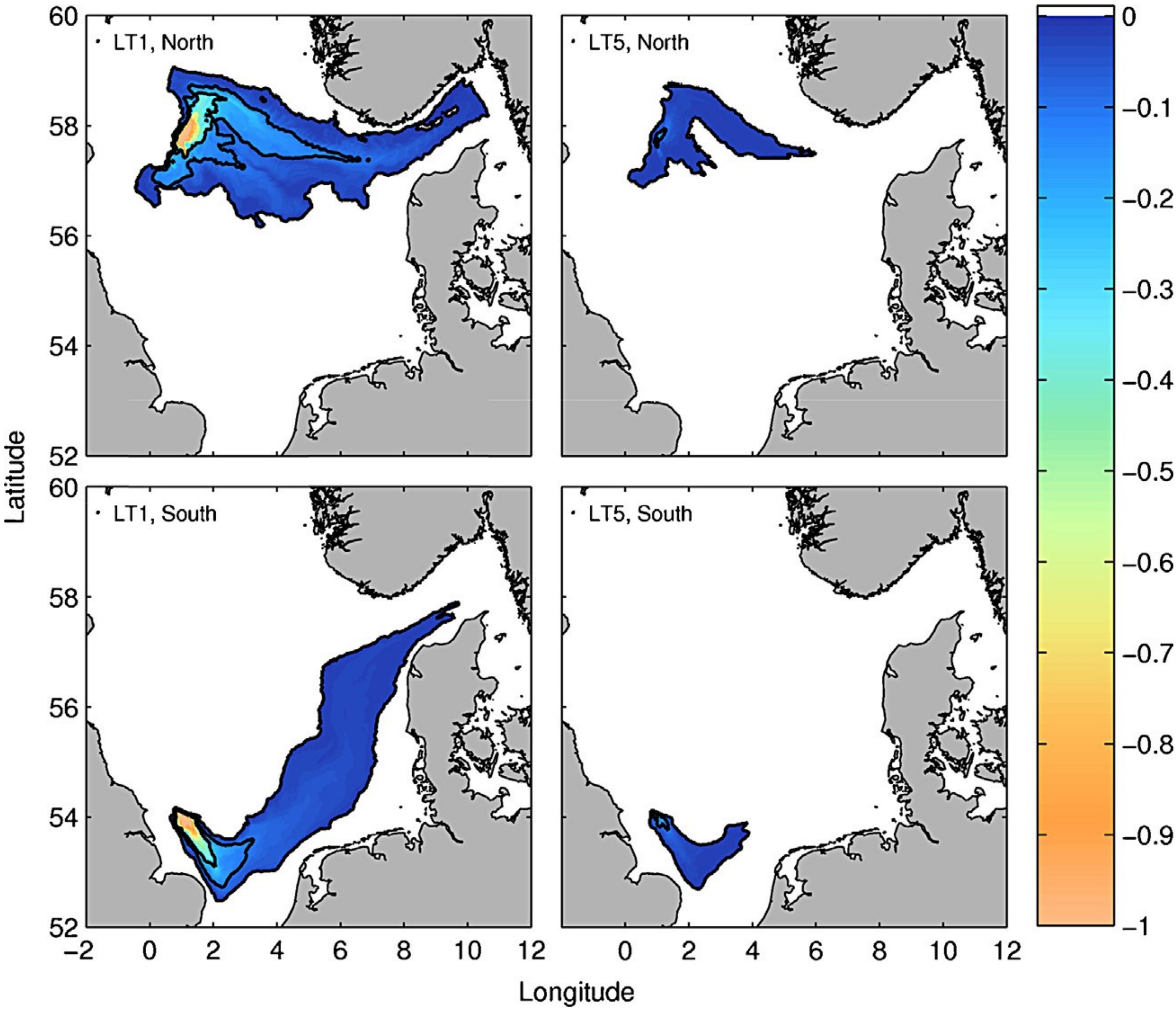
Source: Phelps *et al.* (2015). Notes: Simulations of release of 5,000 tCO_2/d over 1 day. Grid size is 200x200km. The contours shown are for -0.25, -0.1 and -0.01 pH units.

Longer-term releases with release rates of 1,000 tCO_2/d and 10,000 tCO_2/d were modelled over 365 days, representing chronic leakages such as those which might occur through geological faults. As with the short-term release scenario, the leaks were modelled beginning of each season. At the north site most of the CO_2 was carried initially northward then eastward by the mean circulation, broadly reflecting the Dooley Current, and gradually spread laterally to the north and south. However, a considerable proportion was also advected south of the release station (LT1 in Figure 5.80). The pathway of CO_2 released at the south site appeared to be much more persistent, initially flowing in a slow and narrow south-eastward pathway adjacent to the English coastline, then rapidly advancing north-eastward towards the Skagerrak in a much weaker concentration. The greatest reductions to pH were 2.67 and 2.32 pH units at the north and south site respectively, whilst acidification by 1.0 pH units (long-term reductions in pH

289 0.1pH units being regarded as a level where impacts are regarded to be unlikely (e.g. Widdicombe *et al.* 2013).

approaching or exceeding 1.0 unit can be considered as significantly harmful, Widdicombe *et al*. 2013) could be found as far as 39km from the north site, and 24km from the south site. The smaller release scenario of 1,000 tCO_2/d (LT5 in Figure 5.80) generated plumes which followed the same trajectory as the larger releases, though with changes an order of magnitude less (largest reductions to seawater pH were 1.1.9 and 0.98 pH units at the north and south site respectively. The carbonate system was found to return to natural values almost instantly following cessation of each release, however, analogous to the modelled short-term releases, this was in part due to advection away from the site rather than outgassing to the atmosphere (Phelps *et al*. 2015).

Figure 5.80: Maximum changes in pH at the seabed from long-term simulations



Notes: Simulations of release of 10,000 tCO_2/d (LT1) and 1,000 tCO_2/d (LT5) over 365 days. Each release was modelled starting in January 1998. The contours shown are for -0.25, -0.1 and -0.01 pH units. Source: Phelps *et al.* (2015).

Phelps *et al.* (2015) indicate that any predicted acidification should be considered in the context of natural variability of pH in the North Sea, which can exceed 1.0 pH units in coastal regions of freshwater influence, although further offshore annual variability is typically around 0.1-0.2 pH units (Blackford & Gilbert 2007). Furthermore, the North Sea is expected to acidify by an average of 0.2 pH units compared to pre-industrial levels by the year 2050 due to anthropogenic CO_2 emissions, and by an additional 0.13–0.28 pH units by 2100 (Blackford & Gilbert 2007).

They highlight that any acidification due to CO_2 leakages would be in addition to natural variability, and the rate of acidification would be considerably faster than the long-term trend associated with rising atmospheric CO_2 (Phelps *et al.* 2015).

The influence of stratification upon the fate of a CO_2 plume was evident. Strong seasonal thermoclines are able to inhibit the exchange of CO_2 between surface and bottom waters, and ultimately prevent outgassing of CO_2 into the atmosphere. Overall the carbonate system at the south site appeared to be considerably less sensitive to CO_2 additions than the north site, primarily because the shallow depths and generally well mixed vertical profile meant CO_2 could readily escape to the atmosphere, and strong tidal currents ensure that CO_2 was well mixed within the water column. Although seasonal variability to the air–sea flux was significant at both sites, on average the CO_2 injected at the south site reached the atmosphere twice as fast as the corresponding CO_2 at the north site (Phelps *et al.* 2015).

As part of the quantifying and monitoring potential ecosystem impacts of geological carbon storage (QICS) project, a small-scale leak (between 10kg/d and 210kg/d) was simulated in Ardmucknish Bay in western Scotland (Blackford & Kita 2013, Blackford *et al*. 2014, Taylor *et al*. 2015). The experiment used a narrow directionally drilled borehole which terminated in a 5m long diffuser contained in unconsolidated sediments 12m below the seabed, in 12m of water. A series of instruments were deployed at various distances from the simulated release location (epicentre, 10m, 25m, 75m and a control at 400m), and surveys undertaken before, 7 and 30 days after the release commenced and then 7, 30 and 90 days after cessation of the simulated leak. In addition to faunal experiments, changes in seawater pH were monitored.

The QICS study provided insights into the reaction of pore water in seabed sediments, which absorbed much of the emitted CO_2, though underwent physical changes immediately above the release site in the form of CO_2 chimneys (and gas columns in the waters above), which were seismically resolvable (Blackford *et al*. 2014, Cevatoglu *et al.* 2015). As pore water became supersaturated with CO_2, a greater proportion of the leak reached the seabed surface and therefore the water column (Dewar *et al.* 2015), being either subject to dissolution or outgassing. Sedimentary interactions with bubbles or droplets may change depending on shallow geological heterogeneity, with sudden large escapes possibly caused by accumulation of CO_2 in pockets which eventually exceed hydrostatic head (Caramanna *et al.* 2014).

Blackford *et al*. (2008), Phelps *et al*. (2015) and Dewar *et al*. (2013) indicate that tidally driven mixing is the primary CO_2 dispersal mechanism, and that small-scale catastrophic releases and smaller chronic releases tend to generate localised changes in pH and the carbonate system which rapidly recover following cessation of the release. While the largest release scenarios were found to generate widespread acidification, such leaks are highly unlikely to occur. Model simulations suggest that a release of 1 tonne day^{-1} may be detectable at 50m distance, scaling to 5km distance for a 100 tonne day^{-1} release, although local hydrodynamics would cause significant variability in the detection length-scale (Blackford *et al*. 2018).

An experimental CO_2 release was conducted in 2019 within the surface sediments overlying the proposed Goldeneye CO_2 storage reservoir, a depleted gas condensate field in the Outer Moray Firth in 120m water depth, as part of the Strategies for Environmental Monitoring of Marine Carbon Capture and Storage (STEMM-CCS) project (summarised in Flohr *et al*. 2021). For the experiment, a curved pipe was pushed into the unconsolidated marine sediments with the leading end terminating *ca*. 3m below the seabed. The surface end of the pipe was connected to a gas container some 80m east of the pipe, containing 3 tonnes of CO_2 gas and additional gas tracers. The curved pipe was to ensure that the sediment directly above the release point was undisturbed by its emplacement and migration pathways could develop naturally (Roche *et al.* 2021). During the main phase of the experiment, gas was released into the sediment via the injection pipe. The injection rate was 6 kg/day on day 0, and almost immediately after injection began sporadic gas bubbles were visible along the seabed above the release site and within hours small seeps (the continuous release of gas bubbles from a fixed position) began to form. The dissolution of bubbles within the overlying water column was observed using an ROV within a 4m radius of the expected position of the pipe outlet, with no bubbles visible with the ROV camera at >8 m above the seabed. The injection rate was progressively increased to a maximum of 143 kg/day (D + 8) before gas release was stopped on Day 11. A range of techniques were deployed to detect and monitor the escaping CO_2 in the subsurface sediments and the overlying water column, including geochemical, optical, passive acoustic, and seismic reflection profiling (Roche *et al.* 2021).

During the experiment, the released CO_2 was detectable in its gaseous and dissolved form in both the sediments and the water column but within a very localised area. In the sediments close to the bubble streams, the impact of injected CO_2 was detectable based on changes in the pore water chemistry, as a temperature increase in the pore water and in gas form from chirp measurements. Gas bubbles in the water column were detectable optically and acoustically, and CO_2 that dissolved in the water column created a distinctive signal that was detectable chemically by in-situ and lab-based methods (summarised in Flohr *et al.* 2021). Gros *et al.* (2021) note that deeply sourced leaks such as from targeted CO_2 storage reservoirs might be expected to cover larger surface areas at the seafloor than that observed during the experiment. The maximum distance observed for STEMM-CCS between the bubble stream origins (*ca*. 4m) for a CO_2 source at 3m below the seabed was smaller than the maximum distance between the bubble stream origins (*ca*.13m, Dewar *et al.* 2015) seen in the QICS experiment, where the CO_2 injection point was located at 10m below the seabed. Given the likely small spatial extent of a plume and its rapid dilution away from the seabed, future monitoring strategies will need to be supported by model simulations (e.g. Blackford *et al*. 2017, Lessin *et al*. 2016, Vielstäde *et al*. 2019) to provide optimal deployment strategies of sensors for detection, location, and quantification of leakages (Alendal *et al.* 2017).

5.13.3.2 Effects of accidental releases

Environmental effects

Accidental events related to exploration and production

The most vulnerable components of the ecosystem to oil spills in offshore and coastal environments are seabirds and marine mammals due to their close association with the sea surface. Mechanisms of impact on seabirds include oiling of plumage and loss of insulating properties, and ingestion of oil during preening causing liver and kidney damage (Furness & Monaghan 1987). Indirect effects associated with bioaccumulation of contaminants from prey, and reduced prey availability, are also possible, whilst metabolic, endocrine and cardiotoxic effects from inhalation/consumption may also be emerging (King *et al.* 2021). Pollution of the sea by oil, predominantly from merchant shipping, can be a major cause of seabird mortality.

Fortunately, there is little experience of major oil spills in the vicinity of seabird colonies in the UK. In January 1993 the Braer ran aground at Garth's Ness in Shetland and began leaking, spilling a total 85,000 tonnes of Gulfaks crude oil. 207 birds were received at the cleaning centre set up to deal with oiled birds, of these 23 were successfully rehabilitated, while an estimated 31 out of 34 seals were successfully rehabilitated. There was difficulty in determining the number of birds that died as a result of the oil as some would never have been found and stormy weather at the time of the spill caused a high mortality of storm victims that became oiled after death. 1,538 dead birds were found on the beaches including shag (857), black guillemot (203), kittiwake (133), and long-tailed duck (96), as well as great northern diver (13), eider (70) and great black-backed gull (45). There was a clear excess of females over males found. The main groups of breeding seabirds affected by the spill were locally resident species, as summer visitors were not in Shetland waters at the time of the spill. In general the 1993 breeding season was successful for most species that may have been affected by the oil spill, with the exception of shag and black guillemot (SOTEAG 1993, DTI 2003). The stormy weather during the Braer spill resulted in the rapid dispersion of the oil in the water column. Long term effects on wildlife have proved to be less than first feared with the most notable impact on breeding populations of resident seabirds closest to the spill (SOTEAG 1993).

The impact of the Macondo (Deepwater Horizon) well blowout on birds offshore is difficult to quantify due to the low resolution of antecedent seabird surveys and the paucity of observed carcasses during the oil spill response, potentially due to the rapid decomposition rates of bird carcasses in the relatively warm seas, opportunistic scavenging (e.g. by tiger sharks), and due to in situ burning of surface oil slick (Haney *et al*. 2014a). Modelling (Haney *et al*. 2014a, b) estimated mortality of 200,000 in coastal and open waters immediately after the blowout, when considered across the range of species known to be affected by the spill, would represent <10% of their breeding population. When considering those birds exposed in coastal and estuarine environments, Haney *et al*. (2014b) estimated that bird mortality was approximately 700,000. Within coastal waters, mortality was estimated to have mainly affected four species: northern gannet *Morus bassanus* (8%), brown pelican *Pelecanus occidentalis* (12%), royal tern *Thalasseus maximus* (13%) and laughing gull *Leucophaeus atricilla* (32%). Both studies suggested future work was required to understand the demographic consequences to the Gulf's coastal birds from this large marine spill. Sackmann & Becker (2015) criticised the study by Haney *et al*, who suggested there was an overestimation of bird deaths, from the underestimation of carcass transport probability to shoreline, this was subsequently refuted by Haney *et al.* (2015) (Beyer *et al.* 2016). Another study looking at birds (western sandpipers) affected by the incident, looked at the impact of oiling on wings and tail feathers on birds and what impact this had on flight behaviour, from the perspective that hindered flight could reduce escape performance leaving the bird more vulnerable to predation (Maggini *et al.* 2017a). It was found that feather damage through oiling could affect flight performance by decreasing lift and thrust, increasing drag, imbalance and cause difficulties to take off. Whilst a complimentary study also looked at the potential effects of oil on feathers could have on the energy cost of flight and migration ability of birds (Maggini *et al*. 2017b). This found that the energy cost of transport was 0.26±0.04 kJ km^{-1} in controls, and increased by 22% when the trailing edges of the wing and tail were oiled (<20% of body surface; considered light oiling). Additional crude oil on breast and back feathers (~30% total surface; moderate oiling) increased the cost of transport by 45% above controls. Trace-oiled birds which had access to clean water for bathing, were found to return to a flight performance comparable to that of control birds after a two week recovery period. The authors suggested that this additional energy cost could have implications for birds undertaking migration, particularly if birds did not have access to clean water (Maggini *et al*. 2017b).

Twenty-five species of seabird regularly breed in the UK, which supports breeding colonies of international importance. The birds from these forage in inshore and offshore waters, and, whilst the major breeding areas for most waterbird species (e.g. wildfowl and wader species) are outside the UK, areas of the UK support overwintering and birds on passage, in numbers reaching tens and hundreds of thousands. The potential spill impact on birds could therefore be significant. However, population dynamics are largely controlled by factors including breeding success (largely related to short-term climate fluctuations, but also habitat loss and degradation) and migration losses. Variability in movements of wintering birds, associated with winter weather conditions in continental Europe can also have a major influence on annual trends in UK numbers, as can variability in the staging stops of passage migrants.

Oil spill risks to marine mammals have been reviewed by successive SEAs for previous licensing Rounds and in a number of supporting technical reports (e.g. Hammond *et al.* 2005, Hammond *et al.* 2008).

Generally, marine mammals are considered to be less vulnerable than seabirds to fouling by oil, but they are at risk from hydrocarbons and other chemicals that may evaporate from the surface of an oil slick at sea within the first few days, and any accidental ingestion or breathing of oily fumes could cause physiological stress (Law *et al*. 2011). Symptoms from acute exposure to volatile hydrocarbons include irritation to the eyes and lungs, lethargy, poor coordination and difficulty with breathing. Individuals may then drown as a result of these symptoms (Hammond *et al*. 2002). In their study analysing muscle tissue samples for total PAHs (which are found in oil), from 26 UK-stranded harbour porpoise, Law & Whinnett (1992) found levels were relatively low, with only one death considered to be the result of cancer. In the unlikely event of mortality from a spill, population recovery rates are likely to be lower than for most bird species.

The effects of the Macondo blowout on marine mammals in the Gulf of Mexico were evaluated, including through using an area known to have received heavy and prolonged oiling (Barataria Bay, Louisiana) and a control site (Sarasota Bay, Florida) (e.g. Schwacke *et al.* 2013,Takeshita *et al* 2017, Smith *et al* 2017, McDonald *et al*. 2017, Kellar *et al*. 2017). Disease conditions in Barataria Bay dolphins were significantly greater in prevalence and severity than those in Sarasota Bay dolphins, as well as those previously reported in other wild dolphin populations. Many disease conditions observed in Barataria Bay dolphins were uncommon but consistent with petroleum hydrocarbon exposure and toxicity (Schwacke *et al*. 2013). The mortality signal from the Macondo blowout is made less clear by an ongoing Unusual Mortality Event (UME) declared by NOAA Fisheries that covers the broader northern Gulf of Mexico region. This UME began two months prior to the Macondo blowout, and since that time the frequency of strandings has fluctuated both spatially and temporally. The timing and underlying pathologies for the strandings are being examined as part of the UME investigation to understand the potential differing causal factors, including the Macondo spill.

In follow-up studies, capture-release health assessments were carried out in Barataria Bay to document disease outcome in individual dolphins and examine the population recovery process, and compared to additional data from the control site (Smith *et al*. 2017 – this study also evaluated dolphins from another oiled area, Mississippi Sound). Overall improvement in population health was evident, however, pulmonary abnormalities and impaired stress response persisted for at least 4 years after the event; moderate to severe lung disease remained elevated but decreased slightly with time (i.e. 34% in 2011 and 23-25% in 2013-2014)), with similar findings at the Mississippi Sound site (Smith *et al*. 2017). The authors found no supporting evidence that either morbillivirus or Brucella, were significant contributing factors to the prevalence of either moderate to severe lung disease, or moderate to severe alveolar-interstitial syndrome; this having been previously reported to cause unusual mortality events in bottlenose dolphins (e.g. Litz *et al*. 2014).

Grey and harbour seals come ashore regularly throughout the year between foraging trips and additionally spend significantly more time ashore during the moulting period (February-April in grey seals and August-September in harbour seals) and particularly the pupping season (October-December in grey seals and June-July in harbour seals). Animals most at risk from oil coming ashore on seal haulout sites and breeding colonies are neonatal pups, which rely on their prenatal fur and metabolic activity to achieve thermal balance during their first few weeks of life, and are therefore more susceptible than adults to external oil contamination (Hammond *et al.* 2005).

Direct mortality of seals as a result of contaminant exposure associated with major oil spills has been reported, e.g. following the 1989 Exxon Valdez oil spill in Alaska. Animals exposed to oil over a period of time developed pathological conditions including brain lesions, and additional pup mortality was reported in heavily oiled areas compared to un-oiled areas.

Coastal otter populations are also vulnerable to fouling by oil, should it reach nearshore habitats. They are closely associated with the sea surface and reliant upon fur rather than blubber for insulation.

Fish are at greatest risk from contamination by oil spills when the water depth is very shallow. In open waters deeper than 10m, the likelihood that contaminant concentrations will be high enough to affect fish populations is very small, even if chemical dispersants are used. Any spilled oil with a specific gravity lower than seawater, would be expected to float on the sea surface and, some low viscosity oils may disperse naturally within the top few metres of the water column. Therefore, these would not be expected to penetrate the lower depths of the water column, and as such the impact on species in these lower levels, or on the seabed (e.g. demersal spawning sandeels), is expected to be low (ITOPF 2014). However, in oil spills where there is a higher level of benthic deposition, e.g. as seen in the Deepwater Horizon event, there is deeper penetration through the water column, to the seabed. For pelagic spawning species such as mackerel, there may be a potential pathway for impact, if oil is present in the water column, depending where in the water column eggs are released and how far the oil penetrates the water column.

In shallow or enclosed waters (note that chemical dispersants are not generally appropriate for use in such areas), high concentrations of freshly dispersed oil may kill some fish and have sublethal effects on others. Juvenile fish, larvae and eggs are most sensitive to the oil toxicity (Law *et al*. 2011).

Available evidence suggests that salmon smolts utilise shallow water depths (1-6m) and that adults show varying behaviour, swimming generally close to the surface (0-40m depth), with occasional deeper dives – e.g. Holm *et al.* (2005, cited by Malcolm *et al.* 2010) noted dive depths of between 85 and 280m. The most sensitive period for Atlantic salmon is likely to be during the peak smolt run, rather than when adult salmon are returning to rivers. This is because Atlantic salmon return to natal rivers throughout the year, whereas the smolt run is more seasonally defined (April and May). It should be noted that salmonids play a critical role in the life cycle of the freshwater pearl mussel.

Benthic habitats and species may be sensitive to deposition of oil associated with sedimentation, or following chemical dispersion. The proportion of a surface spill that is deposited to the seabed might be expected to increase as a result of high turbulence and suspended solids concentrations in the water column, both associated with storm conditions in shallow water. Studies of seabed infauna following the Braer spill (Kingston *et al.* 1995), which occurred under such conditions, found no significant changes in benthic community structure, as characterised by species richness, individual abundance and diversity, which could be related to the areas of seabed affected by the spill. This may have been because Braer oil was of low toxicity, or because the sampling programme was carried out too soon after the spill to enable the full effects of its impact to be detected. In recognition of this as part of the BEIS SEA programme, further sampling of the study area was undertaken ten years after the spill, results from which have indicated a substantial decline in sediment hydrocarbon concentrations.

In contrast, evidence from the Florida barge spill (Buzzards Bay, Massachusetts, September 1969, in which 700m^3 of diesel fuel were released) suggests that in certain circumstances, contamination from oil spills could be long-term. Monitoring immediately following the spill suggested rapid recovery (reviewed by Teal & Howarth 1984), while subsequent studies (sampling in 1989) indicated that substantial biodegradation of aromatic hydrocarbons in saltmarsh sediments had occurred (Teal *et al.* 1992). However, thirty years after the spill, significant oil residues remain in deep anoxic and sulphate-depleted layers of local salt marsh sediments (Reddy *et al.* 2002, Peacock *et al.* 2005). The ecological consequences of this residual contamination are unclear, although there is potential for remobilisation of sediment-bound contaminants through bioturbation or storm events (in which case, aerobic biodegradation would be expected to be rapid).

The concentration of petroleum hydrocarbons in sediments was measured in three Louisiana estuaries before Macondo well oil entered the wetlands, and nine times afterwards, from September 2010 to June 2013. The average concentrations of alkanes and PAHs were 604 and 186 times the pre-spill values respectively (Turner *et al*. 2014). The concentrations of alkanes and PAHs in June 2013 were about 1% and 5%, respectively, of the February 2011 concentrations, but were higher than in the May 2010 baseline. The concentration of alkanes declined rapidly and Mahmoudi *et al.* (2013) suggested that baseline conditions for alkanes may be reached in 2015. Work undertaken offshore in proximity to the blowout location (see Montagna *et al.* 2013), revealed that benthic effects (e.g. faunal abundance and diversity) was greatest within 3km of the Macondo wellhead covering an area of around 24km^2 with a zone of 'moderate effects' observed to extend up to 17km towards the south-west and 8.5km towards the north-east of the wellhead, covering an area of around 148km^2. Recovery time of the benthos is unknown, but is likely to take years or decades; the presence of numerous natural oil, gas and brine seeps and associated microflora and other biota in the Gulf of Mexico may allow a more rapid recovery than would be the case in other deep sea areas. White *et al.* (2012) and Fisher *et al*. (2014) investigated 13 deep water coral sites, most of which did not show evidence of impacts from the spill. Despite extensive survey and sampling, no compelling evidence of acute impact from the spill at any coral sites between 400 and 850m depth or more than 30km from Macondo led Fisher *et al*. (2014) to suggest that this was the footprint of acute impact to deep water coral communities from the blowout.

The ecological effects of chemical spills are clearly dependent on the physical properties and toxicity of the chemical involved. Since chemical selection and use on offshore facilities is tightly regulated and the majority of chemicals are in low risk categories, the potential risk is considered to be relatively low (e.g. in contrast to bulk shipping of hazardous chemicals).

Accidental events related to gas storage

Accidental subsea gas releases can result in seabed disturbance and crater formation, although such events are extremely rare. Wright (2006) reports a gas kick during drilling to deepen a depleted production well which resulted in well broach and uncontrolled gas flow for 10 hours; this led to the formation of a seabed crater some 25m x 15m and 8m deep. Minor gas releases subsea would be expected to result in significant dissolution in the water column, with a proportion of gas released to atmosphere (dependent on various factors including water depth and gas flow rates). Major releases, and all releases direct to atmosphere, will contribute to local air quality effects and to global greenhouse gas concentrations. The relative contribution of all foreseeable releases is minor.

Accidental events related to carbon dioxide storage

A range of effects are possible from an accidental release of CO_2 from a pipeline or storage site, with the change in seawater pH being the main source of effect for short-term releases, and additionally disturbance to the carbonate system for longer-term releases (e.g. through a reduced ability of some organisms to produce hard shells and increased erosion of shells, particularly sessile forms which are in close association with the seabed – Pearce *et al*. 2014a, also see Hennige *et al*. 2014). Much research has been undertaken on the potential effects of ocean acidification resulting from oceanic uptake of anthropogenic CO_2 on marine organisms, these the subject of numerous laboratory, and field experiments (e.g. Kirk 2011, Pearce *et al*. 2014a, Hennige *et al*. 2014, Sokoloski *et al*. 2018, Amaro *et al*. 2018, see also the summaries in Williamson *et al*. 2017 and Birchenough *et al.* 2017).

The potential effects of CO_2 on bacterial communities has been investigated (e.g. Borrero-Santiago *et al*. 2017); bacteria have an important role in the degradation of organic matter and remineralization (e.g. Pomeroy *et al*. 2007) and are an important trophic level. Quantifying sensitivity of an ecosystem to raised levels of CO_2 is complex (Jones *et al*. 2015, Blackford *et al*. 2020), as impacts will depend on species and life stages present, nutritional status of individuals, and length of exposure (e.g. Kroeker *et al*. 2013, Lessin *et al*. 2016, Blackford *et al*. 2020).

While many marine species are able to cope with short-term perturbations of reduced pH and elevated CO_2, having some resistance due to natural variability, they are unlikely to be able to cope with larger, longer-term changes that could occur from chronic leaks depending on their magnitude and the nature of the receiving physical environment (Pearce *et al*. 2014a).

Direct field and laboratory studies have been undertaken to understand the potential effects of short- to medium-term releases (Amaro *et al*. 2018), and longer-term releases (Molari *et al.* 2019), for example using naturally occurring CO_2 vents and benthic faunal transplant experiments, both of which generally indicated a decline in benthic diversity. Amaro *et al.* (2018) acknowledge a number of limitations in mesocosm studies, and that the results are likely to be context specific (e.g. to the species assemblage studies and sediment mineralogy which can determine its buffering capacity to leaks).

With regards to long-term leaks, Hennige *et al*. (2014) indicates that calcifying organisms such as echinoderms, molluscs, corals and specific algae are more vulnerable to the effects of enhanced levels of CO_2, with fish (Hennige *et al.* 2014) and annelids (e.g. see Calosi *et al*. 2013) having a greater tolerance to acidification and hypercapnia. Most organisms which have been investigated tend to tolerate a large change in pH (to 7.3) before significant effects including mortality are observed at lower levels (<7.0) (Dorey *et al*. 2013, Hu *et al.* 2014, Murray *et al.* 2013, Morgan *et al*. 2014). Experimental results from the RISCS (research into impacts and safety in CO_2 storage) project[290] suggest that benthic shell gravel marine communities in cool temperate shallow marine environments are able to withstand at least 10 weeks of exposure in pH levels not less than 7.5 (Pearce *et al*. 2014a).

Hu *et al.* (2014) found that the brittlestar (*Amphiura filiformis*) experience a naturally low oxygen and pH environment in their burrows, being relatively robust down to pH 7.3, but showed the onset of metabolic depression at exposure to pH 7.0. Murray *et al*. (2013) found that the species was robust to changes in pH, though exhibited emergent behaviour during simulated rapid acidification (down to pH 6.5). Pearce *et al*. (2014a) notes that sea urchins living at higher levels of CO_2 tend to show reduced reproductive success (though no specific pH value is given). With regards to effects on larvae, Dorey *et al.* (2013) found larvae of the green sea urchin (*Strongylocentrotus droebachiensis*) to be resistant to reductions in pH to levels as low as 7.0, but with changes in body symmetry, morphology and respiration, which were significant and caused mortality after 13 days at pH ≤6.5, which contrasts with previous findings of Dupont *et al.* (2008), who found mortality in brittlestar (*Ophiothrix fragilis*) larvae at a change of just 0.2 pH units being exceeded for 8 days, which may reflect variations in individual responses of

[290] http://www.riscs-co2.eu/

echinoderm species to rapid pH changes, as they have been generally found as resistant to enhanced pH (see review in Dupont *et al.* 2011).

Caged mussels *Mytilus edulis* and king scallops *Pecten maximus* were subject to the QICS simulated CO_2 release in Ardmucknish Bay (see above for experiment parameters) with no evidence of significant impacts noted for ion or CO_2 regulation (Pratt *et al.* 2014). Earlier laboratory experiments (Gazeau *et al*. 2007) indicated a linear decrease in calcification rates of *M. edulis* with increasing pCO_2, with longer-term experiments (6 months) indicating continued shell growth with increased pCO_2 concentrations of a magnitude expected through anthropogenic CO_2 input by 2100 (see Ciais *et al.* 2013), though with a reduction in shell integrity (Fitzer *et al.* 2014). While adults may have some resilience to changes in pH, the impact of chronic reductions in pH (e.g. analogous to ocean acidification) are likely to be more pronounced for larval stages in bivalves (Hennige *et al.* 2014). Specifically looking at species from the Baltic Sea, in a mesocosm experiment with the benthic clam *Limecola balthica* exposed to CO_2 induced seawater acidification (pH 7.7, 7.0 and 6.3), changes in behavioural (e.g. burrowing activity, moving vertically toward sediment surface; at pH of 6.3 burrowing depth reduced by nearly 6mm, by 24% relative to the control) and physiological (e.g. increased respiration) traits were observed (Sokoloski *et al*. 2018). A decrease in shell weight was also observed (although soft tissue weight remained across the acidification treatments), the most likely cause of this given was the external dissolution and erosion of the inorganic layer of the shell (which almost completely lost its organic matrix). Producing the organic layer is thought to be the most costly shell growth process, and, in response to seawater acidification the clams increase metabolism and enhance energy assimilation from food to maintain acid-base cellular regulation, and reduce energy allocation to other physiological processes such as shell organic matrix production/counteracting shell dissolution and erosion (Sokoloski *et al*. 2018). However, the harmful influence of lower pH appeared to be mitigated somewhat at pH 6.3, which indicated that the threshold acidity for decline in external carbonate skeleton growth was between pH 7.0 and 6.3, and, even the most acidic conditions did not prove to be fatal. The clams also appeared to have a period of acclimatisation to elevated seawater pCO_2 and presumably to hypoxic conditions in the sediment. At the end of the CO_2 incubation (42-56 days), the bivalves increased metabolism, accompanied by active burrowing into deeper sediment layers and smaller declines in shell length/thickness growth.

Polychaetes have received relatively little attention in terms of potential impacts from elevated pCO_2 (Calosi *et al.* 2013, Lewis *et al.* 2013). Adaptation has been shown in some species in response to elevated levels of pCO_2 associated with natural seeps in the Mediterranean (Calosi *et al*. 2013), while experiments in intertidal areas have shown reduced fertilisation success with pH reductions from 8.1 to 7.4 and an extreme 7.2 (Lewis *et al*. 2013). The onset of impacts from a reduction in pH of this magnitude is in general agreement with those suggested by Pearce *et al*. (2014a).

Generally, wider benthic macrofaunal community changes were observed at the Ardmucknish release site within a few days (with effects from the release discounted for all stations at 25m, 75m and 450m) which became more severe during the release though showed rapid recovery by 18 days after cessation (Widdicombe *et al.* 2015). Kita *et al*. (2015) observed benthic megafauna in association with the same experimental release which frequently included, *Virgularia mirabilis* (sea pen), *Turritella communis* (snail), *Asterias rubens* (starfish), *Pagurus bernhardus* (hermit crab), *Liocarcinus depurator* (crab), and *Gadus morhua* (cod), none of which displayed any abnormal behaviour.

The sensitivity of planktonic and pelagic communities (e.g. fish, cephalopods) to high CO_2 concentrations and reduced pH is variable. Hennige *et al.* (2014) note that fish are generally able to maintain oxygen delivery under higher CO_2 levels (e.g. citing research on Atlantic cod which maintained standard metabolic rates at high CO_2 concentrations after exposure of up to 12 months, Melzner *et al*. 2009), and reproductive success is variable, but generally robust in species studied to date (e.g. herring, *Clupea harengus*). Squid have the potential to be affected due to use of the respiratory pigment haemocyanin which is sensitive to CO_2, while the cuttlefish (*Sepia officinalis*) has not shown significant effects of reduced pH unless water temperatures are also enhanced (Hennige *et al*. 2014).

In appropriate circumstances greater CO_2 concentrations can lead to enhanced primary production, particularly of non-calcifying phytoplankton (Hennige *et al*. 2014), but this requires relatively clear, shallow waters which are not present over much of the North Sea and are limited by nutrient supply (Pearce *et al.* 2014a). The phytoplankton community of the North Sea, is dominated by the dinoflagellate genus *Tripos* (*Tripos fusus, T. furca, T. lineatum*), with diatoms such as *Thalassiosira* spp. and *Chaetoceros* spp. also abundant. Information on the response of some zooplankton such as copepods is limited, though Arctic mesocosm experiments showed no change in abundance after 30 days of exposure to enhanced CO_2 (>1,000µatm, greater than the projected oceanic pCO_2 in 2100 by IPCC) in *Calanus* spp., *Oithona similis*, *Acartia longiremis* and *Microstella norvegica*, though grazing rates of *Calanus* spp. decreased with increasing CO_2.

Generally, how effects of exposure to high levels of CO_2 and related reduced pH in early life stages may affect later adult growth and reproduction is a key information gap and an area which requires continued research (Hennige *et al*. 2014), particularly in the context of a background trajectory of rising oceanic acidification. Early life stages (e.g. larvae) of fish are expected to be more vulnerable to high CO_2 concentrations, as their capacity for acid-base regulation (as seen in juvenile and adult fish) has not yet fully developed (Wright *et al*. 2020).

While short-term catastrophic events have been observed to generate significant changes in seawater pH (up to 1.22 units), recovery is likely to be rapid, with effects highly localised around the release location, and dependent upon the communities present and their resilience to changes in pH. Assuming an ambient seawater pH of 8.1, an absolute and highly localised reduction to pH 6.9 is unlikely to elicit long-term responses in most animals, though could generate mortality for some individuals in proximity to the source. The presence of strong tidal currents and turbulent waters in the southern North Sea and the very localised area of detectability associated with a leak as evidenced by the STEMM-CCS experiment in the central North Sea suggests that any short-term leak will be rapidly dispersed and diluted from the release location reducing any longer-term interaction with areas of reduced pH or enhanced pCO_2. Longer-term chronic emissions from storage site leaks could produce effects at the seabed and in the water column, however even under this scenario, the return to normal pH and pCO_2 levels in seawater can be expected to occur within days for the pelagic system on cessation of CO_2 entering the environment (Hennige *et al.* 2014, Phelps *et al.* 2015). Depending on the release rate or flux, such effects may be comparable to those from natural CO_2 seeps, or those which have been assessed in relation to wider ocean acidification. Set in the context of the wider anthropogenic emission of carbon dioxide to the atmosphere any such leak would be minor.

Socio-economic effects

All hydrocarbon spills have the potential to affect fish and shellfish populations by tainting caused by ingestion of hydrocarbon residues in the water column and on the sea bed. If large-scale releases of oil were to reach the sea bed, there is potential for smothering of habitats used by fish either as spawning, feeding or nursery grounds; unless these spills were in shallow water, and of a hydrocarbon type which is likely to sink (for many oils in the North Sea, the specific gravity is lower than seawater, with oil expected to remain on the water surface/penetrate the top few metres of the water column), the potential for spills to reach the seabed is relatively low. In addition to direct toxicity of oil and dispersants, oil and certain chemicals have the potential to introduce taint (defined as the ability of a substance to impart a foreign flavour or odour to the flesh of fish and shellfish following prolonged and regular discharges of tainting substances). Possible effects on human consumers of seafood are also an issue of concern in relation to accidental spills and industrial discharges.

Government may issue exclusion orders preventing marketing of seafood from areas considered to be contaminated following a spill or other incident, resulting in economic impacts on local fisheries and associated processing. Historical experience (e.g. the Braer spill) indicates that irrespective of actual contamination levels, spills may result in significant loss of public confidence in seafood quality from the perceived affected area, and therefore in sales revenue. Either perceived or actual contamination of target species with hydrocarbons or other chemicals may therefore result in economic damage to the fishing industry (and associated industries).

Impact on the recreational, tourism and amenity appeal in the event of a major oil spill would be influenced both by the severity of oiling and by the extent, duration and tone of media reporting and resulting public perception of the severity of the event. For example, following the Sea Empress spill, the local economic impact on tourism was relatively minor (SEEEC 1998). Analysis of the impact on tourism throughout Pembrokeshire suggested a downturn of about £2 million in the commercial service sector in 1996 set against an estimated £160 million contributed by tourists to the economy in 1995. Nevertheless, despite satisfaction with the quality of the environment by those visiting the area, there was evidence from further questionnaires that for one in five who actually considered visiting Pembrokeshire in 1996, the Sea Empress spill was significant in leading to rejection.

Major gas releases and chemical spills both have some potential for significant effects in terms of short-term safety issues and longer-term socio-economic effects. As noted above, chemicals used in offshore E&P are generally in low risk categories, and the socio-economic effects are generally similar in nature, but of lower severity, to oil spill. Potential safety issues of gas releases include explosion and (for subsea releases) loss of buoyancy for vessels and floating installation, although studies (e.g. May & Monaghan 2003, Beegle-Krause & Lynch 2005) suggest that the latter may not be a significant concern.

5.13.4 **Controls and mitigation**

Spill control and mitigation measures are implemented for offshore exploration and production inter alia through the *Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998 (as amended)* and the *Offshore Installations (Emergency Pollution Control) Regulations 2002*. The required measures include spill containment measures, risk assessment and contingency planning. Under the Regulations, all operators of an offshore installation or oil handling facility must have an OPEP in place. The plans are reviewed by BEIS, MCA and relevant environmental consultees, such as the Joint Nature Conservation Committee, the relevant country statutory nature conservation body, e.g. NatureScot, and other relevant organisations.

An OPEP will only be approved following consultation and satisfactory operator response to any comments. Approval of an OPEP does not constitute approval of the operations covered by the plan. Operators are responsible for ensuring compliance with all other regulatory requirements. OPEPs set out the arrangements for responding to incidents with the potential to cause marine pollution by oil, with a view to preventing such pollution and minimising its effect. Additional requirements can be imposed through block-specific licence conditions (i.e. “Essential Elements”). Operators are required to follow international and UK best practice when responding to oil spills (i.e. consistent with BEIS OPEP requirements) and the OPEP must identify appropriate strategies to facilitate a prompt and effective response to a pollution event, including details of how and when they would be employed. These details must include strategies specific to the location which may include:

- Monitoring and surveillance (from installation, vessel, aircraft, satellite)
- Dispersion (natural or chemically/mechanically assisted)
- Containment and recovery (booming and mechanical recovery)
- Source control (well capping and relief well operations)

In the event of a spill, the monitoring and surveillance response also includes undertaking real-time modelling, data from which is fed back into the response.

The vulnerability of seabirds to surface oiling is related to individual species' behavioural patterns, distribution and ecological characteristics, such as potential rate of population recovery and vulnerability varies considerably throughout the year. The Offshore Vulnerability Index (OVI) (JNCC 1999) was developed by JNCC and was used to assess the vulnerability of bird species to surface pollution. This index considered four factors: amount of time spent on the water; total biogeographical population; reliance on the marine environment; and potential rate of population recovery (Williams *et al*. 1994, see JNCC 1999). A revised index, the Seabird Oil Sensitivity Index (SOSI) was published by Webb *et al*. (2016).

The SOSI built on previous indices by Williams *et al*. (1994) and method refining by Certain *et al*. (2015) using seabird survey data collected from 1995-2015 from a variety of survey techniques (boat-based, visual aerial and digital video aerial). The survey data was combined with an individual seabird species sensitivity index value, based on a number of factors considered to contribute towards a species sensitivity to oil pollution such as habitat flexibility (a species ability to locate to alternative feeding sites), adult survival rate and potential annual productivity. The SOSI is presented as a series of monthly UKCS block gridded maps, with each block containing a score on a scale of low to extremely high; these scores indicate where the highest seabird sensitivities might lie, if there were to be a pollution incident.

The *Offshore Installations (Offshore Safety Directive) (Safety Case etc) Regulations 2015* (SCR 2015) aims to increase the protection of the marine environment against pollution, and requires major accident hazards, which may result in a major accident, to be identified and an assessment made of the potential for these to result in a Major Environmental Incident (MEI), including of their environmental consequence (BEIS 2020c).

To be classed as a MEI, the incident must have as a precursor, a safety related major accident which relates to petroleum activities carried out offshore. In its definition of MEI, the SCR 2015 describes this as an incident which results, or is likely to result, in a significant adverse effects on the environment in accordance with Directive 2004/35/EC. Within the Directive, there are different types of damage covered (BEIS 2017):

- Damage to protected species and natural habitats – which is damage that has a significant adverse effect on reaching or maintaining favourable conservation status for such species or habitats; the significance of such effects to be assessed with reference to the baseline condition, taking account of the criteria set out in Annex I of the Directive

- Water damage – which is any damage that significantly adversely affects the ecological, chemical and/or quality status and/or ecological potential as defined in Directive 2000/60/EC, or the environmental status of the marine waters concerned as defined in Directive 2008/56/EC
- Land damage – which is any land contaminated that creates a significant risk of human health being adversely affected

Here, "protected species and natural habitats" means species, habitats of species and natural habitats listed in Articles and Annexes of Directive 2009/147/EC (Bird Directive) and Directive 92/43/EEC (Habitats Directive)[291]; assessment for MEI therefore applies to all species or habitats protected in the UK under the *Conservation of Habitats and Species Regulations 2017* (as amended) and the *Conservation of Offshore Marine Habitats and Species Regulations 2017* (as amended). "Damage" is defined as a measurable adverse change in natural resource or measurable impairment of a natural resource service which may occur directly or indirectly and must be severe enough to have a significant adverse effect on reaching or maintaining favourable conservation status (as derived from the Habitats Directive).

The SCR 2015 requires that specified information regarding emergency response arrangements is provided, to be detailed in an Internal Emergency Response Plan (IERP); IERP is delivered, in part, by the OPEP. While the required content of OPEPs remains largely consistent with existing guidance, the *Merchant Shipping (Oil Pollution Preparedness, Response and Co-operation Convention) Regulations 1998* were amended in 2015 to implement those elements of the IERP relating to oil pollution response and also introduced the concept of the Responsible Person[292]. This requires that the Responsible Person must have an OPEP in accordance with the requirements of the amended regulations; the obligations under the OSD do not extend to internal waters, so the amendments to the 1998 Regulations are limited to an installation in the territorial sea or the continental shelf, to effect this distinction, installations in internal waters are now referred to as "oil handling facilities" and the operator of the oil handling facility, is also required to have an OPEP in place.

Offshore, primary responsibility for oil spill response therefore lies with the Responsible Person and their accredited third party pollution responders, although the Secretary of State's Representative may intervene if necessary. The MCA is responsible for a National Contingency Plan and maintains a contractual arrangement for provision of aerial spraying, with aircraft based at East Midlands and if necessary, Inverness. MCA holds counter-pollution equipment (booms, absorbents etc.) which can be mobilised within 2-12 hours depending on incident location, in addition to a stockpile of chemical dispersant.

The most recent OPEP guidance (September 2021) indicates that the potential for shoreline contamination must be determined for all installations using appropriate worst case oil spill modelling. Where modelling indicates the potential for oil to beach, the OPEP must confirm that appropriate response resources are capable of reaching prioritised locations in sufficient time to allow response measures to be implemented to minimise the impact of any oil pollution. In sensitive locations where the risk of shoreline impact is likely to occur before the arrival of

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[291] Note that the habitats and species listed in the Annexes of these Directives are not listed in UK legislation transposing the Directives, and their content remains relevant to the retained law which makes reference to these.
[292] The Responsible Person covers Installation Operator, Well Operator, owners of non-production installations (i.e. rigs) and operators of oil handling facilities include operators of pipelines and relevant oil handling facilities. See guidance: https://www.hse.gov.uk/osdr/assets/docs/opep-guidance-rev5-apr-2019.pdf

resources from existing Tier 2 or 3 stockpiles, consideration should be given to the establishment of dedicated pre-positioned resources.

A Shoreline Protection Plan (SPP) must also be developed for all installations (including pipelines) operating in Blocks wholly or partly within 40km of the coast. The OPEP arrangements for any installation (not pipelines) located within 40km of the coast should also confirm that:

- an appropriate dispersant[293] can be applied within 30 minutes of a pollution incident; and
- sufficient dispersant stocks are available to treat a minimum oil release of 25 tonnes,
- appropriate at sea and shoreline response resources can be available on scene within half the time taken for the oil to beach.

In addition to loss of well control, risk of oil and diesel loss resulting from collision is considered for drilling activities. A consent to locate a drilling rig is required in advance of drilling which is subject to consultation with relevant stakeholders (e.g. the General Lighthouse Authority, MCA, MoD). Such consent applications require to be supported by a vessel traffic survey and collision risk assessment (where relevant), and the consent requires the movement and location of the rig to be notified to other users of the sea (e.g. through notices to mariners). A statutory 500m safety zone is established around the rig when in the field, and a standby and/or guard vessel is also located next to the rig during drilling operations to ensure that vessels do not enter the safety zone, and to provide emergency response.

Activity specific management measures (e.g. implemented through the operator's accredited (and BEIS required) Safety and Environmental Management System) can reduce the potential for spills of oil and chemicals of all sizes through, for instance, identification of environmentally critical equipment, related maintenance schedules, training and good practice. During onshore emergency pollution control exercises, BEIS may request a list of personnel responsible for responding to oil pollution incidents and evidence of training. BEIS Environmental Inspectors may conduct an offshore inspection of the installation and gather evidence to prove compliance with exercise requirements, and check training records for offshore personnel to ensure compliance with training requirements.

The Offshore Pollution Liability Agreement (OPOL) is an oil and gas industry voluntary agreement, whereby operators take financial responsibility for any accidental release from E&A operations and provide reimbursement for remedial measures undertaken; all oil and gas operators in the UKCS are party to this agreement and OPOL is applied when an operator is unable to service their pollution liability. The OPOL Agreement provides for each operator to provide an orderly means for compensating and reimbursing any person who sustains pollution damage and incurs costs for taking remedial measures (clean-up) as the result of a discharge of oil from any offshore installation. OPOL requires every operator to provide satisfactory evidence of its ability to meet any liability under the Agreement. OPOL provides for the mutual

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293 Chemical dispersant use is generally inappropriate in shallow sheltered waters, in water depths of less than 20 metres and in waters extending up to 1.15 miles (equivalent to 1 nautical mile) beyond the 20 metre contour, or on refined oil products such as diesel, gasoline or kerosene which should disperse naturally prior to reaching the coast or any sensitive environments. The use of chemical dispersants will, therefore, be dependent upon several factors including the quantity of oil, oil type, sea temperature, time of year, prevailing weather and environmental sensitivities. There are strict controls on the use of dispersants, with only those on an approved list (https://www.gov.uk/government/publications/approved-oil-spill-treatment-products) permitted for use. All oil spill treatment products are tested for their efficacy (effectiveness) and for toxicological hazard.

agreement from all of its members for the settlement of claims up to US$ 250 million per incident, in the event of a default by an operator.

There is no financial cap on the liability of oil and gas companies for the consequences of an incident for which they are legally liable . BEIS initially put financial systems in place following the Macondo incident these replaced by the financial liability provisions within *The Offshore Petroleum Licensing (Offshore Safety Directive) Regulations 2015* ("the OPL Regulations 2015"). In agreement with BEIS, Oil and Gas UK (now Offshore Energies UK), developed guidance regarding financial liability and these confirm that liability provisions must be declared to cover multiple elements (e.g. platform production/development wells, offshore installations, including FPSOs, the drilling of E&A wells, and decommissioning operations). In addition, in response to the Oil Spill Prevention and Response Advisory Group (OSPRAG) recommending the establishment of a new oil spill forum under the governance of the OGUK, the Oil Spill Response Forum was set up which in 2019 became the OSR Technical Working Group.

5.13.5 Likelihood of significant effects

In view of the maturity of the UKCS basins and fields, the recent trajectory of oil and gas exploration and production, and the nature of many new developments given extensive fixed infrastructure in place (e.g. subsea tiebacks), any increase in shipping activity (e.g. supply vessels, vessels for maintenance and tankers), is considered to be minor, and would be subject to vessel traffic survey and collision risk assessment both at the exploration and any subsequent development phases, and is not considered likely to lead to a significant effect.

The incremental risk associated with activities resulting from the proposed licensing (i.e. additional to existing risk, primarily associated with shipping and other maritime activities) is low. This reflects the combination of low probability and low severity (since most spills would be small in volume). The overall risks of a major crude oil spill, which would require a catastrophic loss of well control, are quantitatively and qualitatively comparable to those considered ALARP (As Low As Reasonably Practicable) under the relevant UK health and safety regulations.

The potential for accidental spills to have transboundary impacts is recognised in project-level oil spill modelling which includes assessment of travel times to cross boundaries as well as the likelihood of beaching on different countries. The review of oil spill modelling undertaken for the assessment indicates that potential transboundary impacts were identified for large oil spills in Regional Sea 1 (Norway), Regional Sea 6 (Republic of Ireland, Isle of Man), and in Regional Seas 8 and 9 (Norway, Faroes). The prospectivity of much of Regional Sea 2 (natural gas, also present in the eastern Irish Sea) precludes transboundary impacts as significant oil spill is not likely.

5.13.6 Summary of findings and recommendations

The environmental risks of accidental spill events associated with proposed activities following further rounds of oil & gas licensing are qualitatively similar to those of previous and ongoing activities in the North Sea, Irish Sea and west of Shetland, and mitigation in the form of risk assessment and contingency arrangements is well established. Offshore wind farm developments (and wave and tidal stream developments) are not considered to represent a significant source of accidental spills where navigational safety risks have been fully considered in the planning and siting of such developments.

E&P project-specific risk is associated with reservoir fluid type (e.g. heavy oil compared with condensate or gas), distance from sensitive coastal habitats and locations, and prevailing winds and currents. The areas of enhanced risk are therefore west of Shetland (Regional Sea 8) and to a lesser extent the northern North Sea (Regional Sea 1). Project-specific risk of major incidents in Regional Seas 2, 3, 4 and 6 are moderated by prospective fluid type (primarily condensate or gas) although oil is also present in the Eastern Irish Sea and the Eastern English Channel.

Subsea drilling equipment has evolved over the years into reliable systems with multiple redundancy. The subsea drilling pressure control system comprises several inter-related components including the wellhead assembly, BOP stack, choke & kill line system and riser. There have been very few drilling incidents resulting in loss of well control, and historic improvements in spill prevention and mitigation have stabilised the volume of oil spilled from E&P operations on the UKCS at a relatively low level, primarily through identification of root causes of spills and improvements in operational control procedures. The causes of the Deepwater Horizon blowout have been identified and a combination of technical, operational and regulatory measures have been put in place to effectively control the risk of a similar event in UKCS operations. These have been implemented through initiatives by HSE, BEIS, OSPRAG and individual operators and further strengthened by the introduction of the Offshore Safety Directive and the transposition of this into UK Regulation.

Effective National Contingency Planning, and adequate response resources at a national level, including Emergency Towing Vessels (ETVs), are considered to be important mitigation measures.

In some cases, there is strong seasonality in specific species' sensitivities, in particular in relation to (breeding and wintering) bird populations, moulting birds and breeding/moulting seals. Existing regulatory controls emphasise the risk management and contingency planning aspects of environmental management, including the timing of operations; and additional controls at an SEA level are not considered to be necessary.

Oil spill response planning and capability, by the MCA, the oil industry and relevant authorities is generally consistent and as effective as practicable. It is clear that prevailing weather conditions will rarely facilitate offshore containment and recovery of surface oil (also that the emphasis should be on prevention rather than cure).

Operational risks, principally of large-scale CO_2 risk from transportation or offshore injection facilities are broadly similar to those associated with gas production and relevant experience and effective control will be possible under existing regulatory systems. The environmental consequences of large CO_2 releases are not considered likely to be severe (i.e. comparable with a large hydrocarbon release), although further consideration is needed of the potential consequences of loss of containment from storage reservoirs over long timescales.

5.14 Ancillary development

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport	Assessment Section
Other interactions with shipping, military, potential other marine renewables and other human uses of the offshore environment	X	X	X	X	X	X	X	X	5.7, 5.15
Potential effects of development on seascape including change to character (interactions between people (and their activities) and places (and the natural and cultural processes that shape them))	X	X	X	X	X	X	X	X	5.8
Physical damage to/loss of biotopes from infrastructure construction including seabed preparation, operation and maintenance, and decommissioning (direct effects on the physical environment)	X	X	X	X	X	X	X	X	5.4
Physical effects of anchoring and infrastructure construction (including pipelines and cables), operation and maintenance, and decommissioning on seabed sediments and geomorphological features (including scour)	X	X	X	X	X	X	X	X	5.4
Local air quality effects resulting from vessel and power generation exhaust emissions, flaring and venting	X	X	X	X	X	X	X	X	5.11
Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc. and impacts on the setting of coastal historic environmental assets and loss of access.	X	X	X	X	X	X	X	X	5.4

5.14.1 Introduction

The issue of ancillary development and related potential environmental effects is an important strategic consideration, this section focuses on works that could arise from further offshore energy development, as specified in the draft plan/programme, but which are not elements of the draft plan/programme themselves. For example, it notes potential offshore grid development which could arise, in particular, from the expansion of offshore wind. Note that the onshore distribution of electricity, natural gas, including imported gas and onshore transportation of carbon dioxide, is not part of this plan/programme.

The sources of potentially significant effect identified in the table above are those which may be relevant to ancillary developments. Given that ancillary developments are not covered directly by the draft plan/programme but are linked closely to the implementation of some aspects of it, these ancillary development effects are considered to be secondary in nature. Therefore, the relevant assessment section in the table above (right hand column) identifies where each of the potentially significant effects are more fully considered. Below is a description of those components from new oil and gas, gas storage (including carbon dioxide) and renewable developments, including offshore hydrogen production, that could lead to potentially significant effects.

5.14.2 Sources of potentially significant effect

5.14.2.1 Oil and gas, gas and carbon dioxide storage

The majority of oil production from the UKCS is transported to shore by pipeline with the remainder exported by tanker. Gas is transported to shore by pipeline or liquefied natural gas (LNG) may be imported by carrier (e.g. tanker). Similarly, to date, pipelines have been used for offshore gas storage operations, or have been proposed as the means to transfer carbon dioxide from point sources onshore to offshore injection infrastructure and storage sites, though tanker transport is considered possible. For offshore hydrogen production, either pipeline transport or tanker transport are considered possible options.

There is a well-developed hydrocarbon export pipeline infrastructure on the UKCS, and measures in place to allow for third party access where practicable, and production from small new developments can be expected to access these existing facilities, and in many cases, such new development would be entirely subsea in nature. The development of very large new reserves could justify the installation of new pipelines and terrestrial reception facilities, however, this is considered less likely compared to the use of existing host facilities and their export infrastructure for new developments. Tanker offloading requires both oil storage and offloading facilities. New pipelines with onshore components, new processing facilities and development of quayside facilities, could potentially have significant effects on the receiving environments, through the construction, operation and decommission phases. Pipeline landfall for carbon dioxide storage and hydrogen transport would involve analogous techniques of installation to oil and gas pipelines, and may require onshore facilities should pressure enhancement prior to export offshore be required for carbon dioxide, or for pipeline inspection gauge (PIG) facilities.

5.14.2.2 Grid system

The main components of the transmission system are substations (connection and/or bussing points) and the overhead lines or underground cables that connect them. Transformers are used to change the generated power between different voltages used on the system. A number of new cables from offshore wind farms are expected to utilise direct current (DC) technology due to their distance from shore, which will require converter stations to interface with the onshore alternating current (AC) system.

At the onshore interface (between the offshore and onshore transmission systems), land will be required for the underground cable termination, transformers and reactive compensation equipment. These will include buildings for control and communication and access roads within a fenced area. Where offshore wind farms are located at a significant distance from the coast, DC connections are likely to be required. It is expected that Voltage Source Converter (VSC) technology is most economically suited to offshore High Voltage Direct Current (HVDC) connections. The indicative land area needed for a HVDC converter station is more than for an AC connection, with a single 1GW installation occupying some 210m x 70m, with the converters housed in buildings approximately 20m high. Given the scale of current wind farm proposals and those likely to arise in the future, 2 or 3 of these converters may be required.

Where an offshore submarine cable from a wind farm arrives onshore there is a need for a transition joint bay where it is joined to the onshore underground cables. There are usually three cables for an AC connection and two for DC. Along the onshore cable routes, cable joint bays will be needed at intervals relative to cable section lengths, and may be in the order of 800-1,000m; these are wider than the normal cable trench. For more than one connection from a wind farm, or where multiple wind farms will connect to the same substation, separate routes will be necessary for each connection.

To connect offshore wind generation to the onshore transmission system, upgraded or new overhead power lines may be required to accommodate the changes in power flows, especially across congested areas. Towers used to carry the power lines vary in height (e.g. 46.5m to 49m) and width (e.g. 7m to 14.5m) depending upon whether they are a suspension, deviation or terminal tower. The size, height and spacing of the towers are also determined by the type of conductor required, safety, route topography and environmental considerations.

The potential environmental effects of reinforcing the onshore grid transmission system to accommodate new offshore connections are related to the main components of the grid, which are: the substations and related equipment, buried land cables and overhead power lines.

5.14.2.3 Ports and manufacturing facilities

The expected changes to port facilities and the increase in number of ports required for offshore marine energy manufacturing, construction and installation could have some environmental impacts; such developments are being promoted by the Government through funding of up to £160 million[294]. These could include acquiring land (loss of possible habitat and reclamation), noise impacts, changes in sediment regime through dredging, increased road and marine traffic, waste discharges and the construction of coastal defences to protect the ports and surrounding vulnerable areas (OSPAR 2010). How such effects are considered in planning applications is outlined in the national policy statement for ports[295].

5.14.3 Consideration of the evidence

5.14.3.1 Oil and gas, gas and carbon dioxide storage

Given the scale of present hydrocarbon activity and location of existing oil and gas terminals, major additional shore-based infrastructure is not anticipated as a result of future offshore oil and gas licensing; it is envisaged that maximum use would be made by reusing/adapting existing infrastructure.

Natural gas and carbon dioxide storage projects may use existing infrastructure in terms of existing offshore platforms and onshore power stations; however, some new development will be required, along with modifications to existing facilities necessary. For many projects involving the transport of gas or carbon dioxide from onshore facilities to subsea geological storage sites, new pipelines, with onshore sections, will be required. This is particularly true of carbon dioxide transport and storage, with a low proportion of existing pipelines being suitable to transport supercritical phase carbon dioxide[296]. Additional onshore works may involve the construction of compressor booster stations for gas transport. Similarly, offshore hydrogen production will likely require new pipelines, landfalls, and onshore infrastructure, including for offloading if by ship.

5.14.3.2 Grid system

To date, offshore wind grid farms have used radial connections. These are point-to-point connections between an individual wind farm project and its connection with the grid, with no

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[294] https://www.gov.uk/government/news/scotland-and-wales-could-be-home-to-new-floating-offshore-wind-ports-thanks-to-160m-uk-government-funding
[295] https://www.gov.uk/government/publications/national-policy-statement-for-ports
[296] https://www.gov.uk/government/consultations/carbon-capture-usage-and-storage-ccus-projects-re-use-of-oil-and-gas-assets

coordination between wind farm operators, for example, to minimise infrastructure and the number of landfalls. While useful during early wind farm development, the scale of current and future deployment related to UK Government targets, makes continuing with radial connections a potential consenting barrier. In order to address this potential barrier, the Offshore Transmission Network Review (OTNR) was launched in 2020 and is led by BEIS with support from a number of other UK Government departments, devolved administrations, The Crown Estate and Crown Estate Scotland, the ESO and Ofgem[297]. The OTNR has two workstreams, one of which is identify and implement changes which can be made in the immediate term focussing on projects due to connect after 2025 (Early Opportunities)[298], and the second is design and implement a new regime that incentivises coordination, including considering the role of multipurpose interconnectors[299] with a focus on projects to be delivered after 2030 (Enduring Regime). The final outputs of the review are expected in 2023.

A “generation map” was produced as part of the OTNR process showing the location of existing and planned offshore wind farms and the expected timing of their connection[300], (also see Figure 2.6, and Appendix 1h: Figure A1h.16, A1h.20). This is complemented by a separately commissioned East Coast Grid Study (AECOM 2021), which had the objectives of establishing key spatial constraints to future grid connections in the east of England, their related risks, and whether adopting one or more coordinated approaches could mitigate these risks. Conservation sites already subject to multiple cable crossings, the availability of suitable landfalls, and the distance to grid connection points were all highlighted as potential constraints. The study did not discount the potential for future radial connections, but noted that landfalls in particular were a pinch point that made long-term use of this connection method a risk. The study noted that a coordinated approach should result in less infrastructure and less potential for spatial conflict, however, the difference in scale of coordination (e.g. number of cables in a single cable route) were highlighted as something that stakeholders should be made aware of.

As part of the recent Energy Ten Year Statement (ETYS) under key message 2 (National Grid ESO 2021), a number of growing needs the National Electricity Transmission System (NETS) will face in the next ten years were identified relevant to renewables developments in the following areas:

i. A tripling of wind generation connected across the Scottish networks by 2030 driving higher north to south power transfers.

ii. A doubling at least of transfer requirements from northern Scotland to the Midlands over the next 10 years. New reinforcements will be required to facilitate these power flows through the North of England.

iii. Up to a 12GW increase in transmission connected low carbon and renewable generation in East Anglia from 2020 to 2030 is expected. Future offshore wind connecting along the east coast and new interconnectors in the region are expected to increase the transfer requirements including during low wind periods.

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297 https://www.gov.uk/government/groups/offshore-transmission-network-review
298 https://www.ofgem.gov.uk/publications/consultation-changes-intended-bring-about-greater-coordination-development-offshore-energy-networks
299 https://www.gov.uk/government/consultations/offshore-transmission-network-review-proposals-for-an-enduring-regime
300 https://www.gov.uk/government/publications/offshore-transmission-network-review-generation-map

5.14.3.3 Ports and manufacturing facilities

Offshore wind generation capacities of the scale targeted by 2030 and beyond will require development of port facilities. A number of ports around the UK have the potential to assist project construction, but lack suitable facilities for services such as turbine assembly and manufacture of towers, blades, key nacelle components and foundations.

Several reports have previously been commissioned considering the requirements for port infrastructure and opportunities based on current and potential UK port capabilities, for example DECC (2009b), BVG (2014) and ARUP (2020). ARUP (2020) reviewed opportunities for Scottish ports in relation to the potential buildout of offshore wind in Scottish waters (not a consideration of this plan/programme), including floating wind farms, and concluded that while there is a risk that existing port capacity will be insufficient to support targets towards reaching net zero, that there are multiple suitable locations likely suitable for use as both construction phase ports and for operation and maintenance.

Typical requirements for a construction port include: a heavy lift capacity; large lay-down and storage areas to enable assembly of components and rapid deployment of devices for larger scale developments; suitable space adjacent to quayside for final assembly; dry and potentially wet commissioning of electrical parts and supply of support vessels and personnel.

In terms of infrastructure requirements for wave and tidal installations which are still evolving, The Crown Estate commissioned a report on the ‘Build Out’ of the Pentland Firth and Orkney Waters leasing programme, in partnership with Scottish Government, Highland and Islands Enterprise and Local Authorities (The Crown Estate 2011). The plan acknowledged that the delivery of the Pentland Firth and Orkney Waters commercial scale leasing programme from 2016 will require development of port infrastructure proposals alongside development of the technology and deployment techniques (Scottish Enterprise and Highlands and Islands Enterprise 2010). No such assessment has been undertaken for ports in England and Wales, however, it is understood that similar to offshore wind, and in view of the expected scale of expansion in the latter, additional port capacity may also be required to support other renewable technologies in the future.

5.14.4 Controls and mitigation

The UK has a long history of experience in subsea cable and pipeline installation, for which an extensive set of regulatory and planning controls exist, including for environmental aspects such as through EIA.

There is also a growing body of experience and knowledge associated with offshore wind farms, their planning and execution and the assessment of their potential impacts, and these too have a regulatory and consenting process with several stages, including pre-planning (this includes survey work, impact assessment and stakeholder engagement), through to consenting with associated conditions, including monitoring requirements through the construction and post-construction phases.

Most offshore renewables developments are of a size covered by the *Planning Act 2008* and therefore fall within the Nationally Significant Infrastructure planning process. For renewables developments this covers all aspects of the development, including both onshore and offshore elements (see Appendix 3). Onshore “gas transporter” pipelines above a threshold (more than 800 millimetres in diameter and more than 40 kilometres in length) are similarly covered by this process, and while the offshore aspects of gas storage (including CCS) are outside of the *Planning Act* remit, offshore elements may be considered as part of the process to understand the potential combined effects projects as a whole. Offshore aspects are also separately covered under the *Offshore Oil and Gas Exploration, Production, Unloading and Storage (Environmental Impact Assessment) Regulations 2020*. The legislative and planning remit of hydrogen transport and storage offshore is not currently clear, however, onshore aspects including transport are likely to be similar to that for other gas transporter pipeline projects.

5.14.5 Likelihood of significant effects

In general, major additional shore-based infrastructure development for the oil and gas industry is not expected, and is difficult to anticipate as large new discoveries are dependent on successful exploratory activities. The likelihood of significant effects from this are not discussed further here, with impacts of any development that does progress identified and assessed at the EIA level.

During construction and operation, each component of the transmission system will have an impact to varying degrees on several different aspects of the environment. These impacts may include but are not limited to:

- visual intrusion in the landscape, especially from substation and overhead power lines and towers which may cause visual obstructions and changes to the skyline
- loss, damage or disturbance to habitats and species (which may be protected) and
- loss or damage to historical and archaeological features through excavation and construction works, and by altering the visual setting of certain features
- changes to current land-use and hydrology by taking extra land for building works (substations) and infrastructure (towers) and by altering run-off patterns and possibly introducing pollutants during construction

Ancillary grid reinforcements resulting from wet renewables development is expected to be on a much smaller scale than those associated with offshore wind. However, wave and tidal developments may be located off relatively remote sections of coastline where, at landfall, additional transmission infrastructure may be required to provide connections into the grid. Tidal range devices have the potential to have significant generation capacity and therefore additional substation capacity may be required to accommodate any such developments, the locations for which are necessarily limited by the available resource.

The expected changes to port facilities will also have some environmental impacts, again through the construction and operational phases. The extent and magnitude of these impacts will be dependent upon the scale of the development taking place and their proximity to areas that have been designated for their ecological, cultural and landscape value. Some of the impacts such as the building of new infrastructure will introduce permanent changes to the environment whereas others that occur during construction phases will allow for full or partial recovery of the environment after reinstatement.

The approach of radial wind farm connections is presently subject to review, and includes both short-term and longer-term goals for consented and in-planning projects and future projects respectively, in order to coordinate the offshore grid to minimise impacts of transmission offshore and onshore. Proposals as part of revisions to the National Policy Statements for energy[301] make reference to the OTNR, and also the need to consider net gain as part of proposals for onshore aspects of renewables projects, including from grid connections.

Despite the range of potential effects described above, the impacts of such activities in the terrestrial environment are generally well understood and their assessment and management are supported by a strong evidence base. Consequently, existing planning procedures and regulatory controls, including project-specific EIA, are considered appropriate for managing any potentially significant effects.

5.14.5.1 Cumulative impact considerations

Grid reinforcement will impact incrementally to existing electricity transmission networks, with noise, habitat loss/modification, landscape impacts and interactions with other users among the key issues, though note the recent change in approach to net gain for onshore aspects of projects. Almost all other forms of terrestrial land use and development have the potential to act cumulatively with grid reinforcements in respect of these key issues.

The majority of port development that may arise in the coming years will likely be extensions of the capabilities of existing facilities and impacts from these activities can therefore be described as incremental to existing/past impacts. There may also be cumulative impacts in terms of association with other coastal activities such as shipping traffic and adjacent construction (e.g. coastal defences). Other users of the marine environment are likely to be major considerations in the assessment of cumulative effects, as is the presence of adjacent conservation designations and existing pressures on such features (e.g. coastal squeeze).

While considered less likely than for other aspects of the draft plan/programme, there is the potential for further oil and gas pipelines to come ashore related to future developments, and this is also likely for any future carbon dioxide transport or hydrogen transport projects, and these could act cumulatively with other aspects of the draft plan/programme.

5.14.6 Summary of findings and recommendations

Major additional shore-based infrastructure is not anticipated as a result of future offshore oil and gas licensing; it is envisaged that maximum use would be made by reusing/adapting existing infrastructure.

Some new onshore development will be required for natural gas and carbon dioxide storage projects, and possibly offshore hydrogen production and transport, namely modifications to existing facilities, new pipelines, and potentially the construction of compressor booster stations for gas transport. From a strategic perspective, this will be of relatively small scale and likely limited to a very small number of projects, all of which will be subject to planning procedures and regulatory controls, including project specific EIA and Habitats Regulation Assessment (where appropriate).

Ancillary onshore development will be necessary to facilitate, primarily, the achievement of the offshore wind element of the draft plan/programme, with reinforcements to the national electricity transmission system continuing and enhancements to the capacity of the UK's port facilities required. The influence of the likely wave and tidal development on port and manufacturing facilities development will be comparable in nature, but considerably smaller in scale than that associated with offshore wind. These will have some environmental impacts,

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[301] https://www.gov.uk/government/consultations/planning-for-new-energy-infrastructure-review-of-energy-national-policy-statements

with possible habitat loss/modification, noise, landscape impacts and interactions with other users among the key issues to be considered.

Both the onshore grid reinforcements and enhancement of port facilities associated with further leasing remain uncertain in terms of scale and location; in this respect, there are no specific plans, programmes or projects which are sufficiently developed to be fully assessed. These potential developments and their associated environmental effects are secondary effects to the draft plan/programme currently under assessment, and relevant projects will be subject to EIA. The existing planning and regulatory framework, will contribute towards appropriate management of any potentially significant effects.

While it is acknowledged there may be cumulative impacts from the development of any associated ancillary infrastructure (e.g. noise, habitat loss or modification and interactions with other users) from existing activities, the extent and magnitude of these will depend on various factors, including landfall location. These are expected to be fully assessed as part of that consenting process and mitigated at the project stage. In terms of transboundary effects, any ancillary infrastructure associated with future developments in the UKCS, will likely be onshore, or in UK waters, some distance from median lines and other national waters. As such, transboundary effects from UK projects are not likely unless the projects are transboundary in nature, e.g. for export across median lines.

5.15 Overall spatial consideration

Potentially significant effect	Oil & Gas	Gas Storage	CO_2 transport/ storage	Offshore Wind	Tidal Stream	Tidal Range	Wave	H_2 production/ transport
Other interactions with shipping, military, potential other marine renewables and other human uses of the offshore environment	X	X	X	X	X	X	X	X

5.15.1 Introduction

There are multiple activities on much of the UKCS which have, or potentially have, overlapping resource areas and a low capacity for co-location with activities associated with the draft plan/programme. This includes inter-plan co-location issues such as between oil and gas and carbon dioxide storage installations and offshore wind. The *Marine and Coastal Access Act 2009* was intended to simplify and strengthen strategic management of the marine environment by enabling economic, social and environmental impacts and objectives to be considered simultaneously. A key objective of the Act was to implement a nationwide system of marine planning that will direct decision-makers and users towards more efficient, sustainable use and protection of marine resources. The Marine Policy Statement (MPS) was jointly adopted in March 2011 by the UK Government, Scottish Government, Welsh Government and the Northern Ireland Executive and applies to all UK waters and provides an overarching framework within which regional marine plans have been drafted. The Act established the Marine Management Organisation (MMO) with responsibility for marine plan development covering English territorial and offshore waters on behalf of the UK Government, with the respective devolved administrations responsible for plans of Wales, Scotland and Northern Ireland.

Marine planning has a key role in informing strategic and project level spatial considerations, as indicated in the MPS, "*Marine Plans should reflect and address, so far as possible, the range of activities occurring in, and placing demands on, the plan area. The Marine Plan should identify areas of constraint and locations where a range of activities may be accommodated. This will reduce real and potential conflict, maximise compatibility between marine activities and encourage co-existence of multiple uses.*[302]" The marine plans for English waters and those of the devolved administrations contain a number of policies which relate to the potential for spatial conflict and/or the potential for activity co-location, including for areas of defined resource for particular activities so as not to risk precluding future use, unless the need for a particular activity can be justified. Whilst the marine plans acknowledge the potential interactions between activities through policy wording which is largely analogous across all marine plan areas, and map relevant activities at a marine plan level, they lack spatial specificity and do not seek to determine areas of relative higher or lower constraint for any sector. Additionally, while "futures" work was undertaken to develop scenarios for how activities in certain marine plan areas may develop over the lifespan of the plans, they were similarly not particularly spatially explicit and provide a limited indication of the location, nature and scale of possible future development. The exception is proposals in the Welsh marine plans to designate strategic resource areas for tidal stream through a Marine Planning Notice, though no such notice has

[302] MPS paragraph 2.3.1.5.

been made to date. It is acknowledged that this is a challenging area, for example, certain offshore industries are prospective and any projections on future use are likely to be highly conjectural, and the marine plan policies are at too high a level to offer significantly more than consolidation of existing consenting considerations undertaken by a variety of Government organisations with a marine function; there is the potential that future generations of regional marine plans will have sufficient information to be more spatially explicit.

A number of exercises have been undertaken by consenting or leasing authorities to progress a strategic understanding of the potential offshore energy resource, and in particular for offshore wind. This includes work undertaken in Scotland for the Sectoral Offshore Wind Plan and by The Crown Estate for Round 4. While the former led to a more definitive set of potential areas within which projects could be developed, both studies offered insights to assist project bidders in identifying potentially viable sites. In order to extend the consideration of potential development constraints for fixed and floating offshore wind and other renewables across the relevant waters of the UKCS covered by the draft plan/programme, spatial analysis has been undertaken. This analysis builds on former exercises undertaken as part of the offshore energy SEA process (DECC 2009, AEA & Hartley Anderson 2010, DECC 2011, 2016), and has also considered various other constraints analyses including those mentioned for recent leasing rounds, and also, though not limited to peer-reviewed analyses including Jongbloed *et al.* (2014) and Cavazzi & Dutton (2016), Bosch *et al.* (2018) and Gusatu *et al.* (2020).

5.15.2 Sources of potentially significant effect

The potentially significant effects of interactions of activities covered by the draft plan with other users are discussed in greater detail in Section 5.7. The following section provides a high-level consideration of potential interactions and constraints to the deployment of renewable energy mainly presented by other legitimate users/uses of the sea, as a basis for the spatial analysis.

5.15.2.1 Background

The footprint of offshore wind farms is extensive and the total area occupied by a development may be very large (e.g. recent developments have been between ~150 and 700km^2), but not intensive, in that individual turbines are usually separated by large distances (>1,000m in some cases); and can be non-exclusive, in that a variety of other marine activities may be possible within the boundaries of an operational development. The SEA has used data from developments primarily associated with Round 3 on turbine spacing (and therefore installed capacity and density) to inform the analysis in this section. It is noted that the capacities of wind turbine generators is expected to reach up to 20MW by 2030, and perhaps >25MW by 2040 (Everoze 2020). While this is unlikely to change the capacity of wind farms, the number of turbines which may be used to achieve a desired wind farm capacity is likely to decline in the coming years with a resulting reduction in turbine density. The height of wind turbines has also increased substantially since the first offshore wind farms, to an expected 280m for the latest available units. Wind farms, therefore, have a potentially large footprint and strong vertical component through the water column and in the air, meaning there is significant potential for interaction with other users and the environment.

Offshore wind deployment has expanded substantially in recent years (see Section 2.5), and the 40GW target set by the UK Government for 2030 will increase competition for space on the UKCS, particularly as the remaining capacity to meet that target is likely to come from fixed offshore wind farms. It should also be noted that the 2030 target in an interim one, and to reach net zero deployment at a rate of approximately 3 to 4 GW/year will need to continue to 2050.

For example, CCC (2020c) estimate an installed capacity requirement in the region of 95GW[303] to achieve net zero. Additionally, repowering of wind farms or losses from complete wind farm decommissioning also need to be accounted for. Assuming an average 30 year lifespan for a development would mean that, depending on the eventual mix of technologies used to reach net zero by 2050, all of the capacity presently operating and those wind farms being installed at present are likely to need repowering by 2050; this amounts to a UK wide total of approximately between 16.5GW and 22GW.

The deployment and configuration of wave and tidal devices will be governed by the physical environment in which they are placed; further, wave devices will, on the whole, impact the sea surface (although tethering to the seabed is required), whereas tidal current devices will mostly affect the seabed and water column (dependent upon water depth, see NOREL 2014). Tidal range devices are likely to be shore connected in the form of lagoons or barrages, and will impact both the water column and surface. They have the potential to affect large areas (e.g. entire estuaries behind barrages, with additional far field effects) and to potentially exclude some activities. While wave and tidal devices have the potential to contribute to renewable energy generation, the technologies have not progressed at the same pace as offshore wind, and deployments to date have been restricted to demonstration or small scale commercial proposals. Recognising that the key resource areas for tidal stream in English and Welsh waters are highly restricted, marine plan policies have sought to safeguard these from other activities which could preclude future development of tidal stream energy (note for Wales, Strategic Resource Areas for tidal stream are to be identified through a Marine Planning Notice).

Safety zones may be imposed in some circumstances around renewables devices. These are typically for installation, operational maintenance and decommissioning and have a radius of 500m, with safety zones of 50m more typical for a partially constructed of pre-commissioning turbine. Operational safety zones of 50m are allowed for in Regulations, but these are rarely applied. The use of safety zones for wave and tidal developments may differ from wind farms as they are likely to be less visible and be partly mobile at or under the water surface, which may affect their navigability. In the case of tidal range devices, safety zones may be used around sluice and turbine housings, for example a 500m zone was proposed for the turbine area of the Swansea Bay tidal lagoon.

In addition to the renewables devices in each array area, cables will be required to interconnect each device and then to export the electricity produced. To date, export has been achieved on a project by project basis, with point to point connections between each array and a landfall at the coast where an onshore grid connection is made. With increasing renewables capacity on the UKCS, this type of connection may not be very efficient and place increasing pressure from multiple landfalls and associated infrastructure at the coast and onshore. In response to these increasing pressures, and following a recommendation from the Climate Change Committee to coordinate interconnectors and offshore wind, BEIS and Ofgem launched the Offshore Transmission Network Review (OTNR)[304]. The review seeks to consider the existing regime and what changes can be made in the medium and long-term, to facilitate coordination, and create an enduring post-2030 regime which incentivises coordination while minimising environmental, social and economic costs. A key aspect being investigated is the role of multi-purpose interconnectors, which could facilitate the connection of multiple offshore wind farms offshore, delivering electricity export both to the domestic market and to other countries served

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303 Based on the Balanced Pathway to Net Zero as set out in the CCC (2020b) Sixth Carbon Budget report. The maximum installed capacity by 2050 noted in CCC (2020c) was in their Widespread Innovation exploratory scenario, which is 140GW.
304 https://www.gov.uk/government/groups/offshore-transmission-network-review

by the interconnector. The OTNR envisages pilot projects in the period up to 2030 so significant levels of coordination may not be expected for the current set of projects in the pre-planning stage (e.g. Round 4 and ScotWind leasing). There is presently too much spatial uncertainty in the likely export routes and landfalls for such projects, and these will not be considered in the following spatial analysis. While not defining particular radial routes from future offshore wind farms, The East Coast Grid Spatial Study undertaken as part of the Offshore Wind Evidence and Change programme (OWEC)[305] provides some indication of the constraints on these connections for the east coast of England.

The physical footprint of any new oil and gas development is likely to be very small and isolated, and the interactions with other users from such developments are generally well understood. The physical size of oil and gas infrastructure does not reflect the scale of potential exclusion of other activities. For example, 500m statutory safety zones are made around temporary and permanent floating and fixed structures and may be applied for around subsea developments, and there is a need to maintain safe helicopter approaches. These restrictions increases the potential for exclusion for certain other activities, albeit typically at a relatively small scale (see Section 5.7). In general, there has been a decline in exploration activity in recent years (see Section 2.5), and the rate of field decommissioning is increasing across the mature basins of the UKCS. While field redevelopment and development of new discoveries (including in previously underexplored areas) cannot be ruled out, it is highly likely that the number of installations across the UKCS will decline in the coming decades, which has the potential to free up space for other activities to take place.

5.15.2.2 Summary of key spatial issues

The following key spatial issues have been identified in the context of offshore energy developments (for additional background information, see Appendix 1h):

Navigation (including recreational users) (Section 5.7, Appendix 1h): maintenance of free and unconstrained navigation routes is vital to the UK as an island nation, and is a requirement for both territorial waters and the EEZ under the terms of United Nations Convention on the Law of the Sea. The strategic importance of shipping is recognised in the MPS, and is considered at a regional level through the marine plans. While many shipping routes may not be formally recognised, safety in some areas is maintained through IMO routeing measures such as traffic separation schemes or deep water routes. Key issues include the minimisation of any increase to the risk of allision/collision and on vessel passage time through route deviation, and the maintenance of safe under-keel clearance, anchorage areas and the interaction with harbour administrative and pilotage areas.

Fishing activities (including their cultural and economic values) (Section 5.7, Appendix 1h): these are variable in space and time. While the vast majority of UK waters are fished to some extent, fishing effort is often focussed in specific areas of prime importance to the industry. Vessel Management System (VMS) data, and also AIS data, has substantially improved understanding of the spatial and temporal distribution of larger fishing vessels (originally >15m and since 2012, >12m); however, the distribution of smaller vessels (which dominate the UK fleet by numbers) is less well understood. Detailed information on smaller vessels is held by Inshore Fisheries and Conservation Authorities (IFCAs) and equivalent bodies, although this is restricted to nearshore waters (typically to 6nm offshore), and is not available in a consistent spatial format. Fishing grounds exploited by smaller vessels with a limited home range and/or of prime importance to a local community may be of particular sensitivity to spatial conflict; such areas may exhibit apparently low effort and value relative to

[305] https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/energy/offshore-wind-a-sustainable-future/

the UK as a whole. It is recognised that as the UK's system of formal marine spatial planning evolves, there is a need to better understand fishing practices, particularly in inshore areas where information continues to be lacking. The MMO has worked with the IFCAs to develop a low cost inshore VMS system (I-VMS) to assist in the management of marine protected areas (e.g. MCZs, SPAs, SACs) and inshore fisheries. A statutory instrument, which is scheduled to come into force in 2021, will create the legal framework to help facilitate the roll-out of an I-VMS system to all under 12 metre vessels[306]. There is presently an ongoing approval process for I-VMS equipment, with a view to most vessels being fitted with the devices in 2022. The data will improve the spatial understanding which is necessary to characterise this aspect of UK fisheries, but it is understood that the data is not likely to be made available for use outside of the purposes of marine management and regulation.

Interactions between fishing activities and offshore wind farms are complex, and experience in Round 2 development locations indicates that the effects are dynamic and not always predictable, and new challenges are likely to come from floating offshore wind farms due to the nature of their moorings. In summary, stakeholder dialogue with the fishing industry indicated that typical offshore wind farm development would effectively preclude demersal trawling with conventional gears, but not necessarily fixed gear or possibly specialised trawl gears. While exclusion of fishing effort would be likely to have a local beneficial effect on fish stocks, a negative effect on other fishing grounds through displacement of effort could also occur, in addition to the potential socio-economic implications of the reduced attractiveness of certain fishing areas. The MPS and Marine Plans (for example, see polices GOV3 and FISH1 in the East Marine Plans) recognise the potential for negative effects from displacement, including economic and social impacts, and on the environment of areas that fisheries are displaced to, and require that proposals demonstrate how fishing will not be prevented or how such displacement could be minimised or mitigated, though the practicalities of such an assessment are challenging in view of the available data to conduct it. Liaison with the fishing industry should be a key component of a project's planning and EIA process. The principles of best practice in this area are outlined in guidance produced by the Fishing Liaison with Offshore Wind and Wet Renewables Group (FLOWW 2014). A pilot study commissioned by The Crown Estate was undertaken by NFFO to understand changes in fishing practices following the installation of wind farms (Gray *et al.* 2016). The project involved a review of VMS and other data on landings, fishing effort and surveillance, and interviews with fishermen and developers. The results of this study and more information on the potential for aspects of the draft plan to interact with other users, are given in Section 5.7.

Protected sites (Sections 5.4 and 5.6, Appendix 1j): conservation sites of relevance to activities associated with the draft plan/programme include Marine Conservation Zones (England and Wales), Marine Protected Areas (Scotland), SACs and SPAs. Various other national and international sites are located at the coast. These include those designated for nature conservation, geological conservation, their historic, cultural value and scenic value.

For nature conservation sites, the designation of an area (e.g. as a SPA, SAC, NCMPA or MCZ) does not necessarily preclude activities within or close to the site boundaries, however, the potential for likely significant effects (in the case of SPAs and SACs) or whether an activity would or might significantly hinder the achievement of the conservation objectives for an MCZ/MPA, must be considered. For example, as noted in Section 4.3 of the National Policy Statement for energy EN-1 (currently under review). A review into how stronger protections could be introduced for certain MPAs (the Benyon Review) in English waters was initiated in

[306] https://www.gov.uk/government/consultations/introducing-inshore-vessel-monitoring-systems-i-vms-for-fishing-boats-under-12m/outcome/summary-of-responses

2019 to examine how Highly Protected Marine Areas (HPMAs) could be introduced. The report concluded that HPMPAs should be introduced which prohibit extractive, destructive or depositional uses, allowing only non-damaging levels of activity, that the sites may be new ones or else existing sites, and must take a "whole site approach", which recognises mobile and migratory species. The report includes a number of other recommendations relating to social and economic opportunities and site identification[307]. As no HPMAs have yet been identified, they cannot be accounted for in this exercise. A shortlist of possible sites should be identified in 2021, with the intention to designate a number of these in 2022 following consultation.

While site boundaries are set to protect key habitats and related species, the mobile nature of certain animals, specifically birds and marine mammals, are such that assessments need to consider the potential for effects often at some distance from site. At the project level, an applicant must provide the Competent Authority (BEIS, MMO or Welsh Ministers in the case of renewables of certain scales) with sufficient information such that an Appropriate Assessment (AA) can be undertaken if it is required under the Habitats Regulations Assessment (HRA) process (e.g. see PINS advice note 10). There is a relatively recent precedent, in particular for nationally significant projects, for developers to undertake "shadow HRA", whereby the consideration of likely significant effects and related appropriate assessment is essentially undertaken by the applicant during the examination process, in consultation with relevant SNCBs. While this can provide some consenting comfort to developers, the Competent Authority must still undertake their own HRA.

It is acknowledged that there is the potential for new conservation sites to be classified during or after the SEA process and that any plan related activities would need to take account of these.

Aggregate extraction and disposal areas (Section 5.7, Appendix 1h): aggregate extraction is of strategic importance to the UK. Areas of the UKCS presently leased for aggregate are generally small but there remains a wider aggregate resource area which may be subject to extraction in the future[308].

It is unlikely that any aspect of the plan will interact with capital dredging operations, however, licensed disposal sites are located offshore for dredged material which may need to be avoided. Unexploded ordnance (UXO) is not typically a significant constraint to any development, though the location of disposal sites and the frequency of encounters particularly in the southern North Sea and in coastal locations should be considered (also see Cooper & Cooke 2016).

Cables (telecommunications and interconnectors) and pipelines (Section 5.7, Appendix 1h): these generally have a small footprint and the potential for spatial conflict with most other users is limited, but there remains a need to avoid or mitigate direct interaction with these. The advice MCA Mariners Handbook that vessels not to anchor or fish (trawl) within 0.25nm of a subsea cable extends the potential footprint of constraint for these. Their level of constraint is also a function of their location, orientation, number and density (e.g. in terms of the number of potential crossings they could generate for array or export cabling, or pipelines). As noted above and in Section 5.7, the potential for offshore grid integration and multi-purpose interconnectors may reduce the potential for conflict and enhance spatial use of the seabed post-2030.

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[307] See the Government response the Highly Protected Marine Areas (Benyon) review: https://www.gov.uk/government/publications/government-response-to-the-highly-protected-marine-areas-hpmas-review (accessed August 2021)
[308] As defined by Bide *et al.* (2016)

Visual intrusion (Section 5.8, Appendix 1c): there are various socio-economic drivers, including the importance of coastal tourism, to minimise significant visual impact of offshore developments, but there are also potential impacts on cultural and non-visual aspects of landscape/seascape which may conflict with activities associated with the draft plan. The ELC recognises that "all landscapes matter", however it remains Government policy (e.g. see NPS EN-3) that designated sites including AONBs, National Parks and World Heritage Sites are those which should be considered most prominently in assessment.

Defence (Section 5.7, Appendix 1h): certain MoD practice and exercise areas may present a constraint due to the nature of the activities undertaken, for example live firing or high energy manoeuvres involving aircraft operating at low altitudes. Some nearshore areas also fall within the range of military radar areas contributing to the UK Air (Surveillance and Control Systems) ASACS network. Technical measures have included the deployment of TPS-77 radars which can provide mitigation from the effects of wind farms, though concerns raised by the MoD in recent consent applications are noted, and there is a continued need for additional technical mitigation measures. The Windfarm Mitigation for UK Air Defence programme [309] is presently in its second phase and has awarded contracts to develop some of the radar mitigation solutions developed in its first phase, which will be applicable to both military and civilian radar.

With the exception of selected danger areas identified as "hard constraints", the presence of a PEXA does not preclude other activities. Planning and consultation between the offshore energy industries and the MoD should help to minimise any conflicts of interest where PEXAs exist, emphasised in the MPS, "Marine plan authorities, decision makers and developers should consult the MoD in all circumstances to verify whether defence interests will be affected."

Aviation (Section 5.7, Appendix 1h): large proportions of the UKCS are identified by NERL as "likely to interfere" with air traffic control radar (based on a 200m blade tip). Technical measures may alleviate this issue to some extent.

Recreational users (Sections 5.7, 5.8, Appendix 1h): The vast majority of recreational vessels (including yachts, diving and angling) would not be excluded from offshore wind farm development areas. As for fishing, there is potential for interaction between recreational boating and wave and tidal development, again particularly for tidal current devices which are likely to be situated within territorial waters. The MPS recognises the positive social, wellbeing and economic benefits of recreational activities (as well as potential for negative environmental implications), and the Marine Plans recognise the importance of tourism and recreation (e.g. TR1 policies of the English Marine Plans and T&R_01 in the Welsh National Marine Plan), and specifically recreational boating (policy TR2, only in the East Marine Plans), and indicate what proposals must demonstrate in terms of their potential impact on these activities. As marine plans are to be consistent with the MPS, similar policy provisions may be expected for other marine plan areas. Guidance available from the Maritime and Coastguard Agency (see MGN 372 (M+F)) suggests that wave and tidal devices may be more difficult to see than wind turbines and that navigation within an array may not be possible, meaning that a development area should be avoided.

Intra-plan conflicts: there are a number of key resource area overlaps, including prospective areas for oil and gas, gas storage (including for carbon dioxide), and those for offshore renewables. While gas storage and oil and gas activities have limited potential for spatial

[309] https://www.gov.uk/government/publications/air-defence-and-offshore-wind-working-together-towards-net-zero/air-defence-and-offshore-wind-working-together-towards-net-zero, https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2021-government-and-industry-led-taskforce-unlocks-new-opportunities-for-offshore-wind/

conflict, the presence of wind farms over potential hydrocarbon reservoirs or geological stores has the potential to preclude effective conventional deep geological surveys required either for exploration and appraisal, or monitoring.

Economic constraints: a consideration of the economics of deployment of any of the technologies considered is beyond the scope of this SEA, however, this has been considered in various publications including, Green & Vasilakos (2011), LCICG (2012a, b), Myhr *et al.* (2014), Astariz & Iglesias (2015), Vazquez & Iglesias (2015), The Carbon Trust (2015), Cavazzi & Dutton (2016) and Everoze (2020). Additionally, a separate UK wide project led by BEIS, the Future Offshore Wind Scenarios to 2050[310], is estimating the LCoE for offshore wind deployment across the UKCS.

5.15.3 Consideration of the evidence

5.15.3.1 Spatial constraints mapping

Screening of potential spatial constraints has previously been undertaken in relation to offshore renewables (wind, wave and tidal stream) by The Carbon Trust (2008, 2012), AEA & Hartley Anderson (2010), DECC (2009, 2011, 2016), WAG (2011) and more recently examples including, Jongbloed *et al.* (2014) and Cavazzi & Dutton (2016), Bosch *et al.* (2018), Gusatu *et al.* (2020) and The Crown Estate (2018). These reports have been reviewed, bearing in mind their principal focus is sometimes economic rather than environmental, and the analysis undertaken for previous OESEAs (DECC 2009, 2011, 2016) has been modified and updated. The assessment does not specifically consider constraints on renewables export cabling. The analysis was undertaken in a staged manner as outlined below:

5.15.3.2 Stage 1: geographical scope

The geographical scopes for the four renewables technologies being considered in OESEA4 are outlined below (also see Section 2 for more details). The scope builds on input derived from previous SEAs, technical reports by industry bodies and The Crown Estate (2012, 2013, 2018), Everoze (2020) and dialogue with the SEA steering group and others. The geographic areas largely reflect the prime resource (wind, wave and tidal) criteria for each technology:

- Wind (fixed foundations): water depths of 10-60m. See Figure 2.5.
- Wind (floating foundations): water depths 50-250m. See Figure 2.5[311].
- Wave: water depths of 10-200m. Annual mean wave power >20kW/m. See Figure 2.7.
- Tidal stream: water depths ≥5m. Current speed >1.5m/s. See Figure 2.8.
- Tidal range: water depths of up to 25m. Mean tidal range of >5m (considers where both spring and neap tides >5m). See Figure 2.9.

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[310] https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/offshore-wind-evidence-and-change-programme/offshore-wind-evidence-and-change-programe-themes-and-projects/finding-space-for-offshore-wind/

[311] The resource areas for fixed and floating wind can be further broken down by the foundation sub-type (after Everoze 2020) that would likely be deployed across certain depth ranges, for example, monopile (10-45m), jacket (45-60m), semi-submersible (50->200m), spar-type (120->200m) and tension leg platform (80->200m). Also note the potential limitations to floating technologies in certain shallower water depths noted by Carbon Trust (2018).

5.15.3.3 Stage 2: defining potential constraints

Spatial data (sourced from a number of organisations and agencies in the UK) representing various environmental and socio-economic characteristics, sensitivities and constraints for offshore renewable energy development and operation were input to ESRI's ArcGIS (ArcGIS Pro 2.8).

This analysis distinguishes between “hard” constraints (which are likely to definitively and consistently exclude development) and “other” constraints (which would presume against, but not definitively exclude development, e.g. subject to further assessment, developer dialogue and mitigation). Primary constraints identified at a strategic level are listed in Table 5.35, although it is recognised that other studies have included a range of other users and uses of the sea area or suggest varying levels of constraint for the same activity (see for example Begg and Wadsworth 2009, PMSS 2010, Royal Haskoning 2010, The Offshore Valuation Group 2010, Welsh Government 2011, Veum *et al.* 2011, Schillings *et al.* 2012, Tweddle *et al.* 2013, Jongbloed *et al.* 2014, Neill *et al.* 2017), and that despite the continued improvement in the quantity, quality and availability of marine spatial data, there are still limitations in coverage, resolution and confidence. As indicated above, marine planning provides indications to developers with regard to their potential interactions with other users, and what they will need to demonstrate as part of their application (e.g. how they would not adversely impact, or else minimise or mitigate any effect on other users as defined in the plans). For more localised studies, additional constraints will need to be taken into account for a particular area, for example, the Zone Appraisal and Planning (ZAP) process for offshore wind used as part of the Round 3 process assisted developers in choosing locations within wider Round 3 zones to make project proposals, and similarly as part of the Round 4 process, the characterisation, resource and constraints reports for the areas considered are available to assist in developers bidding for project areas (The Crown Estate 2018). The constraints exercises undertaken by The Crown Estate for Round 4 have been consulted as part of this assessment, but this analysis is independent of that for Round 4 and conclusions reached on areas of higher/lower constraint may not necessarily reflect those identified by The Crown Estate.

The following analysis provides a consideration of the theoretical area available to certain activities relevant to the draft plan. The output from this work is time limited, as the areas used in the underlying constraints analysis have the potential to change over time. It is anticipated that in the relative near-term such changes will include, but not necessarily be limited, to:

- Round 4 projects: six projects have been identified as part of the Round 4 offshore wind leasing process which are being subject to a strategic level HRA. Agreements for Lease are expected in spring 2022. Depending on the timing of the Round 4 process, the flexibility in the proposed project areas in the years which follow, and final project design, there could be changes to the level of constraint for further development.
- Decommissioning of offshore wind farms is not expected to take place in the near-term (though the recent decommissioning of Blyth is noted), but some Round 1 and 2 wind farms may be subject to decommissioning or repowering over the course of the next decade.
- Connected with the above, there is the potential for some changes to ship routes from the imposition of a higher number of wind farms (e.g. as predicted in Navigation Risk Assessments for offshore wind developments; also see Anatec 2013, 2016 and Section 5.7).

- Oil and gas infrastructure: the major hydrocarbon basins of the UKCS are generally mature and infrastructure decommissioning is likely to result in the removal of some physical constraints (e.g. consultation zones, helicopter routes and safety zones). The analysis has considered the timescale of assets subject to decommissioning planning at the time of publication and removed these from the relevant dataset. This includes those fields and related facilities for which a decommissioning plan has been submitted[312] and those facilities identified in OGA's decommissioning Energy Pathfinder[313]. An additional exercise was undertaken to identify those fields likely to cease production before 2030. This was based on expected decommissioning timescales from field EIAs and publicly available information, largely from operator websites, for fields and facilities for which decommissioning was being considered but for which a decommissioning plan has not yet been submitted.
- Conversely, the exploration of previously underexplored areas may result in additional activity or infrastructure, and there is the potential for redevelopment of fields formerly abandoned. The exploratory nature of oil and gas activities are such that it is challenging to make any prediction as to the location and scale of future development, however, those fields and related platforms which have been consented (e.g. those associated with the Blyth hub) but not yet commissioned, have been taken into account.
- Five Carbon Storage Licences have been granted for areas of the UKCS, in the southern North Sea, central North Sea and Irish Sea (see Appendix A1h and Section 2). These licences, in conjunction with the UK Government ambition to capture and store 20-30MtCO_2 per year by 2030, indicate that a likely mix of offshore carbon transport and storage projects using depleted hydrocarbon reserviours and saline aquifers will be required in the coming years.
- Conservation sites: there is the potential for additional sites to be designated during the currency of this SEA (SPAs, SACs and MCZs), or for the management measures or conservation advice associated with certain sites to alter their level of constraint.
- The location, but not necessarily the intensity, of marine aggregate extraction (for example see the wider areas of technical opportunity for aggregates in MMO 2013a, Bide *et al.* 2016), and areas identified in aggregate bidding rounds and recently awarded.
- Multiple years of VMS data have been reviewed which show some consistency in annual fishing effort on the UKCS, however, there may be longer term changes in fishing location and intensity that this analysis cannot reflect, including resulting from fisheries displacement from wind farms either recently completed, consented or in planning.

Whilst such changes are anticipated and can be qualitatively considered, for most it is not regarded that enough information is available to be spatially and temporally explicit about them. Understanding the potential future change in the use of UK seas is a key component of marine spatial planning, and the MMO has undertaken and commissioned work to try and understand the potential future use of each marine plan area through a series of "futures" analyses (e.g. MMO 2013b, 2017). For marine energy, MMO (2017) made a range of assumptions around the

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312 https://www.gov.uk/guidance/oil-and-gas-decommissioning-of-offshore-installations-and-pipelines

313 https://app.powerbi.com/view?r=eyJrIjoiZTU3MmFmMDktMDI0Ni00MzllLTg1MTQtMDQxZmQzNWUxZTc5IiwidCI6ImU2ODFjNTlkLTg2OGUtNDg4Ny04MGZhLWNlMzZmMWYyMWIwZiJ9&pageName=ReportSection

status of existing projects and certain potential new projects largely based on those either in early planning or formerly abandoned under three scenarios (business as usual, nature at work and, local stewardship), up to 2036. It should be noted that the scenarios do not account for the viability of any area for development, nor are they based on any target towards meeting marine energy's share of the UK's renewables capacity, and do not reflect any current Government energy policy. The futures work is informative when taken alongside the policy wording and related resource areas presented in the marine plans, but are considered to be of limited utility as inputs to this exercise.

Table 5.35: "Hard" and "Other" constraints used in spatial constraint mapping

Constraints	Figure no.	Wind	Wave	Tidal stream	Tidal range
"Hard" constraints					
Areas subject to lease by The Crown Estate for offshore wind, wave or tidal energy: 5km buffer	A1h.16 and 18	✓	✓	✓	✓
Aggregates licence and application areas	A1h.21	✓	✓	✓	✓
Aggregate exploration and option areas.	A1h.21	✓	✓	✓	✓
Active offshore marine cables and pipelines: 500m buffer	A1h.9, 10 and 19	✓	✓	✓	✓
Offshore wind cable agreements: includes wind farm cable corridors for projects in planning and consented. These typically cover areas greater than the footprint of the cables to be installed, but for the purposes of this exercise they reflect a cable route and reasonable buffer around them.	A1h.16	✓	✓	✓	-
Oil and gas infrastructure: 500m buffer representing safety zones (surface and subsurface)	A1h.9-10	✓	✓	✓	✓
Oil and gas infrastructure: 6nm buffer The 6nm buffer represents the distance at which helicopter final approach typically occurs; but note that obstacles within 9nm of an offshore destination would potentially impact some helicopter operations (low visibility or missed approach) and consultation must therefore take place within this distance from a platform.	A1h.4	✓	-	-	-
IMO vessel routeing measures	A1h.2	✓	✓	✓	✓
Navigation: Primary Navigation Routes 1 (PNR1) with 1nm buffer (derived from MCA 'siting not recommended' areas (draft and unpublished "OREI 1" primary navigation routes) and checked against 2012, 2017 and 2019 AIS annual average data. These routes include those defined in East Marine Plan policy PS2, and those defined as "high density navigation routes" and "main shipping routes" in the remaining English marine plans and Welsh National Marine Plan respectively. In order to account for the likely changes to routeing following the construction of consented offshore wind farms, the navigation risk assessments and indicative post-construction shipping routes for these projects have been accounted for. The Cumulative Navigational Issues in the Southern North Sea report (Anatec 2013) has also been considered, noting the changes to project boundaries since its publication. These routes have been included for tidal stream devices for the purposes of this assessment, however it is recognised that some submerged devices in deeper waters which do not reduce under-keel clearance may not affect shipping during operation (see Section 5.7).	-	✓	✓	✓	✓

Constraints	Figure no.	Wind	Wave	Tidal stream	Tidal range
MoD PEXAs: selected danger areas[314] Airforce danger areas have vertically defined upper and lower limits and in most cases involve supersonic flight and combat training. Those areas identified to take place to surface level and involve live firing/bombing were considered hard constraints for the purposes of this analysis. Also note East Marine Plan policy DEF1.	A1h.6	✓	✓	✓	✓
Protected wrecks: including military remains, scheduled monuments and those designated under the Protection of Wrecks Act 1973, and their related exclusion zones.	A1i.2, 4, 5, 7, 9, 10, 11	✓	✓	✓	✓
Gas storage lease areas	A1h.15	✓	✓	-	-
CCS lease/licence areas	A1h.15	✓	✓	-	-
"Other" constraints					
Designated, candidate, possible, draft SACs and SPAs, where boundaries known. SACs and SPAs sites are not considered to be hard constraints, consistent with National Policy, although they are subject to strict assessment criteria and must be given due weight in site specific environmental assessments and consent applications. Colocation may not be possible. The SNCBs continue to note that they cannot conclude no adverse effect on site integrity for certain SPAs and SACs sensitive to offshore energy projects. These sites in particular are highlighted, but note in terms of spatial interactions (and in particular for mobile species), effects may be generated at some distance from site boundaries.	Maps in Appendix 1j	✓	✓	✓	✓
Marine Conservation Zones	Maps in Appendix 1j	✓	✓	✓	✓
MoD PEXAs: other areas	A1h.6	✓	✓	✓	✓
NATS radar areas. Assumes a 200m blade tip which is the largest structure for which safeguarding maps are available.	A1h.4	✓	-	-	-
Helicopter Main Routes (HMRs). Helicopter main routes have been established from heliports to certain offshore installations. These have no statutory basis but CAA guidelines (CAP764) indicate that there should be no obstructions 2nm either side of the routes. Routes are located in the southern, central and northern North Sea, and Morecambe Bay. These are considered "other" constraints as consultation to date has allowed for development within their boundaries.	A1h.4	✓	-	-	-
Offshore mine lease areas	A1h.21	✓	✓	✓	✓
Disposal sites. The level of constraint posed by these sites will vary considerably depending on their former and current use. See	A1h.22	✓	✓	✓	✓
Statutory Port Limits.	A1h.XX	✓	-	✓	✓
Areas of higher intensity fisheries (identified on the basis of VMS data covering the years 2014-2017) and a comparison	A1h.32-33	✓	✓	✓	-

314 For wind, this includes two areas used by the Royal Naval Air Service Culdrose as identified in ITPEnergised 2020.

Constraints	Figure no.	Wind	Wave	Tidal stream	Tidal range
with fisheries AIS data (2017). VMS data is only mandatory for vessels over 12m in length, and therefore activity of smaller vessels operating inshore is likely to be under-represented in these data. AIS data is mandatory for all commercial fishing vessels, but similarly will not capture smaller inshore fisheries.					
Visibility from landscape designations (Areas of Outstanding Natural Beauty, Heritage Coasts, World Heritage Sites and National Parks, after TCE 2018, noting the limitations cited therein and in MMO 2017), and distances at which a low magnitude of effect may occur for high sensitivity seascapes (after White Consultants 2020).	A1c.2, Figure 5.82, Figure 5.88	✓	-	-	-

5.15.3.4 Stage 3: application of constraints to the defined resource areas

Hard constraints

The spatial extent of the "hard" constraints layer was subtracted from the resource areas identified in Stage 1, providing an area of seabed remaining in which development could theoretically take place, subject to development specific assessment (e.g. Figure 5.81). Some of these areas may not be viable for development, for instance, due to further constraints on cable corridor, landfall and grid connections, or on wider technical, economic or environmental grounds which are beyond the scope of this assessment.

The analysis has included former Round 3 zones which were not progressed to development such as the Bristol Channel and Irish Sea. Whilst they did not prove to be technically or economically viable in the past, future development in these areas cannot be entirely ruled out as cost-reduction and technical ability change over time. Conversely, the refusal of Navitus Bay in the area to the west of the Isle of Wight has provided a basis for not including this former zone and treating it as a hard constraint. The reasons for this refusal (primarily relating to multiple landscape/seascape issues and its effect on the Dorset and East Devon Coast World Heritage Site) could also reasonably be used to suggest that a wider area landward of this former zone is unlikely to result in approvals for offshore wind.

The mapped outputs provide illustrative guides to areas of most/least constraint, and whilst the SEA can provide recommendations in terms of areas of higher or lower constraint (see below), the leasing and planning decisions of relevant authorities are part of a wider planning process which can make more detailed assessments of the suitability of particular areas for development, and the SEA does not prejudge these.

Other constraints

The range of "other" constraints has also been mapped to indicate that despite no significant "hard" constraints being present in some areas, there remain a number of other legitimate uses and users of the sea which may present further constraints, particularly when considered cumulatively. The analysis is necessarily strategic, and constraints may also be experienced other than through direct interaction with certain areas, for instance, the potential for far field interactions with conservation sites, visual intrusion or where the timing and intensity of use is variable, or our understanding of the use of particular areas is indicative (e.g. recreational sailing and fisheries). These potential issues cannot be meaningfully considered using the spatial analysis techniques applied here. In order to inform levels of relative constraint in those areas remaining following the application of hard constraints, data representing the "other" constraints has been mapped and weighted[315] according to the level of constraint they pose to each renewable technology relevant to the draft plan/programme. These constraints are also considered qualitatively in Section 5.15.4, which cross references other sections of this Environmental Report in which the potential impacts of the draft plan/programme on socio-economic and environmental receptors are assessed.

In addition to the other constraints noted in Table 5.35, seabed morphology, process and underlying geology (e.g. see Mellett *et al.* 2015, Everoze 2020) may present some constraint on infrastructure installation. Metocean conditions may similarly introduce additional constraints to deployment, for example areas of high wave energy which can increase cost of deployment (see ETI 2015, Carbon Trust 2018), as does the distance from shore, though this is largely offset by improved wind speed and load factors at these distances, and availability of grid connections may be a greater constraint. Ground conditions and likely related installation methods and potential foundation types defined by Everoze (2020) are reflected in the outputs of the assessment (e.g. see Figure 5.86). This output is provided as context to the broader set of constraints on offshore wind deployment presented here, and the limitations on foundation deployment must be informed by project-specific data collection and assessment, and are beyond the scope of this appraisal.

The coastal waters of the UK are of particular major ecological, economic and cultural importance. Unless appropriately planned and controlled, the possible developments of the scale encompassed by the draft plan/programme could result in adverse effects on coastal features, safety, and present day and foreseeable future uses. The concept of a coastal buffer for offshore wind development was introduced in Round 2, with 0-8km and 8-13km used to assess seascape sensitivity. Reflecting the relative sensitivity of multiple receptors in coastal waters, previous offshore energy SEAs (DECC 2009, 2011e, 2016) concluded that the bulk of future wind generation capacity should be sited well away from the coast, generally outside 12 nautical miles (some 22km). The proposed coastal buffer zone was not intended as an exclusion zone, since there may be scope for further offshore wind development within this area (e.g. Rampion offshore wind farm), and recognised the varying sensitivity of the coast to offshore energy development that may make some areas more or less acceptable for renewables deployment. As noted above, the ability to site wind farms far from shore is a function of seabed topography and suitability. As international context, the average distance to shore of wind farms under construction in 2019 was 59km, which included Hornsea Project One (UK), EnBW Hohe See, EnBW Albatros and Deutsche Bucht (all Germany) (WindEurope 2019, also see Section 5.8). The approach taken in this exercise is to consider the range of "other" constraints, and to map and described these to account for the varying level of significant constraint in the nearshore areas of UK waters relevant to the draft plan/programme.

The complexity of the decisions regarding major developments at or near the coast is reflected in tiers of UK marine and terrestrial planning policy, which includes the MPS, Marine Plans, National Planning Policy Framework (NPPF), National Policy Statements for energy (NPS EN-1,

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[315] A scale of 0-100 was applied based on the following ranges: 80-100: development would be extremely challenging and is unlikely to be viable or would require significant levels of mitigation; 50-80: there is a moderate level of constraint, however, mitigation (e.g. project design or dialogue on co-location issues) could significantly reduce the level of constraint so that development could be acceptable; 20-50: the level of constraint is considered moderate to low, would be easily mitigated through avoidance or minimising impact, and mitigation may not be required. Assessments would still be required including EIA, and likely HRA; 5-20: there is a low to very low level of constraint, however, any issues would still need to be acknowledged and assessed through EIA.

Overarching National Policy Statement for Energy and EN-3, Renewable Energy Infrastructure) and Planning Policy Wales. The majority of major offshore renewables developments will, principally, fall within the remit of the *Planning Act 2008* as nationally significant infrastructure as defined above.

The MPS, and the Marine Plans give coastal regulators and communities further opportunities to have a say in the way the marine environment is managed, in addition to the existing routes for consultation as part of the development consent process. The East Marine Plan area encompasses a substantial portion of existing producing or planned offshore wind development and the bulk of the proposed Round 4 projects. The policies relating to offshore wind make clear that its further development is supported (policy EC3), particularly within existing Round 3 zones (policies WIND1, WIND2, note the policy does not reflect that the former Round 3 wind areas have been dissolved), with the support being contingent upon zone appraisal or an equivalent process having being undertaken prior to development proposals being made. The policy reflects existing investment commitments of Round 3 wind developers and also that a comprehensive appraisal should be undertaken to understand the feasibility of developments prior to defining proposed areas. NPS EN-3 provides guidance on the impacts of renewable energy infrastructure on ecology, biodiversity, the historic environment, landscape and other users, and the considerations to which PINS and applicants for development consent should have regard. The NPSs further highlight the importance and sensitivities of biological and ecological networks and designated areas and the need to protect them, but also that with careful monitoring, design and siting, wind turbines can be located in environmentally sensitive areas and may also have positive benefits to ecology and biodiversity (paragraph 2.6.63).

Definitive criteria for excluding areas within the “other” constraint areas from the theoretical resource was not identified, however, the level of constraint associated a number of areas suggests that they carry a very significant consenting risk; the majority of these were in extreme proximity to the coast.

5.15.3.5 Stage 4: indicative installed capacity

In the analysis summarised below, an assessment was made of indicative generation capacities for the different resources after hard constraints have been applied. In each case this is considered to be a theoretical value of capacity, as a limited number of assumptions have been made about the practical potential for deployment in specific areas.

Offshore Wind

The capacity of any individual development is a function of the number and size of the devices installed, with output related to the load factor for a particular technology[316], which is a function of individual turbine power output characteristics and wind power at a given location. Data relating to 47 wind farm sites[317] were analysed to try and understand typical capacity densities (i.e. MW/km^2) and whether there was any relationship between this factor and wind turbine size. As indicated in Figure 2.2, turbine size has gradually increased from approximately 2MW in 1998 to proposals for turbines of up to 12MW to be installed at the Dogger Bank A & B wind farms, and 14MW at the Sofia wind farm. Applications for wind farms, and related DCOs, now generally set a maximum project capacity, with flexibility built into project design on how to deliver this, with post-consent variation typically being related to a change in the maximum size

[316] Average load factor in 2019 was 40.4% for offshore wind (BEIS 2019). DNV-GL (2019) note the potential for this to rise to, or exceed, 50% subject to local conditions.
[317] Information was gathered from the BEIS renewable energy planning database, developer websites and documents for individual developments on the National Infrastructure planning portal.

of turbines assessed as part of the consenting process. This, and the need to space larger turbines at greater distance, is such that generally fewer and larger turbines are used to achieve the target generation capacity, such that the energy density of the installed capacity is rather static irrespective of the number of turbines used.

The review of power densities indicated a significant range of values between individual wind farms (1.6MW/km^2-17MW/km^2, with an average of ~6MW/km^2 and mode of 9MW/km^2). The data include a range of project types from demonstration scale projects and early nearshore sites, to larger sites located further offshore and with a higher anticipated load factor requiring fewer turbines for the same power output per unit area. Assuming that fixed foundation wind farms currently seeking consent will be similar to those proposed to be deployed for developments or project proposals likely to fully or in part be delivered by 2030, (e.g. The Crown Estate 2017 extensions), the average energy density used in the analysis as a basis for calculating the theoretical potential for installed capacity is 3.1MW/km^2. It is understood that arrays using tethered foundations may deliver different values, however, no large commercial scale development has been proposed which could be used to confidently make assumptions about an energy density.

Further assumptions have been made in an attempt to make the potentially installed capacity of offshore wind more realistic. This includes the removal of small areas and “slither” polygons which are unlikely to be viable. Based on information provided in recent wind leasing rounds and extensions, the minimum viable project size was considered to be 400MW, or 300MW for an extension to an existing wind farm. These areas are based on those remaining following the application of hard constraints to the resource area and the assumed energy density for offshore wind noted above.

Wave and tidal stream

The assumptions surrounding the potential for energy to be generated from the wave resource on the UKCS has been variously estimated, with the most recent studies of The Carbon Trust (2012) and The Crown Estate (2013) using comparable methodologies to derive estimates of the indicative capacities. Of primary interest to this study (for both wave and tidal resources) is the potential practical resource, that is, the resource available once spatial exclusions analogous to those outlined in Table 5.35 have been applied. The above reports use a number of technical inputs including wave power, conversion efficiency of mechanical to electrical energy (70-80%), and the capture width of converters (i.e. the absorbed power relative to the wave power resource), and includes farm-scale effects such as shadowing. The previous analysis of this SEA has used a more simplistic approach to calculating the potential capacity for wave and tidal energy using a range of array sizes and the expected capacities for these (i.e. an energy density based on MW/km^2 for the available resource area). Few proposals have been made on which to definitively generate such assumptions as the technologies are not well developed and commercial arrays have not been deployed. Previous SEAs have used consultation with industry and other sources to provide power density estimates for arrays which had a range of 3-30MW/km^2 for wave and 6-60MW/km^2 for tidal stream devices. Other summaries provide similar values to the upper value in the ranges used in OESEA2 (e.g. values of 10-30MW/km^2 and 50-70MW/km^2 for wave and tidal stream respectively are derived from AECOM & Metoc 2009 and AECOM *et al.* 2010).

Tidal range

The potential scale of energy supply which could be provided by tidal range to contribute to the renewable aspects of the UK energy mix requires highly site specific considerations. No attempt is made here to calculate a theoretical capacity for tidal range in relevant UK waters, however work undertaken for The Crown Estate is referred to below which provides an indication of the location and potential maximum contribution that could be made from this source.

The area remaining following the application of hard constraints has been used to provide a theoretical maximum capacity for English and Welsh waters, however no minimum separation distance or economic constraint was considered in relation to individual potential projects – the main focus of this section is to highlight areas of potential spatial constraint and provide a high level indication of the areas with the greatest potential resource.

5.15.3.6 Summary of theoretical capacity within remaining resource areas

The following technology scenarios were used:

- Offshore wind: 3.1MW/km^2
- Wave: 10-30MW/km^2
- Tidal stream: 50-70MW/km^2

Using the generation capacity scenarios noted above, estimates for total theoretical output for wind, wave and tidal devices have been calculated, based upon the total area of sea (seabed and/or surface) available after hard constraints have been applied. These estimates are shown in Table 5.36 and do not make any allowance for reductions in available area as a result of "other" constraints, which may be appreciable (see Section 5.15.4).

Table 5.36: Indicative maximum theoretical capacity after hard constraints applied

Resource	Regional Sea				
	1*	2	3	4	6*
Wind					
Fixed foundation: 0-60m	8	41**	12	16	15
Tethered foundation: 50-200m	84	5	1	148	6
Tidal stream					
Tidal current: >1.5m/s	0	6.5-9.1	33-46	28-39	18-26
Wave					
Wave power: >20kW/m	28-82	0	0	453-1,359	0

Note: *does not include Scottish or Northern Irish waters. **When considering the potential for the decommissioning of oil and gas installations for which a decommissioning plan has not yet been submitted, the total increases to 54GW. The wave and tidal arrays, the total area available does not take account of the size needed for an individual commercial scale development. For wave and tidal arrays, the space required between arrays has also not been factored in. The potential capacity for such developments are therefore considered to be an overestimation.

5.15.4 Regional Sea consideration

The above analysis only considers the area relevant to renewables development for this SEA, namely the territorial and offshore waters of England and Wales. Previous SEAs (DECC 2009, 2011) have included target generation capacities for offshore wind of 25GW in addition to the 8GW that was to be delivered from Rounds 1 and 2, providing an overall capacity of 33GW to be covered by the plan, with spatial analysis at the time indicating the potential for this to be delivered.

The UK Government has indicated that it will support up to 40GW of offshore wind by 2030[318], which compares with a current UKCS operational total of 10.4GW, a consented capacity of 14.6GW, and a total further capacity (consented and in planning) of 18.9GW. There are also a number of wind farms at the pre-application stage, for example all of the 2017 extension projects (totalling 2.8GW), and Hornsea Project Four (~1GW). If all the above projects were to be consented and constructed, the total UKCS installed capacity would be 33GW, leaving an as yet unidentified ~7GW to be consented and installed by 2030 to meet a 40GW target. As noted in Section 2, The Crown Estate's Round 4 wind leasing and The Scottish Government's sectoral plan for offshore wind (and related ScotWind leasing round) have indicated the potential to deliver 8GW[319] and 10GW of additional capacity respectively, however, the timescale for delivering the part of this capacity needed to meet the 2030 target is not certain in view of typical wind farm consenting and construction timescales. In view of the capacity needed to reach 40GW, a deployment rate of at least 3.3GW/year, stating in 2021, is needed to meet the target. This is recognised in the Energy White Paper 2020, and it is proposed that a Ministerial Delivery Group be established that will work to reduce consenting delays.

The UK Government expects 1GW of the 40GW capacity to be generated by floating offshore wind turbines, the corollary of such a value being that the remaining ~6GW must be delivered by fixed offshore wind. OESEA4 is a separate though complementary process to The Crown Estate's Round 4 leasing Round. The spatial limitation of Round 4 to bidding areas in the North Sea and Irish Sea reflects constraints analysis undertaken for fixed offshore wind, and it must be recognised for this SEA that the capacity to meet the 2030 target is likely to come from within the bidding areas. While Table 5.36 above and the narrative below reflect the outcome of the analysis undertaken for OESEA4, which includes a geographical scope wider than the bidding areas, the remaining capacity following the removal of hard constraints within the bidding areas is considered to be approximately 37GW (Regional Sea 2), 6GW (Regional Sea 3) and 8GW (Regional Sea 6), however significant further constraints to development remain (e.g. see Section 5.6).

The areas noted in Table 5.36 indicate that there is theoretically significant scope to deliver the remaining capacity as part of the 2030 target from fixed offshore wind, and additionally, sufficient theoretical capacity to deliver, or make a substantial contribution to, that suggested by the CCC (2019, 2020x) and National Grid (2020) in their assessment of the required capacity likely to be needed to contribute to net zero (75GW-125GW, and up to 87.1GW respectively). It is anticipated that the bulk of the additional capacity needed to meet figures consistent with achieving offshore wind's contribution to net zero would need to be delivered by floating offshore wind, as the remaining areas for fixed wind which are not subject to one or more significant constraints has diminished significantly.

A summary of the constraints covering the relevant waters of each Regional Sea are described below. Note that the potential sources of significant effect referred to are discussed further in other sections of this report, and these are cross referred to where relevant.

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318 https://www.gov.uk/government/publications/energy-white-paper-powering-our-net-zero-future
319 https://www.thecrownestate.co.uk/en-gb/media-and-insights/news/2021-offshore-wind-leasing-round-4-signals-major-vote-of-confidence-in-the-uk-s-green-economy/

The text is complemented by a number of mapped outputs from the spatial analysis (Figure 5.81-Figure 5.91). Certain constraints such as fisheries and landscape interactions are mapped separately for emphasis.

5.15.5 Regional Sea 1

Offshore wind

The majority of the fixed wind resource area in Regional Sea 2 is located within territorial waters (Figure 2.5). Following the application of hard constraints to the resource area, which primarily relate to navigation issues, the remaining areas are of a sufficient size to theoretically accommodate offshore wind farms, but are located in areas coinciding with a number of other constraints to offshore wind development, some of which are likely to present significant consenting barriers.

The northernmost remaining fixed wind resource in Regional Sea 1 is located adjacent to the North Northumberland Heritage Coast and Northumberland Coast AONB, both of which reflect areas of relatively high landscape/seascape value, and there is a moderate to higher level of visibility from these designations across the resource area (Figure 5.82, see Section 5.8), and at least moderate (see White Consultants 2020) or higher levels of effect can be expected for any development located here. The area is almost completely coincident with the Berwick to St Mary’s MCZ and Northumberland Marine SPA (Figure 5.84). The latter is used by seabirds and auks associated with SPAs including Farne Islands, Coquet Island, Lindisfarne and Northumbria Coast (see Section 5.6, Appendix 1a) for foraging, bathing and preening. Collision risk and displacement are key issues of relevance for the site and its related colonies, such that significant overlap with this site is likely to present a significant constraint. There is the potential for effects on the Remote Radar Head at Brizlee Wood (Figure A1h.7, see Section 5.7), in addition to broader interaction with NERL air traffic control radar. Taken together these factors pose a significant level of constraint to any development taking place here (Figure 5.85).

Similar levels of constraint feature for the nearshore resource area located between Teesside and Tyneside (Figure 5.81), which is immediately adjacent to the Durham Heritage Coast, and there is some overlap with the Teesmouth and Cleveland Coast SPA (terns and wintering waterbird species). The eastern extent of the area is on the edge of an area of higher intensity fishing involving high value catches including of *Nephrops*, crabs and lobsters (Figure 5.83, also see Appendix 1h). Together, these factors and the nearshore location of the resource indicate significant levels of constraint to development.

Further south, the remaining resource area located in the extreme nearshore along the north Yorkshire coast coincides with the North York Moors National Park and North Yorkshire & Cleveland and Flamborough Head Heritage Coasts, effects on which would likely be significant (see Section 5.8). The area also overlaps, or is in close proximity to, the Flamborough and Filey Coast SPA. The Flamborough and Filey Coast SPA includes features which are sensitive to collision (kittiwake, gannet) and displacement (auks) (see Section 5.6). It should be noted that Natural England has highlighted significant consenting risks in relation to this site for future wind farm development, in-combination with existing projects, and those currently being consented are proposing compensatory measures for its kittiwake feature (see Section 5.6).

The resource area offshore of the north Yorkshire coast is located at the edge of an area of higher intensity fishing with catches of mainly crab, scallop and lobster (Figure 5.83), and is also likely to pose at least a low level of effect on the landscape designations noted above in view of the distance (20-39km) of the area from the coast (after White Consultants 2020). The location of the area relative to the Flamborough and Filey Coast SPA is likely to present similar constraints and consenting risks to those noted above.

Additionally, the resource areas in the nearshore and offshore of the North Yorkshire coast are in close proximity to Staxton Wold RRH (Appendix 1h), interaction with which could represent a significant constraint[320].

The remaining fixed wind resource in Regional Sea 1 is mostly underlain by hard bedrock (chalk) with some sandstone/mudstone elsewhere. Shallow Quaternary sediments (potentially <5m, or with lower confidence, locally 5-50m, see Figure 5.86), such that drilling may be required to secure piles (jacket pin piles or monopiles) in these areas (Everoze 2020). The development of fixed foundation offshore wind farms in Regional Sea 1 is considered to be severely limited by the range and nature of hard and other constraints relating to the resource area (also see Figure 5.85).

Conversely, Regional Sea 1 has a considerable available resource for floating offshore wind (Figure 5.87), with much of this outside of higher visibility areas from landscape designations, and well beyond the limits of low magnitude effects (Figure 5.88). There is similarly limited interaction with other users across much of the offshore area which remains following removal of hard constraints (removals largely relate to defence and navigation issues); the area is subject to less intense fisheries (Figure 5.89) and while some large MCZs are present (Swallow Sand, Fulmar – see Figure 5.90), there remains considerable area outside of these sites within which large wind farms could theoretically be constructed.

Wave

The available wave resource in relevant waters of Regional Sea 1 is limited (Sections 2.6 and 2.7, Figure 5.92), relatively distant from shore (>250km), and contains a range of constraints including oil and gas installations (decommissioned and operating), shipping routes and a significant proportion of the area overlaps the Fulmar MCZ, which is designated for subtidal sediments (sand, mud, mixed) and the bivalve *Arctica islandica*. The distance from shore will likely make early wave projects in this area challenging.

Tidal

There is no technical resource in relevant waters of Regional Sea 1 for tidal range or tidal stream development, and it is considered highly unlikely that such activity will take place here.

5.15.6 Regional Sea 2

Offshore wind

A resource area is located adjacent to the northern section of the Holderness coast which overlaps parts of the Holderness Inshore and Offshore MCZs and the Greater Wash SPA. The overlap with an area of higher winter usage of red-throated diver, which are known to be highly sensitive to displacement by offshore wind farms (see Section 5.6) and with a significant potential for in-combination effects, the close proximity to the Flamborough and Filey Coast SPA (see above) and the extreme nearshore nature of the area in terms of landscape/seascape interactions, recreational use, and potentially inshore fisheries, are such that development in this area is considered to face significant levels constraints.

The majority of the remaining resource is outside of territorial waters and of sufficient distance offshore that there is limited potential for interaction with visual aspects of landscape/seascape

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[320] Note at the time of writing the TPS-77 system from Saxton Wold RRH has been moved to Saxa Vord, Shetland, and the MoD has paused the acceptance of mitigation proposals for Saxton Wold RRH from large offshore wind developments.

(see Section 5.8), and are generally underlain by Quaternary deposits of more than 20m or 50m depth (Figure 5.86), reducing the potential requirement for drilling to install piles. The largest area of potential fixed wind resource remaining following the removal of hard constraints in Regional Sea 2 is located to the north and south of the existing Dogger Bank wind farms (Dogger Bank A, B, C and Sofia). Substantial portions of these remaining areas are located within the Dogger Bank SAC and the Southern North Sea SAC (Figure 5.84), which are designated for features which are sensitive to the physical disturbance (see Section 5.4) and underwater noise (see Section 5.3) related impacts from offshore wind. There is potential for interaction with mobile features from Flamborough and Filey Coast SPA (kittiwake, gannet, auks) throughout much of the remaining resource areas offshore, and the consenting challenges and potential constraints this poses are already described above.

There is the potential for fisheries interactions across much of the Dogger Bank (Figure 5.83, also see Section 5.7 and Appendix A1h), and management measures have been proposed relating to certain fisheries in this area in relation to the Dogger Bank SAC[321]. It should be noted that the Dogger Bank SAC is presently considered to have an unfavourable conservation status, such that further disturbance from offshore wind, in combination to that already planned, could present a consenting risk and a significant constraint to development across the SAC.

Nearshore areas to the east and south of East Anglia overlap or are within a distance of sites with features sensitive to offshore wind development, such that they could present significant constraints. For example, the Greater Wash SPA and Outer Thames Estuary SPA due to the presence of terns and red-throated diver[322], or the North Norfolk Sandbanks and Saturn Reef SAC, primarily due to the physical effects of wind farm installation and operation, including that of cabling (e.g. pre-sweeping, cable and scour protection) – see Section 5.4. It should be noted that SNCBs have recently advised that they cannot exclude an adverse effect on integrity for the North Norfolk Sandbanks and Saturn Reef SAC in relation to wind farm cabling effects for specific projects. While such a conclusion was not supported in related project HRA[323], and are clearly project specific, further proposals for large wind farms inside the site would need to consider the risk presented by in-combination impacts for wind farm installation and maintenance. Trimingham RRH also poses a potential constraint in the south of Regional Sea 2. While it is equipped with a TPS-77 radar capable of mitigating the effect of offshore wind farms, the acceptability of any interference and the potential to mitigate effects, in-combination with other wind farms in this area, would need to be subject to project-level assessment.

While the area of the Outer Silver Pit is identified as the only remaining resource area for floating wind (Figure 5.87) in Regional Sea 2, the area may be both topographically challenging and is subject to, higher intensity fishing (Figure 5.89) which is targeting demersal and high value shellfish (mainly *Nephrops*) species, which may present significant constraints to consenting.

Wave

There is no technical resource in Regional Sea 2 for wave energy, and it is considered highly unlikely that such activity will take place here.

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[321] https://consult.defra.gov.uk/mmo/call-for-evidence-mmo-mpa-assessments/ (accessed December 2020)
[322] Also see The Crown Estate (2019) on advice received from SNCBs on their HRA for the 2017 wind farm extensions.
[323] For example: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-003226-Hornsea%20Project%20Three%20HRA%20-%201%20July%202020.pdf (accessed October 2021)

Tidal

There technical resource for tidal stream energy in Regional Sea 2 is highly limited to areas off Norfolk and north of the Humber (Section 2.6). Following application of hard constraints (Figure 5.94), which primarily relate to shipping in both areas, relatively limited resource remains. The small area (2.7km^2) off the Humber and immediately to the east of Spurn Point is in relatively shallow waters and adjacent to an area of high vessel traffic, as well as being located within conservation sites including the Greater Wash SPA (red-throated diver, common scoter, little gull, terns), and the Holderness Inshore MCZ (broadscale marine habitiats, including subtidal sediments, and Spurn Head and “the Binks” features of geological interest. The area off the Norfolk coast (127km^2 in total, over half of which is located in two larger areas just off the Norfolk coast) is similarly in an area of moderate to high shipping traffic and overlaps multiple conservation sites including the Greater Wash SPA, Outer Thames Estuary SPA (red-throated diver, terns), Haisborough, Hammond and Winterton SAC (reefs, sandbanks) and the Southern North Sea SAC (harbour porpoise). Both of the resource areas are subject to East Marine Plan policy TIDE1, which indicates that other proposals should demonstrate that they will not compromise potential future development of tidal stream in the areas, or how adverse impacts would be minimised, mitigated or the case for proceeding if that are not possible; such a policy introduces an element of “safeguarding” for these resource areas. There are likely to be significant constraints in the deployment of tidal stream devices in either of the main resources area mentioned above, and particularly close to the Humber.

The areas identified as having a potential resource in Figure 5.95 coincide with many sites previously investigated for tidal range energy (see Appendix A1h) and are primarily located around the Humber and Wash. A high level of constraint is associated with many of these areas. For Holderness, the presence of pipelines, cables, offshore wind farms and a locally important inshore fishery, along with a relativelt small area of resource, likely makes this area of low prospectivity for future development. Similarly, the areas off the Lincolnshire coast and North Norfolk Coast are located in areas where local vessel traffic (e.g. wind farm maintenance) is important or are adjacent to high density shipping routes. All of the resource areas are also located within multiple conservation designations including the Greater Wash SPA, North Norfolk Coast SPA, the Wash SPA (terns, wintering waterbirds), and the Wash and North Norfolk Coast SAC (Figure 5.94 and Figure 5.95). Additionally, the shore at this location contains a range of important habitats including, but not limited to, Gibraltar Point, Scolt Head and Blakeney, which may pose significant constraint to tidal range development.

5.15.7 Regional Sea 3

Offshore wind

Of the remaining fixed wind resource area in Regional Sea 3, a significant proportion are nearshore and within high visibility of landscape designations. In the west, these include South Devon AONB, East Devon AONB, Dorset AONB, Dorset & East Devon Coast WHS, and Isle of Wight AONB (Figure 5.82). The nearshore nature of these areas and former offshore wind project refusal on the basis of landscape-related issues[324] highlights that the visual aspects of any proposal in this area would be a key constraint and consenting risk (see Section 5.8). The remaining resource area in Lyme Bay (which also includes that for floating wind, Figure 5.83 and Figure 5.89) coincides with high intensity fishing activity targeting a range of species including sprat, crab, cuttlefish, scallop, sole and plaice, and also overlap parts of one or more conservation designations (Start Point to Plymouth Sound & Eddystone SAC, Lyme Bay and

324 https://webarchive.nationalarchives.gov.uk/ukgwa/20210109225703/https://infrastructure.planninginspectorate.gov.uk/projects/south-east/navitus-bay-wind-park/ (accessed October 2021)

Torbay SAC, Exe Estuary SPA). It should also be noted that the MoD raised concerns as part of the Round 4 process in relation to potential effects on the magnetic compass test facilities and acoustic maritime ranges at Portland Bill, for wind farm development in Lyme Bay. The seabed sediments to the west of the Isle of Wight and offshore into the English Channel are thin (mostly <5m), underlain by hard bedrock, and may require drilling to set piles, and the presence of outcropping hard substrate is reflected in a number of designations that overlap the nearshore resource areas (Studland to Portland SAC, South Wight Maritime SAC). Overall, the area to the west of the Isle of Wight has multiple constraints that present potentially significant consenting risks.

While the remaining resource area in the eastern English Channel between Dungeness and Beachy Head has an apparently lower level of visibility from landscape-related designations, there remain potential landscape/seascape interactions from coastal elements of the South Downs National Park, the High Weald AONB and Kent Downs AONB, and the scale of future offshore wind turbines is such that there is the potential for a at least a medium magnitude of effect across these areas (after White Consultants 2020, also see Section 5.8). Such landscape/seascape constraints are likely to be less for those areas further offshore in the English Channel, but a low level of effect could still be generated from larger turbines (Figure 5.82). The nearshore area overlaps the Beachy Head East MCZ and Dungeness, Romney Marsh and Rye Bay SPA (waterbirds and terns), which together with the landscape/seascape interactions have the potential to result in significant constraints.

The eastern English Channel is subject to high shipping densities, primarily transiting through an IMO traffic separation scheme (In the Strait of Dover and Adjacent Waters). Development in such areas will not be viable, and projects within the separation area have the potential to limit areas for refuge within the IMO measures (see Section 5.7). Wind farms have not been developed within such separation schemes previously, though there are examples of wind farms having been consented adjacent to these, such as East Anglia Three and Greater Gabbard. The acceptability of any development in this area would need to be subject to project level assessment.

Wave

There is no technical resource in Regional Sea 2 for wave energy, and it is considered highly unlikely that such activity will take place here.

Tidal

While containing the largest tidal stream resource in UK waters (Section 2.6), there are multiple constraints which limit the area likely to be available for any development, with the majority of the area subject to relatively high levels of shipping traffic. The area to the south and west of the Isle of Wight (Figure 5.94) is a key resource area for tidal stream energy. In view of the limited nature of tidal stream resource across the UKCS, future limitations on this energy source should be considered following the policies in the South Inshore and Offshore Marine Plans. While there are a reasonable number of constraints on potential development, the area is one of the most prospective in waters relevant to this SEA.

The tidal range resource which remains available following removal of hard constraints is located along the Sussex coast in the eastern English Channel. The nature of the coast is such that only tidal lagoons would be viable, however, a range of shipping, fishing and nature conservation concerns are present along this stretch of coast which will present further constraint that would need to be addressed at the project level.

5.15.8 Regional Sea 4

Offshore wind

There are significant interactions with highly valued landscapes for the fixed wind resource areas remaining in Regional Sea 4 (Figure 5.82, South Devon, Cornwall and North Devon AONBs, Cornwall and West Devon Mining Landscape WHS, Pembrokeshire Coast NP) with a high level of visibility from these along the Cornish and Devon coast and through The Severn. A level of intervisibility is also likely from the English and Welsh coasts in the Severn (see Section 5.8). Areas off the Cornish coast are also in close proximity to the Portreath RRH (Appendix 1h), and the potential to mitigate any radar impacts would need to be considered for proposals in this area. Similar to the nearshore areas in the central English Channel in Regional Sea 3, the nearshore area has thin sediments and related SACs (e.g. Start Point to Plymouth Sound & Eddystone, Lizard point, Lands End and Cape Bank).

The largest offshore section of remaining fixed wind resource is located in the Bristol Channel, partly within the former Atlantic Array[325] area. A number of significant landscape effects were identified for this former wind farm (White Consultants 2020), in addition to other issues relating to depth and seabed conditions that were considered prohibitive at the time. Much of the nearshore and offshore resource area located in the Bristol channel overlaps with the Bristol Channel Approaches SAC, designated for harbour porpoise (see Appendix 1a and 1j), and also Lundy SAC. Additionally there are potential interactions with a range of SPAs including Grassholm (gannet) and Skomer, Skokholm and the Seas off Pembrokeshire (European storm petrel, Manx shearwater, puffin, lesser black-backed gull, seabird assemblage), and to a lesser extent, Carmarthen Bay SPA, designated for common scoter.

A considerable area of floating wind resource is located in the Bristol Channel, Celtic Sea and South West Approaches. The constraints remaining in this area outside of those already accounted for as hard constraints include fisheries interactions, particularly off Cornwall, and the south and west of the Isles of Scilly, with this area being one of the main fishing regions in the UK. Amongst others, fisheries in this area primarily target mackerel, hake, pollack, haddock, scallops and crabs (see Appendix A1h). Further offshore, and away from Portreath, it is likely that radar interference presents less of a constraint, with limited overlap with the NERL safeguarding area apart from resource areas in the Bristol Channel.

A range of MCZs (Greater Haig Fras, North West of Jones Bank, South West Deeps) and SACs (Haig Fras) are also present within the remaining floating resource areas (Figure 5.90), which are sensitive to offshore wind farm developments, though the scale of remaining resource is such that interaction with these sites could be avoided. There is also the potential for interaction with mobile species in the Bristol Channel Approaches SAC and Grassholm and Skomer, Skokholm and the Seas off Pembrokeshire SPAs, and closer the median line, with SPAs designated in the Republic of Ireland (e.g. Saltee Islands SPA).

Wave

For wave devices, the analysis shows that the areas of greatest practical resource are off the coasts of south west Wales and south west England. The potential resource here is significant, and while constraints remain for this area including conservation sites and species of conservation concern (see Appendix A1a.8 Marine Mammals), the scale of the resource (Figure

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[325] A range of data is available for this site: https://www.marinedataexchange.co.uk/search?searchQuery=atlantic%20array&pastYears= (accessed October 2021)

5.92) is such that the area is highly prospective for future development, and contains the only two wave lease areas in English and Welsh waters.

Tidal

Much of the tidal range resource along the northern Cornwall and Devon coastlines and the Somerset coast is contained in a relatively small and linear area in close proximity to the coast, other than in Barnstaple Bay and Bridgwater Bay. Likely resource would seem concentrated within the Severn, and the south Welsh coast. Pembroke has multiple issues relating to landscape/seascape, tourism/recreation and ecological factors.

5.15.9 Regional Sea 6

The resource areas in Cardigan Bay overlap the West Wales Marine SAC (harbour porpoise) and parts of the North Cardigan Bay SPA (red-throated diver), in addition to being within areas likely to be highly visible from valued landscape designations (Figure 5.88 and Figure 5.90). The north of the Llyn Peninsula and the west of Anglesey, there remains the potential for significant interactions with landscape designations and relevant conservation sites (Anglesey Terns SPA, North Anglesey Marine SAC) – see Figure 5.82 and Figure 5.84. These interactions continue around the north and east of Anglesey where there is some overlap with Liverpool Bay SPA (which includes red-throated diver), and is adjacent to a number of other existing or proposed wind farms in the area (see Section 5.7). Potential constraints were noted by the MoD as part of the Round 4 characterisation process for RAF Valley Precision Approach Radar (PAR), located on Anglesey. To the north and offshore of Anglesey, a number of areas of remaining fixed wind resource are present which are largely coincident with the former Celtic Array area (Figure 5.87). These areas show apparently lower levels of constraint than elsewhere in the Irish Sea, however certain aspects still have interactions with conservation interests (for example, the Irish Sea Front SPA), and in certain places they coincide with higher fishing effort (Figure 5.83), which are primarily targeting scallops (Figure 5.89 and Figure 5.90).

To the east, a small resource area is located to the south of Morecambe Bay and its related SPA, within the Liverpool Bay SPA, and immediately adjacent to the Shell Flat and Lune Deep SAC. The highly sensitive nature of the red-throated diver feature of Liverpool Bay SPA has already been noted above, and may present significant constraints to further consenting in this area. A number of gull and tern species are associated with Morecambe Bay SPA, which may forage or transit the remaining resource area. While apparently less visible from landscape designations, the area is located in close proximity to land, and any wind farm here would be a significant feature of the seascape. The area to the north Morecambe Bay is similarly close to the coast, and would be visible from coastal views from the Lake District National Park, and the nearshore area is located within the Morecambe Bay SPA, and in an area considered to be of higher use by terns. The offshore portion of this area also coincides with the edge of an area of higher intensity fishing, with including catches of high value species such as *Nephrops* associated with the East Irish Sea Mudbelt (see Figure 5.89 and, Appendices 1b and 1h).

A large area of remaining resource is located in the north of the East Irish Sea and in the outer Solway Firth. The area is located to the north of the *Nephrops* fishery noted above, and its offshore extent coincides with relatively few constraints. The nearshore area and that within the Solway overlap, or are close to, the Solway Firth SPA, which includes red-throated diver and common scoter (assemblage feature) as qualifying features. The area is located immediately offshore of St Bees Head Heritage Coast (Figure 5.88, Appendix 1h, Section 5.8), and all but the furthest offshore part of the area is likely to be highly visible from viewpoints along the north Cumbrian coast. The nearshore area has also been subject to sampling as part of monitoring related to Sellafield.

The floating wind resource is limited in Regional Sea 6, and includes an area off Pembrokeshire which could be subject to significant constraint on the basis of landscape/seascape interactions, which is similarly the case for the area to the north of the Llyn Peninsula. The remaining floating wind resource to the north and northwest of Anglesey is further from landscape designations, though development there still has the potential for a low magnitude of effect across at least part of the area. Other interactions with conservation sites including an overlap with this remaining resource areas and the North Anglesey Marine SAC and Irish Sea Front SPA (Figure 5.90).

Wave

There is no technical resource in Regional Sea 6 for wave energy, and it is considered highly unlikely that such activity will take place here.

Tidal

A significant portion of the tidal stream resource area (Figure 2.8) is located off the north of Anglesey, and future limitations on this energy source from development here would need to be considered in keeping with the Welsh National Marine Plan policies. Other areas of significant tidal stream resource in Regional Sea 6 are located off the Llyn Peninsula and Pembroke, each of which have projects with tidal stream lease agreements, reflecting the highly prospecitive nature of resource at these locations. Any future projects of commercial scale would be expected to be located around the areas described above.

Regional Sea 6 contains some of the largest areas of technical resource for tidal range (Figure 5.95), though their potential to be used for projects is likely to be much smaller and be confined to bays and the immediate coastline. The tidal range resource is coincident with a range of competing interests, including for offshore wind, shipping, fisheries, carbon dioxide storage, and potentially further hydrocarbon gas production and storage. Interaction with features of the Liverpool Bay SPA (red-throated diver, common scoter, terns, little gull, wintering waterbirds) could be challenging for certain project phases, as well as other SPAs in areas covering bays such as Morecambe Bay and Duddon Estuary SPA (terns, gulls, wintering waterbirds), Ribble and Alt Estuary SPA (terns, gulls, wintering waterbirds), the Dee Estuary SPA (terns, wintering waterbirds), and the Solway Firth SPA (red-throated diver, wintering waterbirds), or on the open coast such as Anglesey Terns SPA.

Figure 5.81: Offshore wind: seafloor area remaining following application of "hard" constraints (10-60m) – refer to Table 5.35

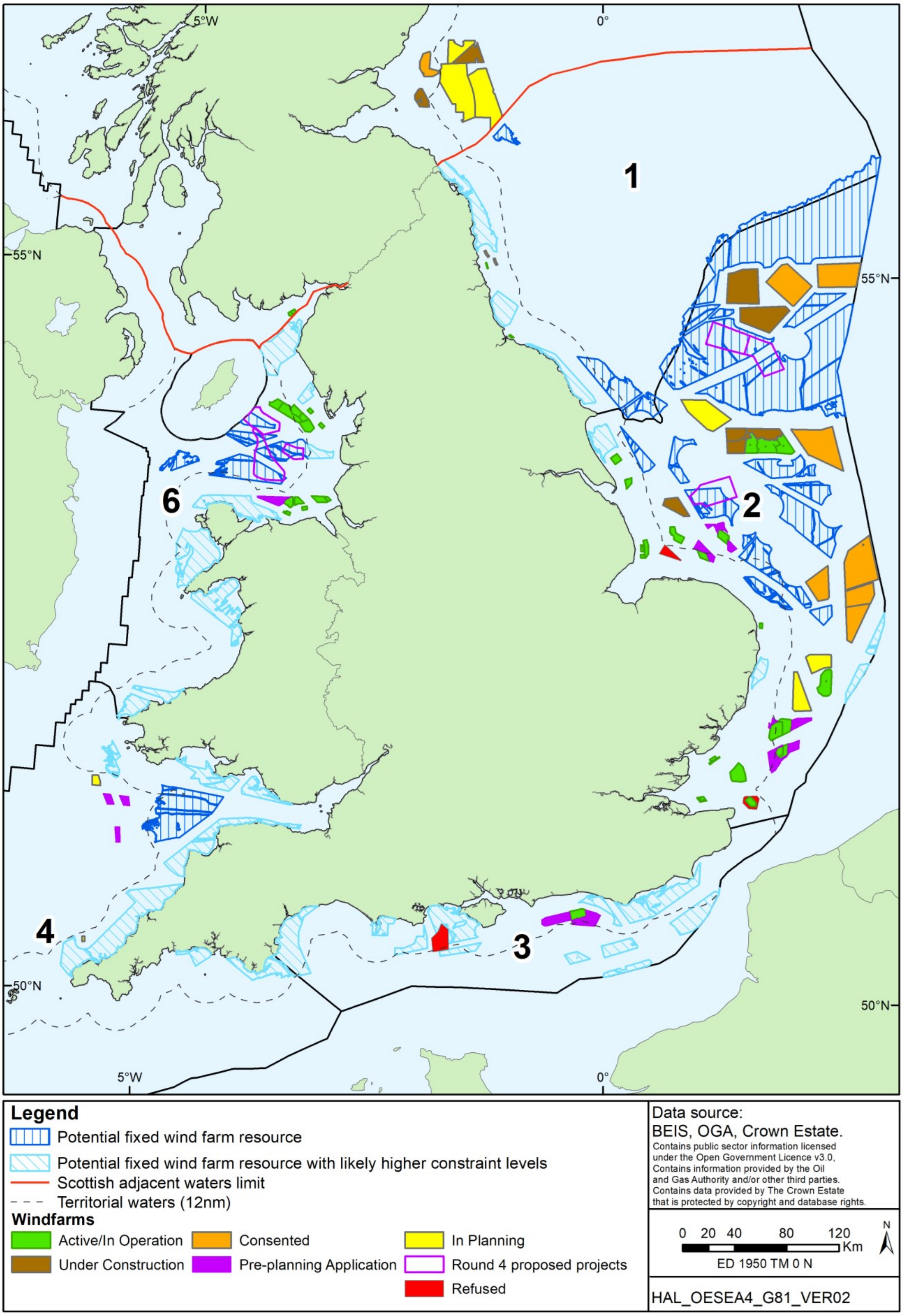


Figure 5.82: Offshore wind: seafloor area remaining following application of "hard" constraints (10-60m) and areas of higher visibility from landscape designations

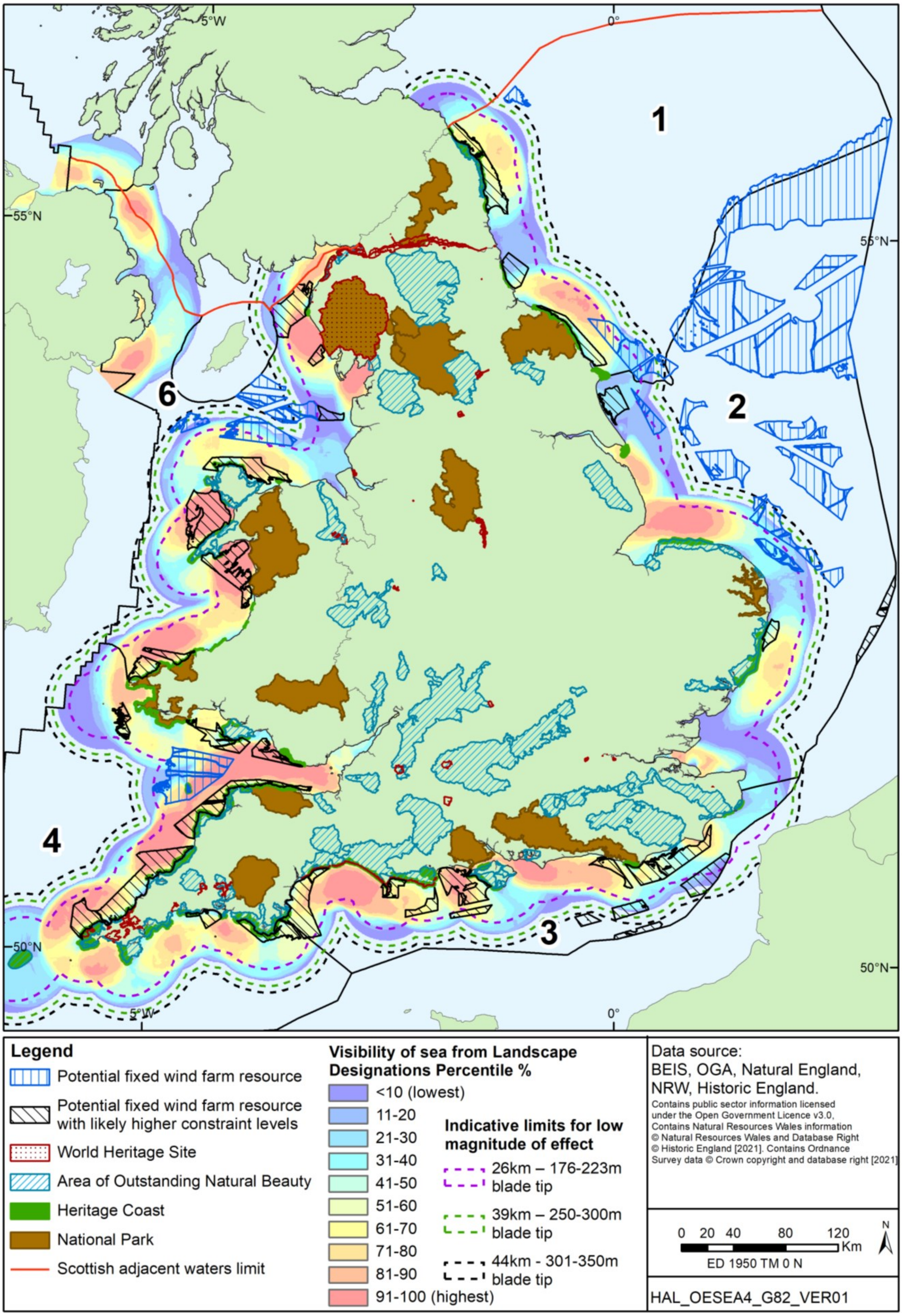


Figure 5.83: Offshore wind: seafloor area remaining following application of "hard" constraints (10-60m) and fisheries effort

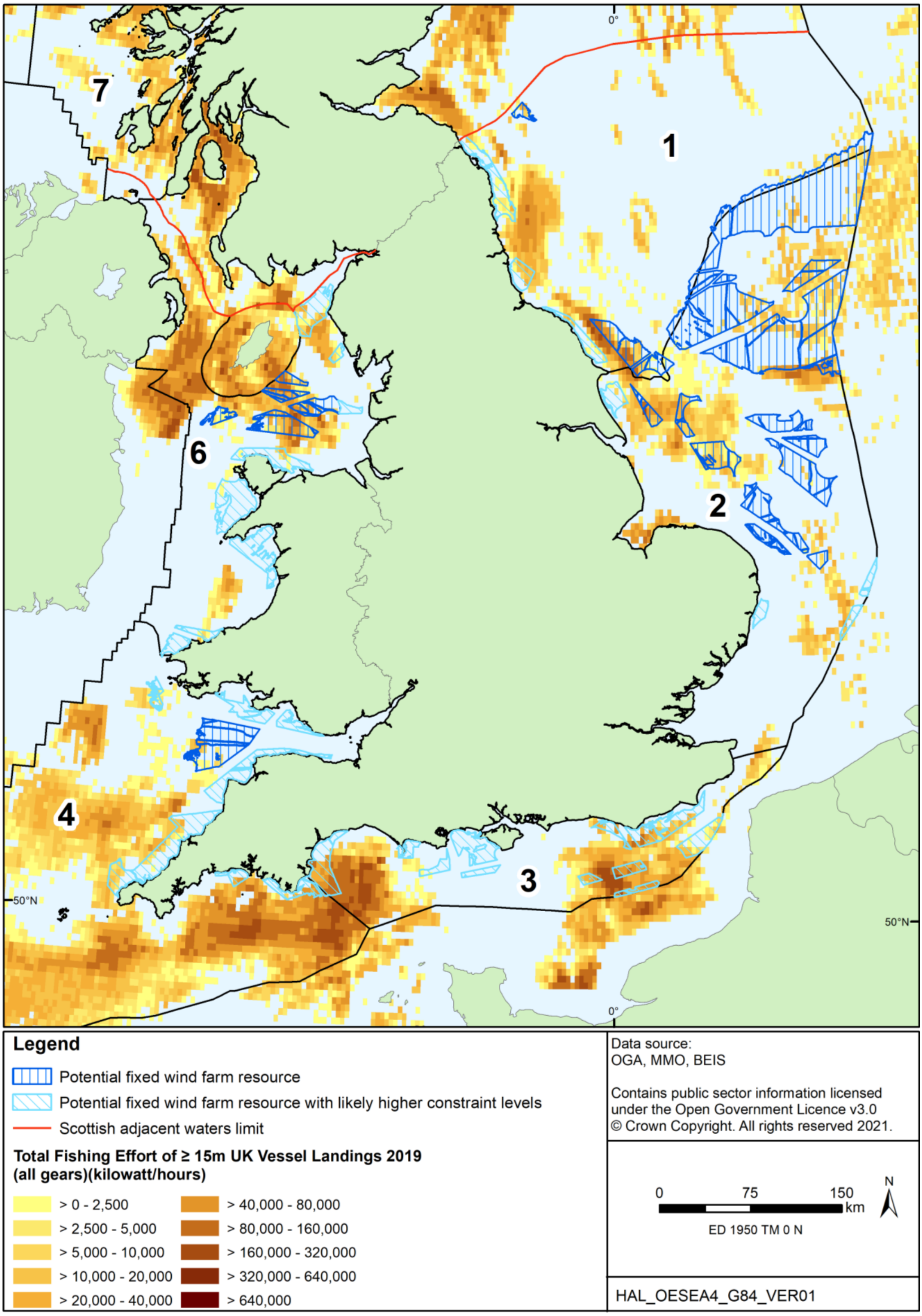


Figure 5.84: Offshore wind: seafloor area remaining following application of "hard" constraints (10-60m) and conservation sites

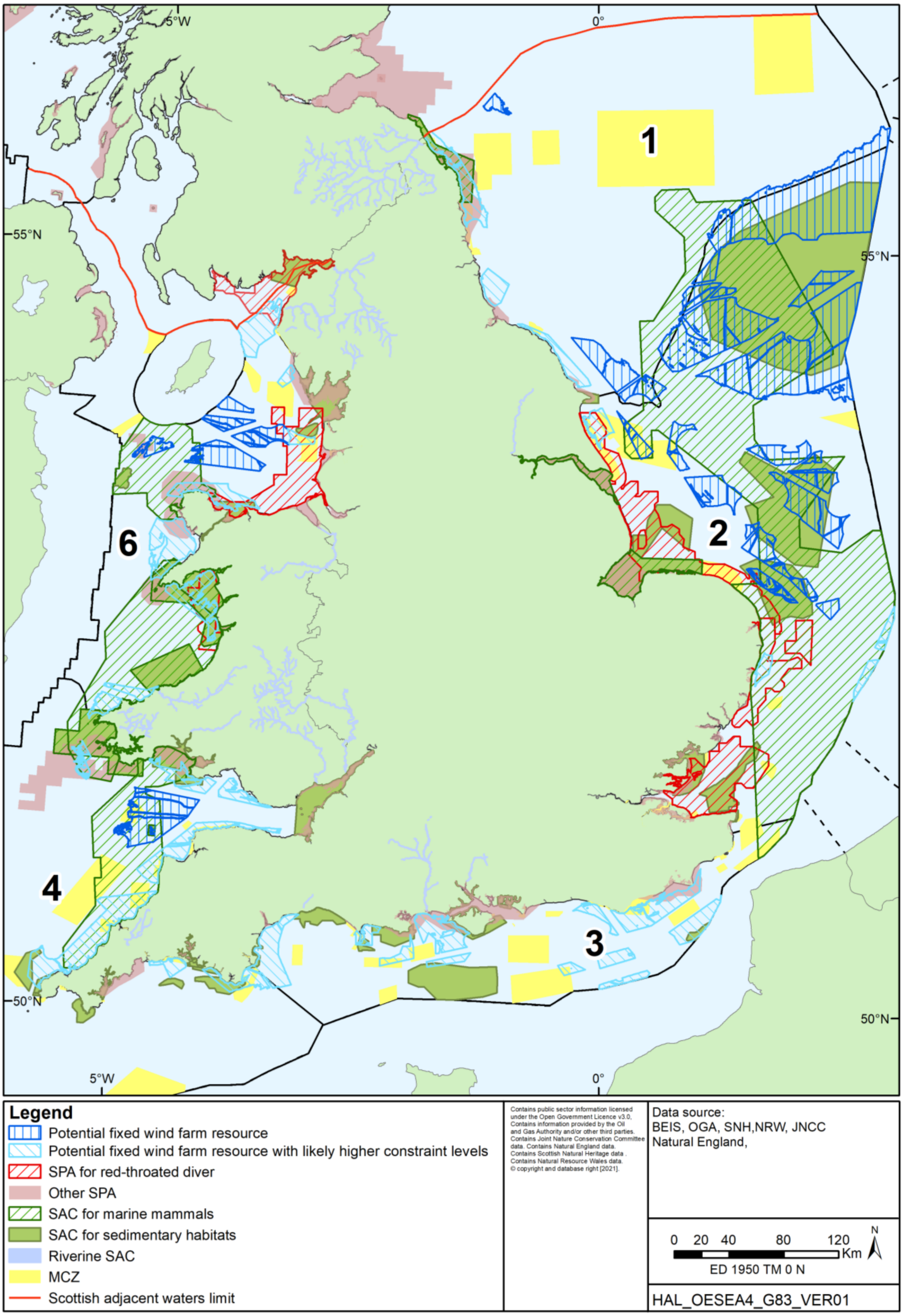


Figure 5.85: Offshore wind: seafloor area remaining following application of "hard" constraints (10-60m), and "other" constraints weighted as per Section 5.X.3 and applied to a 5x5km grid

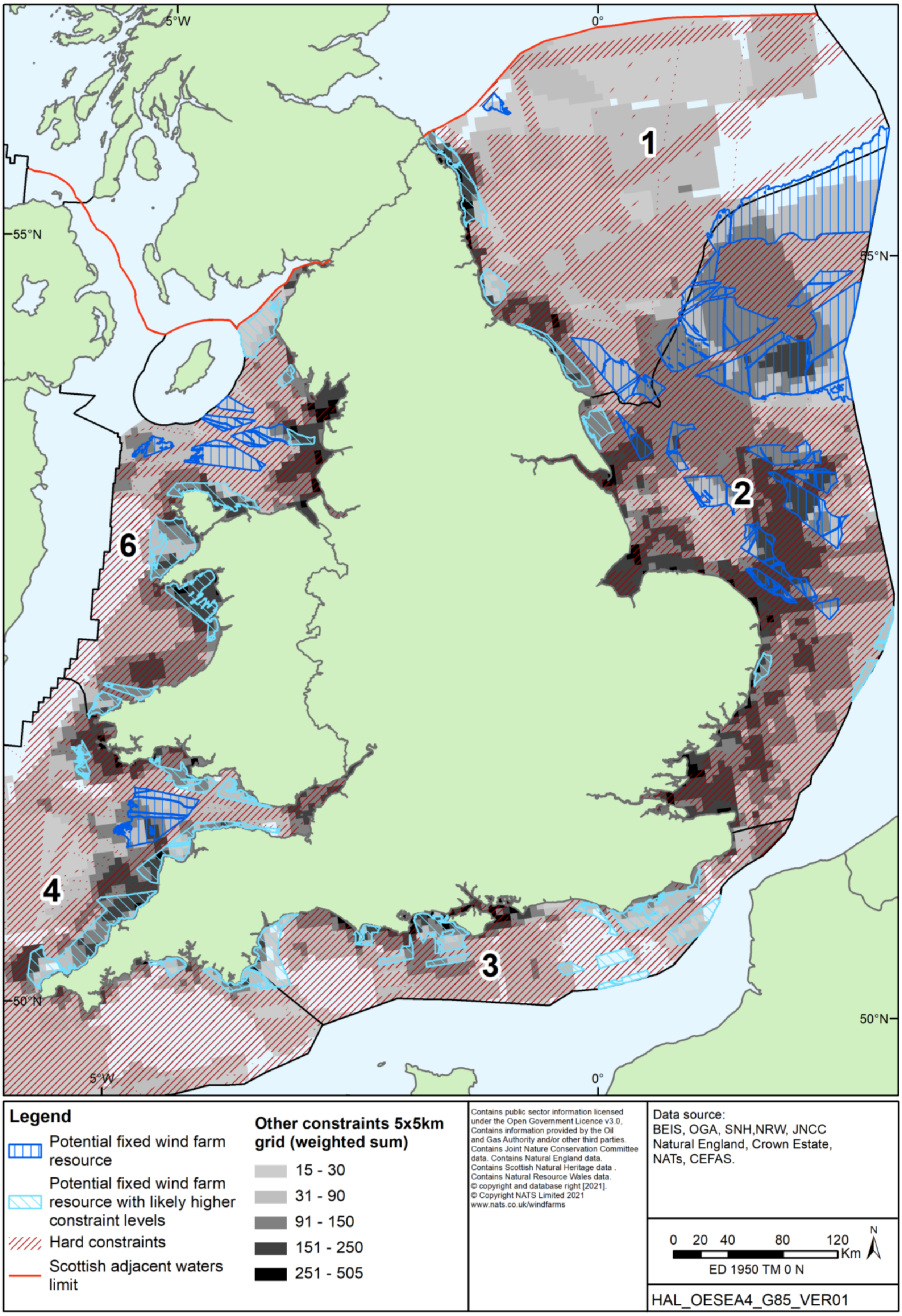


Figure 5.86: Offshore wind: seafloor area remaining following application of "hard" constraints (10-60m) and Quaternary thickness

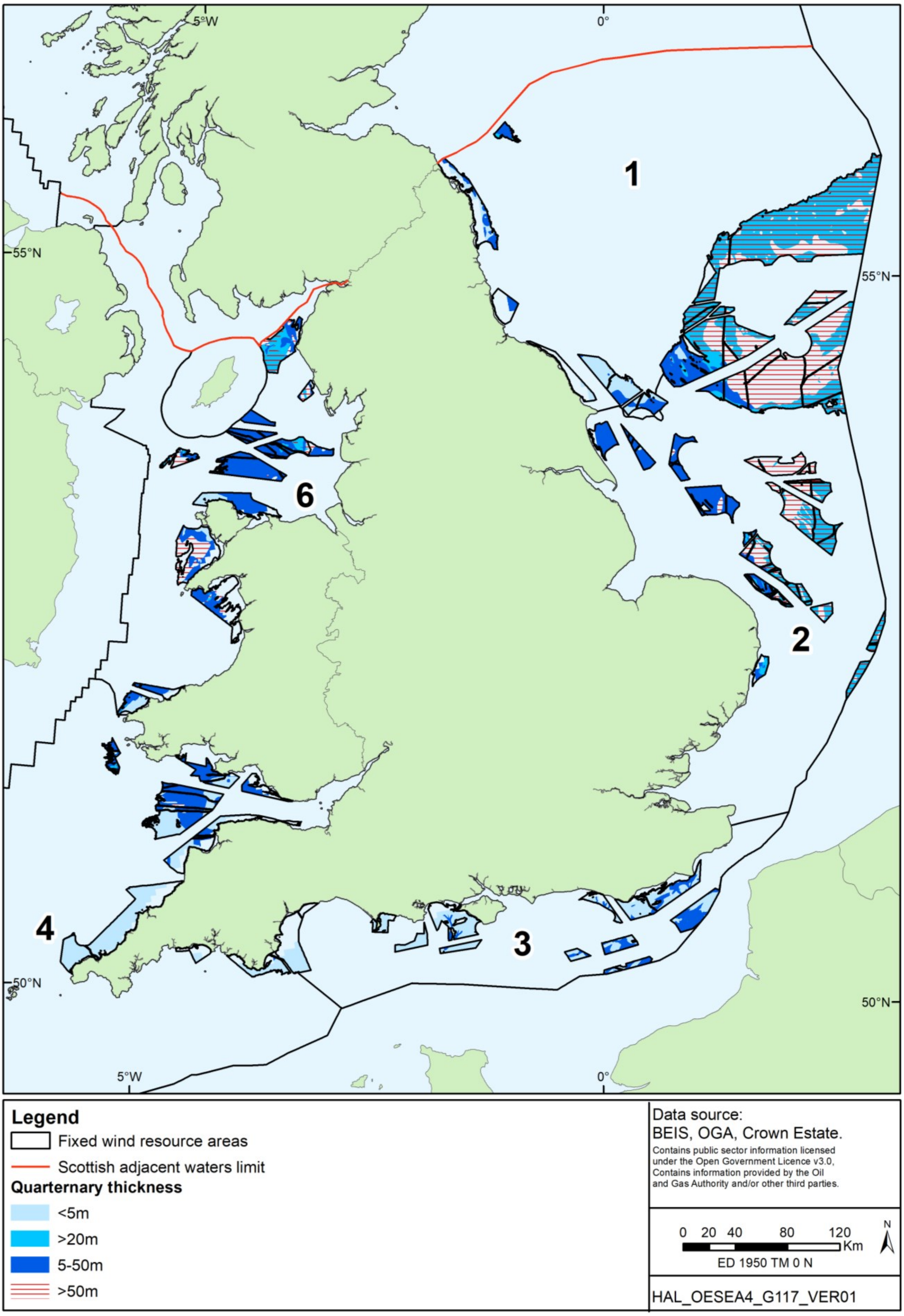


Figure 5.87: Offshore wind: seafloor area remaining following application of “hard” constraints (50-200m) – refer to Table 5.35

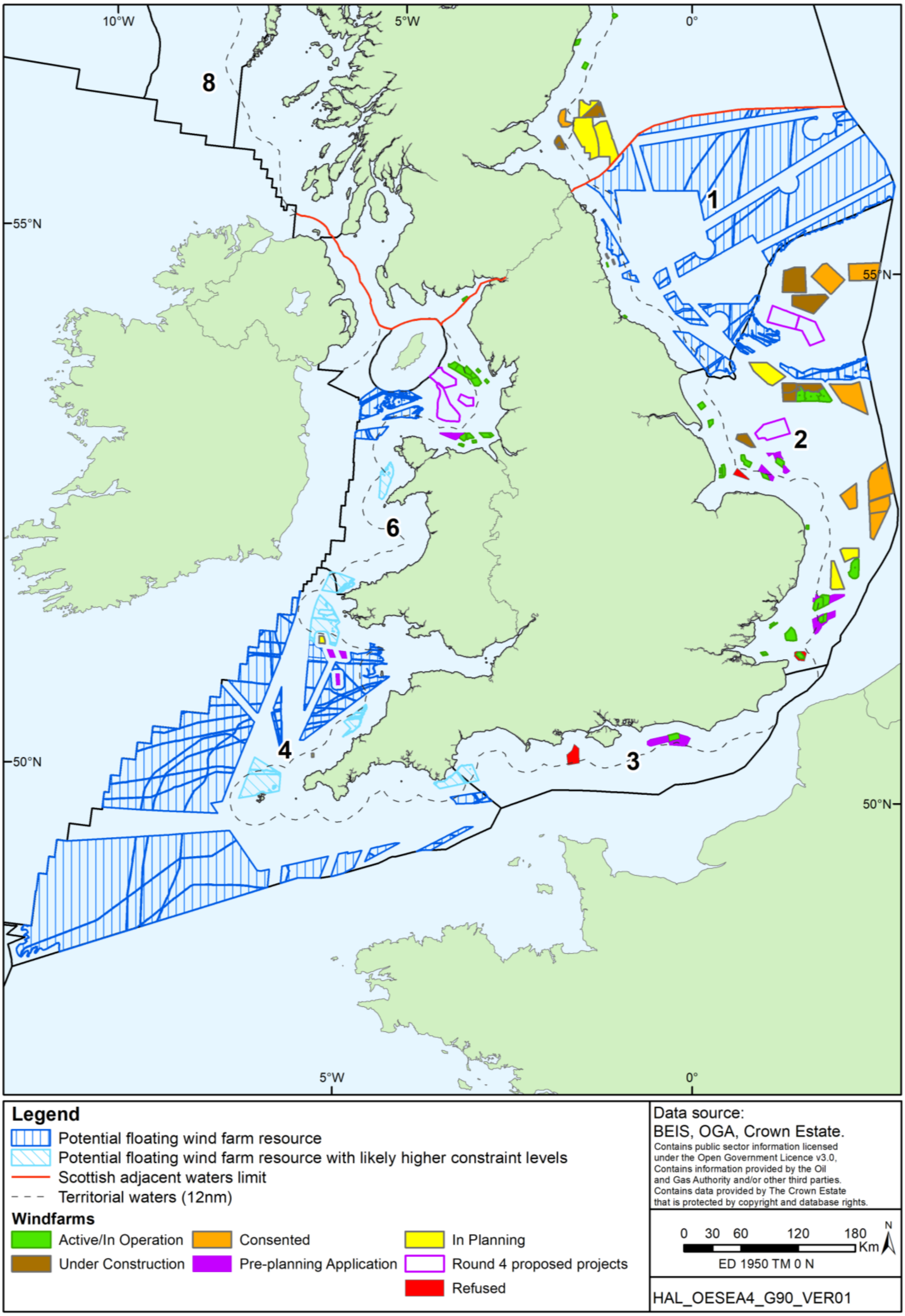


Figure 5.88: Offshore wind: seafloor area remaining following application of "hard" constraints (50-200m) and areas of higher visibility from landscape designations

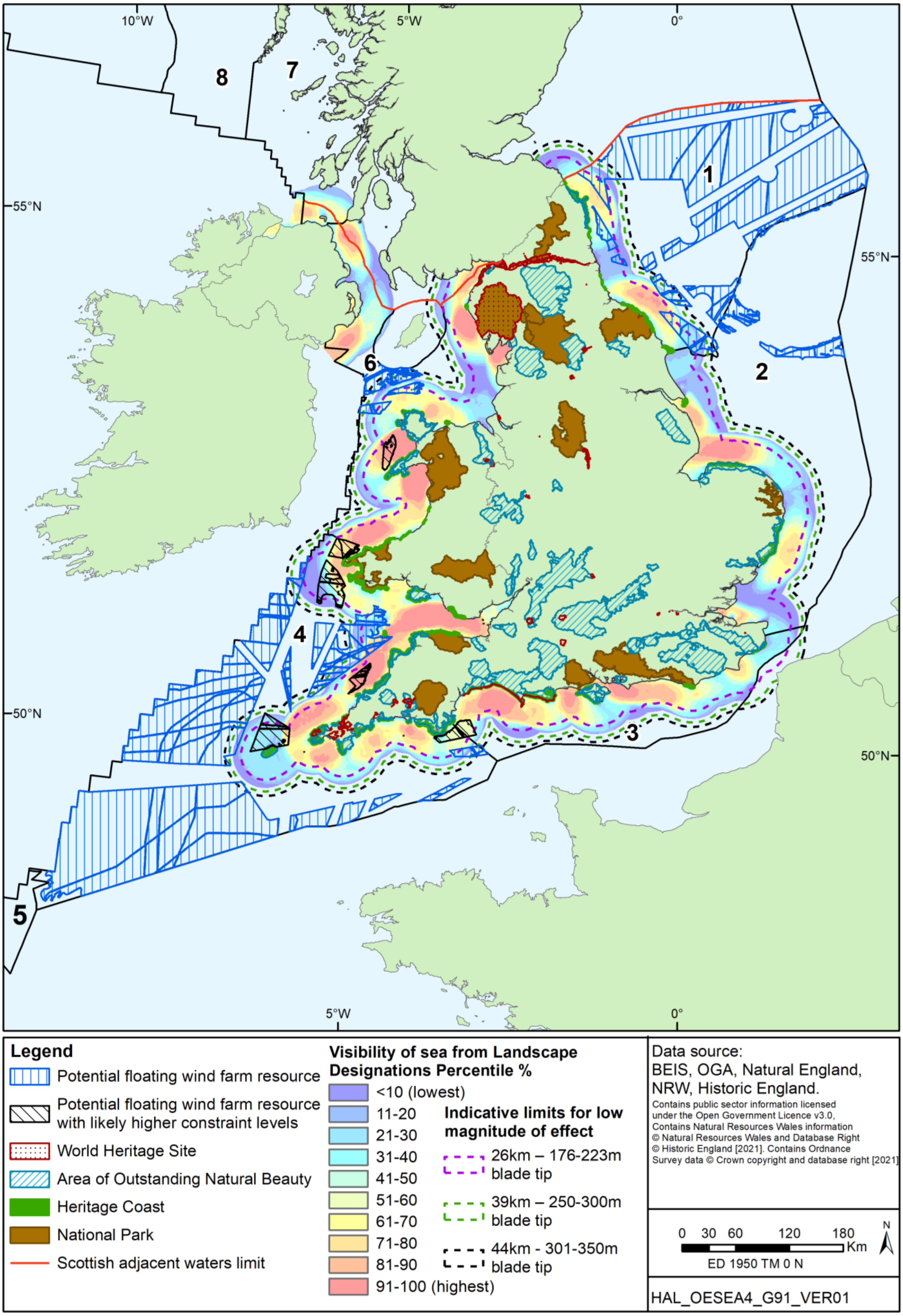


Figure 5.89: Offshore wind: seafloor area remaining following application of "hard" constraints (50-200m) and fisheries effort

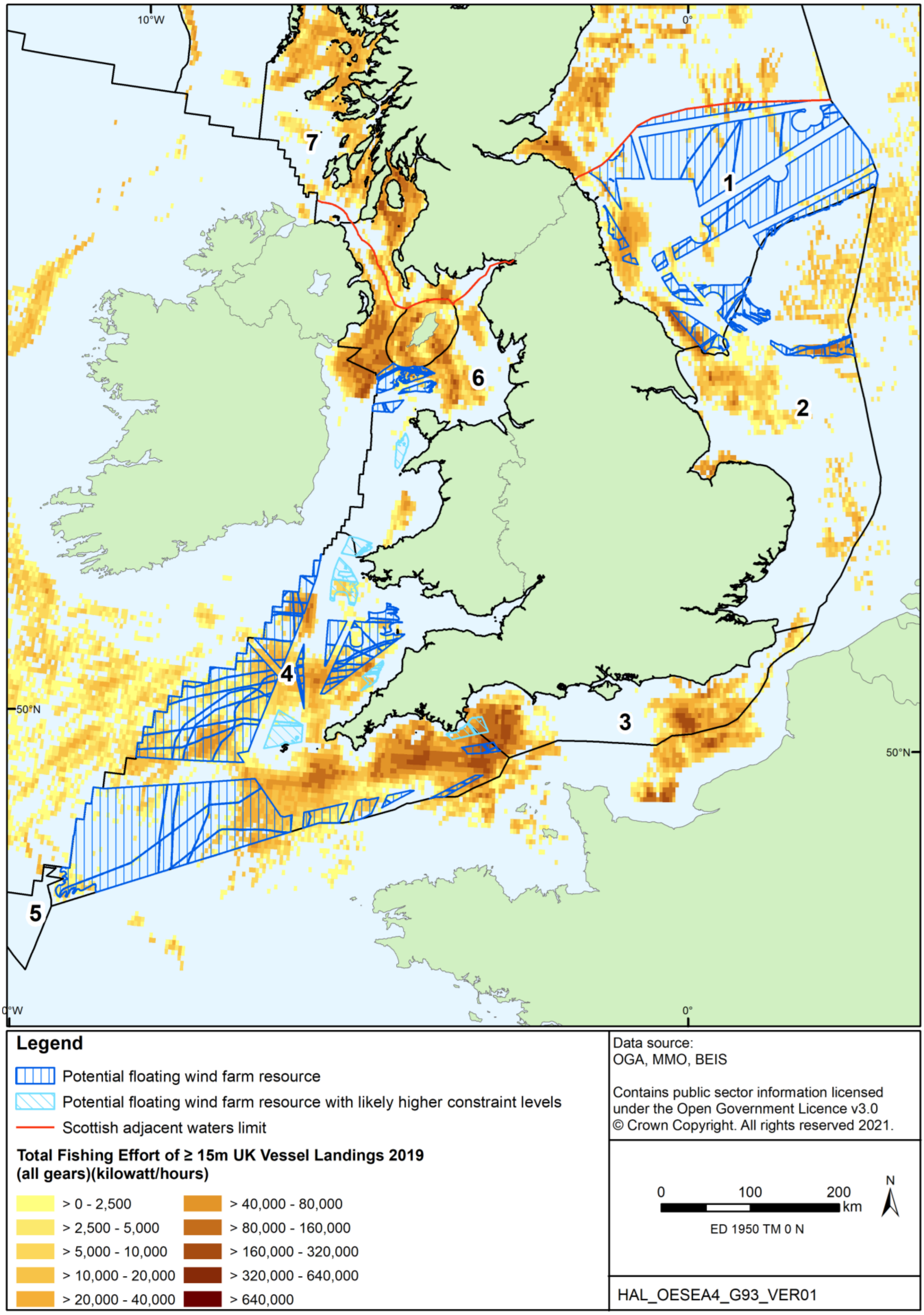


Figure 5.90: Offshore wind: seafloor area remaining following application of “hard” constraints (50-200m) and conservation sites

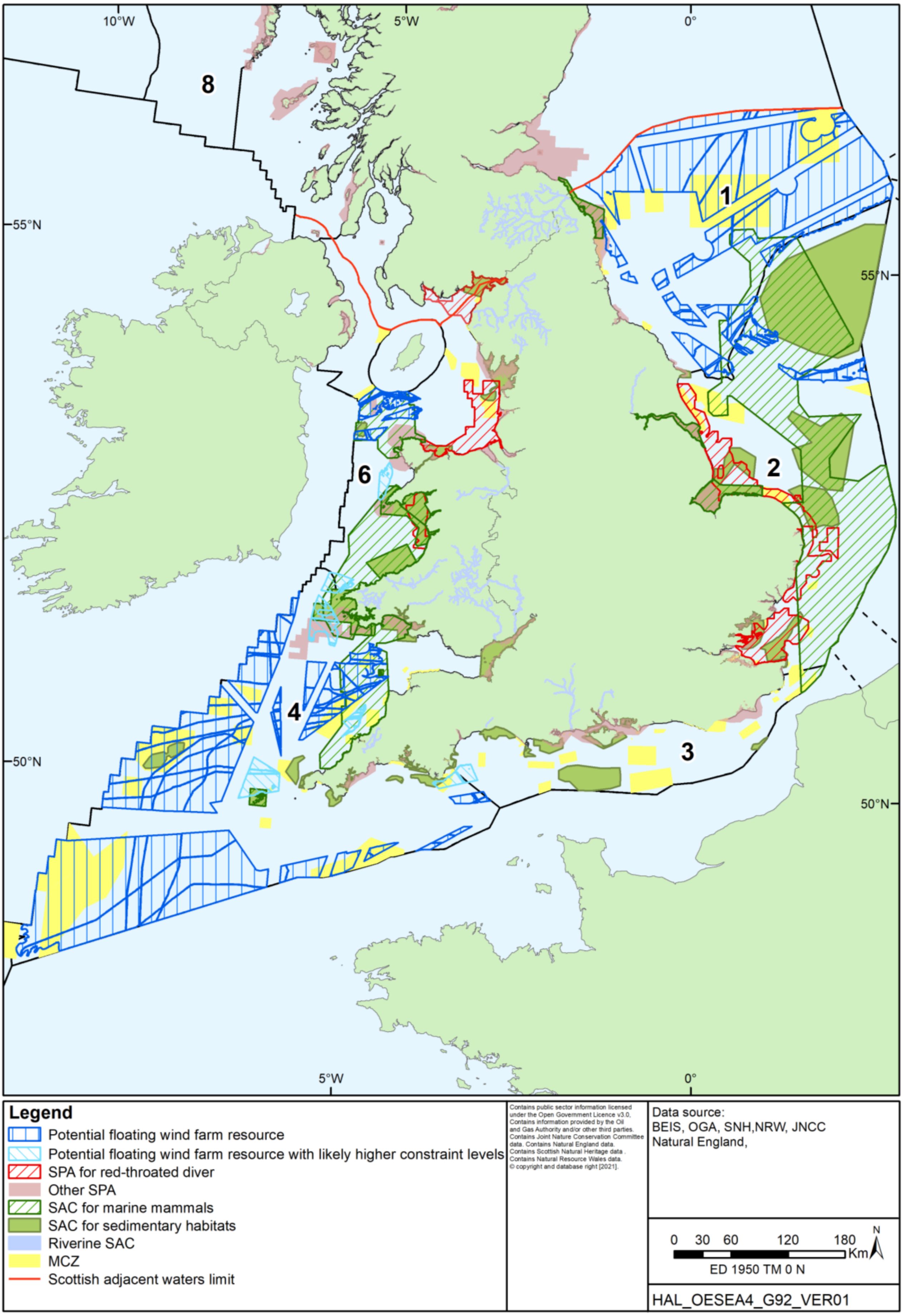
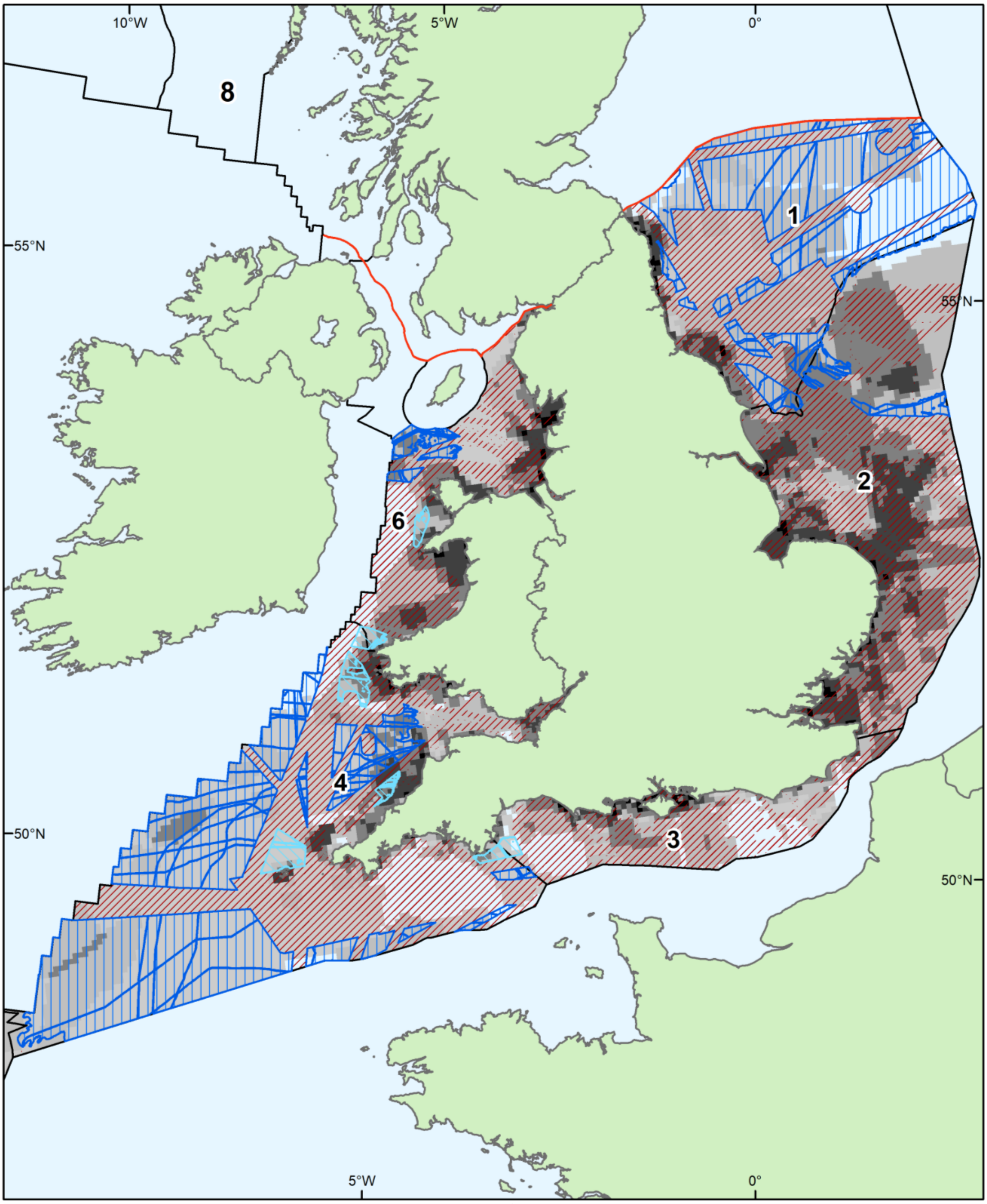


Figure 5.91: Offshore wind: seafloor area remaining following application of "hard" constraints (50-200m), and "other" constraints weighted as per Section 5.X.3 and applied to a 5x5km grid



Legend

- Potential floating wind farm resource
- Potential floating wind farm resource with likely higher constraint levels
- Hard constraints
- Scottish adjacent waters limit

Other constraints 5x5km grid (weighted sum)

- 15 - 30
- 31 - 90
- 91 - 150
- 151 - 250
- 251 - 505

Data source:
BEIS, OGA, SNH,NRW, JNCC Natural England, Crown Estate, NATs, CEFAS.

0 30 60 120 180 Km
N
ED 1950 TM 0 N

HAL_OESEA4_G94_VER01

Figure 5.92: Wave: seafloor area remaining following application of "hard" constraints

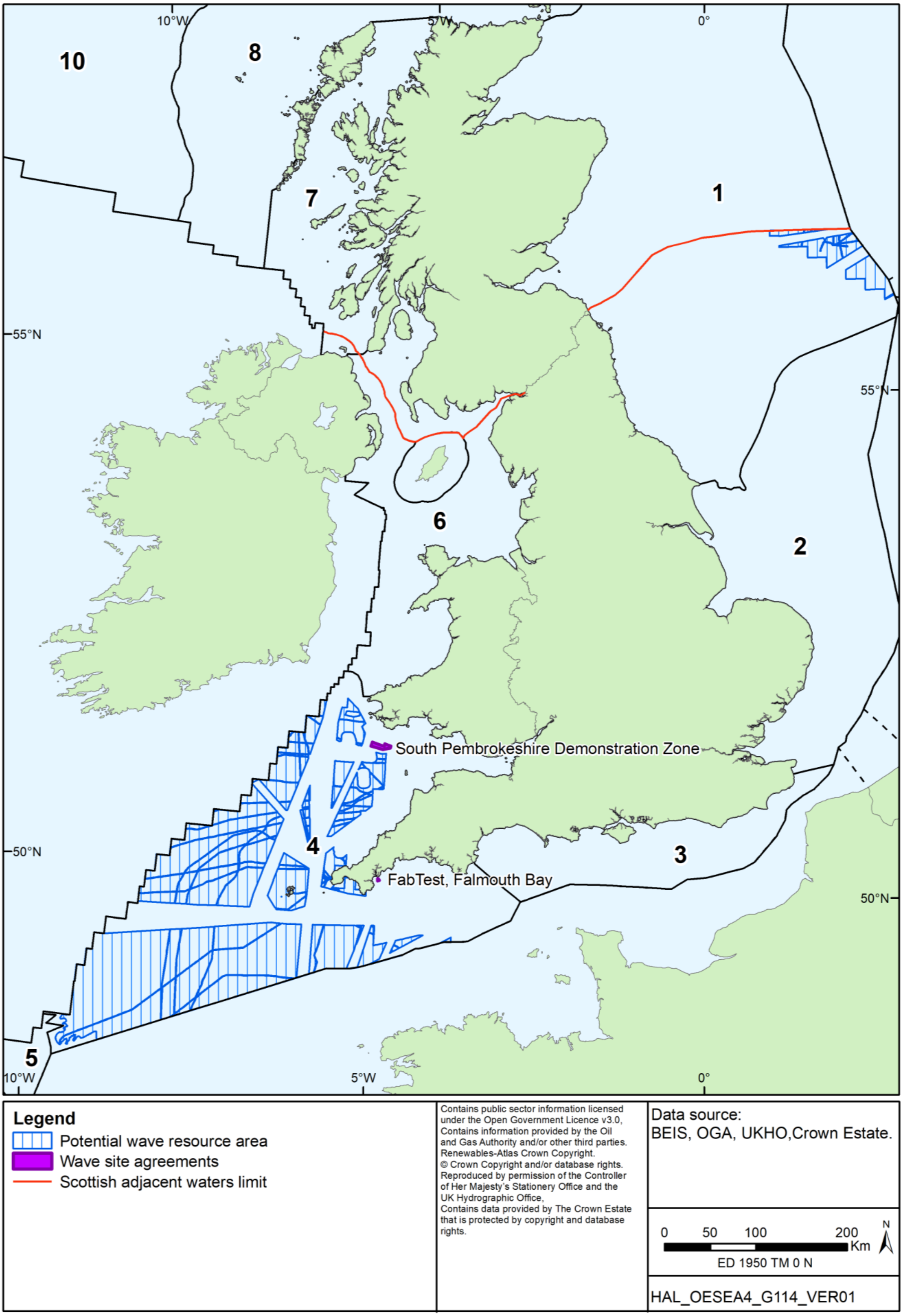


Figure 5.93: Wave: seafloor area remaining following application of "hard" constraints and fisheries effort

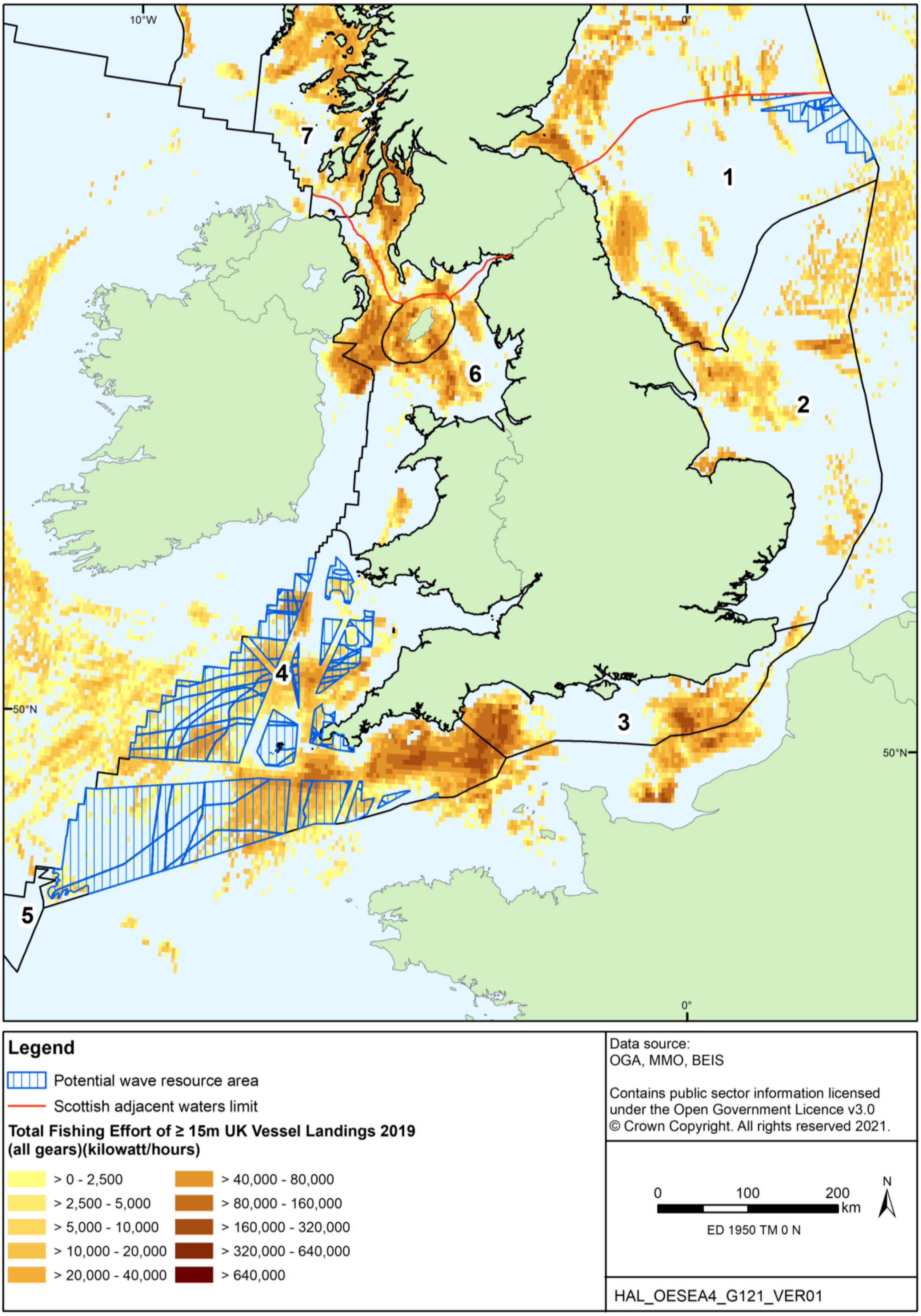


Figure 5.94: Tidal stream: seafloor area remaining following application of "hard" constraints

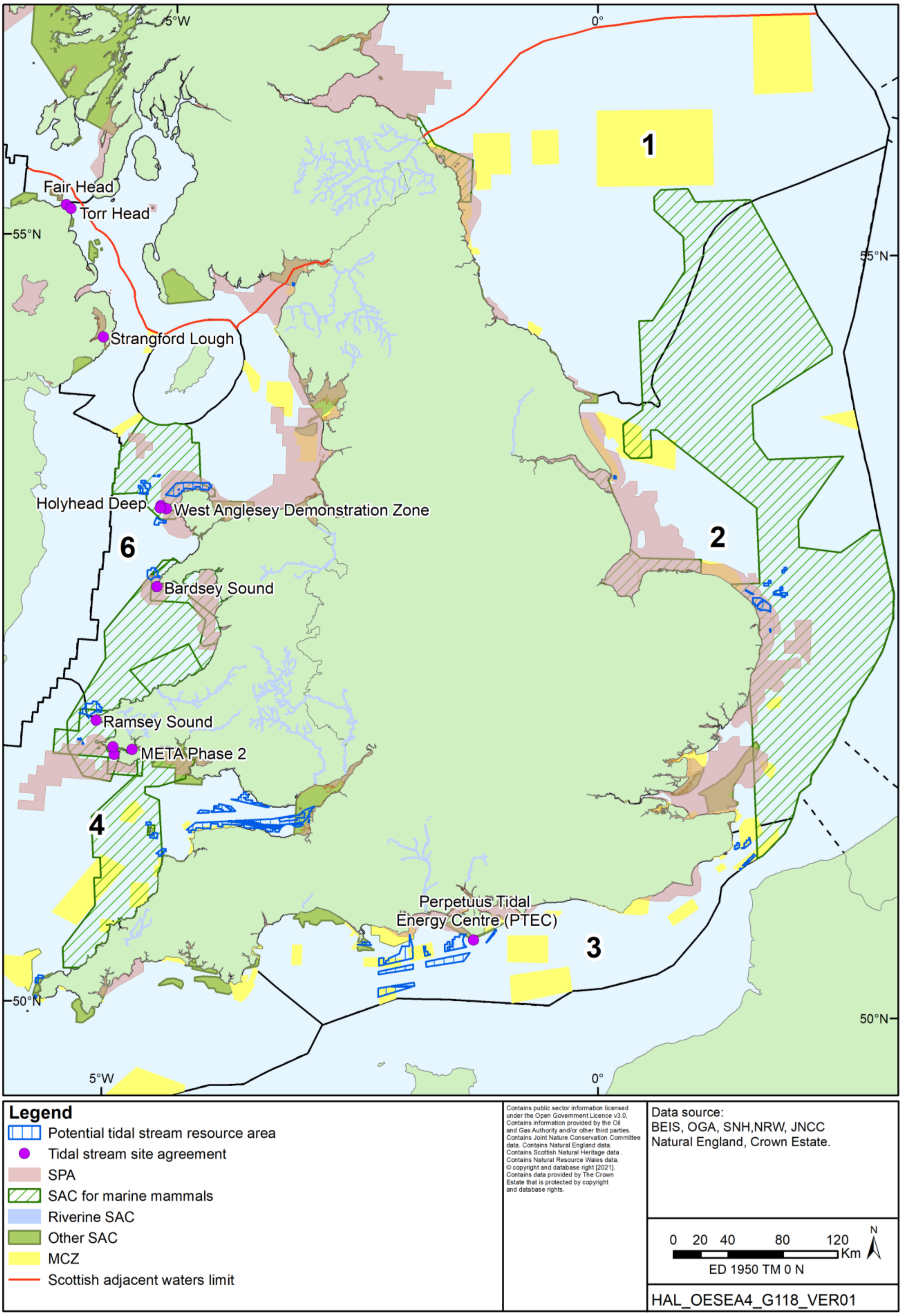
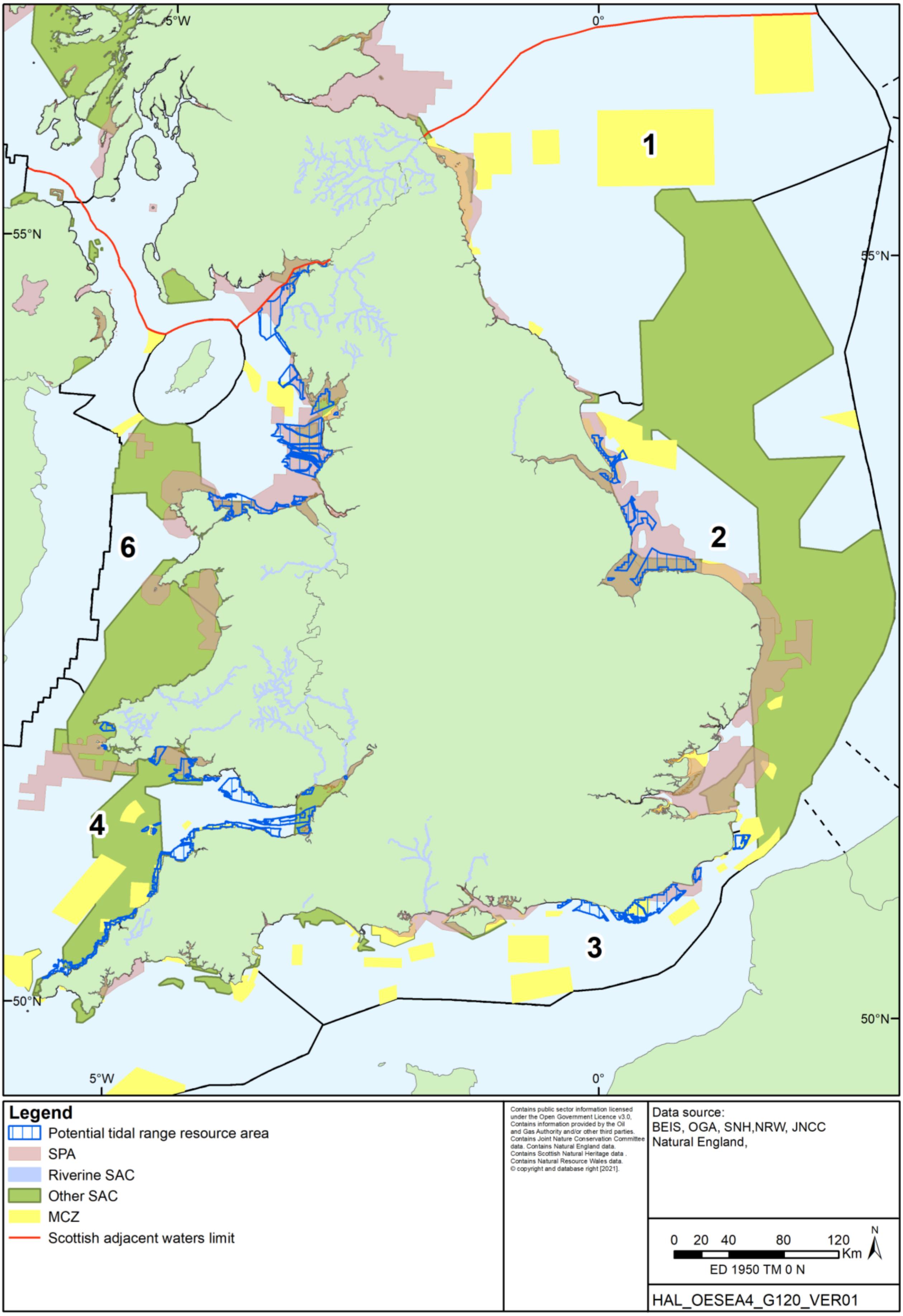


Figure 5.95: Tidal range: seafloor area remaining following application of "hard" constraints



5.15.10 Summary of findings and recommendations

The above consideration, and also the other chapters which precede/follow this, also cover the potential issues on siting any of the technologies covered by the draft plan/programme insofar as they can be spatially explicit.

At a European level, the construction of marine renewable energy installations (primarily wind) has increased significantly in recent years, principally in the shallow southern North Sea (e.g. in UK, German, Dutch and Belgian waters), and in the east Irish Sea (including a proposal in Manx waters). These areas are also intensively used for other activities, some of which are cross-boundary, including fisheries, shipping, ferry routes and recreational sailing. Plan activities could act cumulatively with existing offshore activities by generating further spatial restrictions, though marine spatial planning should assist the strategic identification of such impacts and help facilitate appropriate siting of new developments – marine planning is being undertaken across Europe under the auspices of the Marine Spatial Planning Directive (including the UK under retained EU law), and through a separate but similar process in Manx waters.

The above assessment does not support the alternative not to lease or license areas for development (Alternative 1). The consideration of spatial constraints above has concluded that a significant amount of marine renewable energy could be delivered from offshore wind in addition to those projects which have been consented or are in planning or pre-planning. This includes the removal of certain resource areas where constraints are considered to be particularly high (largely located in nearshore and coastal areas), and no relaxation of the "hard" constraints identified above. It should be noted that this does not suggest that the areas identified as having very high levels of constraint should be definitively excluded from further renewables development, as every project should be assessed on its own merits, but they are identified here in a strategic way to reflect that significant resources remain on the UKCS away from these areas. This is in view of their importance, reflected in numerous uses for recreational, shellfishery, fishery, navigational, commercial and other activities, in addition to designations to protect their scenic, geological, ecological and cultural features. The sensitivity of coastal areas is not uniform and the intensity of uses and designations typically declines further offshore away from the coast. Similarly, the mapped other remaining resource areas should not be taken to represent areas of no constraint, as significant consenting risks may remain for these which cannot be readily accounted for in such a spatial analysis. All activities and developments covered by the draft plan/programme require site-specific information gathering and stakeholder consultation to inform consenting decisions. In addition to marine spatial plan requirements, the particular sensitivity of the coastal zone and must be taken into account during site selection for proposed developments within territorial waters. Some developments may not be compatible with a particular nearshore location.

5.16 Consideration of potential for cumulative impacts

5.16.1 Introduction

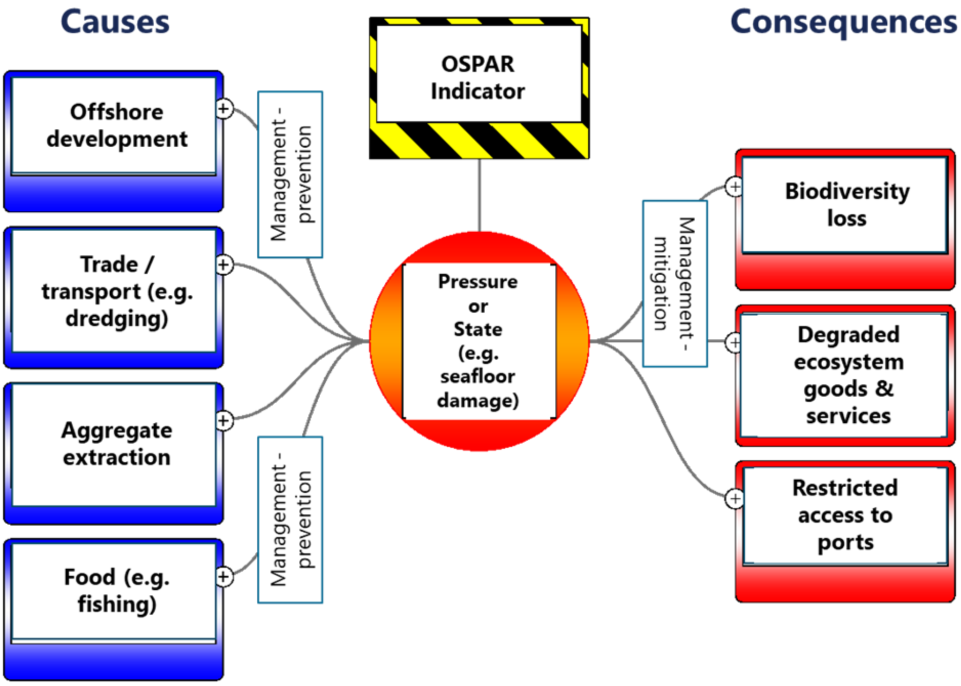
The *Environmental Assessment of Plans and Programmes Regulations 2004* require *inter alia* that secondary, cumulative and synergistic effects be considered. The UK Marine Strategy Part 1 (Defra 2012b, 2019) noted that improving the evaluation of the cumulative effects of human activities on marine ecosystems was an important priority to ensure that the management decisions needed to protect the marine environment were supported by the best possible evidence. In the intervening period, the UK has contributed both nationally, initially through the Cross-Government working group on Cumulative Effects Assessment (CEA) and currently in Productive Seas Evidence Group (PSEG), and internationally, through leading the OSPAR Group on Cumulative Effects, which is examining this issue for the Quality Status Report 2023 (see below).

As part of this work, CEFAS was commissioned to develop a cumulative effects assessment methodology, which applied the ecosystem approach utilising the risk analysis tool Bow Tie Analysis (BTA, described here[326]). BTA is a simple diagrammatic way of describing and analysing the pathways of an environmental risk from causes (i.e. marine activities and the pressures they exert), which contribute to a loss of control (e.g. environmental status represented by an indicator) through to consequences (e.g. environmental impacts), factoring in the effectiveness of any controls (management measures) that may exist. Environmental indicators are commonly used as a representative proxy of the wider ecosystem and linking different BTAs together allows consideration of multiple causes and consequences. Diagrammatically, the loss of control (e.g. the aspect of environmental status that the indicator describes) is represented by the knot of the bow-tie, the causal factors listed to the left and the environmental outcomes listed to the right (Figure 5.96). There are two sets of management measures: preventative controls (which aim to stop a potential cause triggering a change) and mitigation controls (which aim to reduce the impact of a change if it does occur).

Using the example of seafloor damage (the knot), examples of possible causes from the BTA are aggregate extraction, fishing, infrastructure construction or navigational dredging. Possible consequences may be changes to ecosystem goods and services, changes in biodiversity, or a reduced economic capacity if navigation channels are not maintained. This assesses cumulative effects around a single issue (i.e. the multiple causes and impacts associated with seafloor damage).

[326] https://moat.cefas.co.uk/uses-of-the-marine-environment/cumulative-effects-of-human-activities/

Figure 5.96: Example of Bow Tie Analysis constructed around OSPAR pressure or state indicators



Source: Cumulative effects of human activities, https://moat.cefas.co.uk/uses-of-the-marine-environment/cumulative-effects-of-human-activities/

The relationships between the ecosystem components are further investigated by chaining associated BTAs together building a picture of the collective pressures arising from human activities without losing sight of the causal factors and any management measures applied. The current focus is to develop specific case studies to practically evaluate the interaction of multiple pressures in real world scenarios, being done as part of the CEA for the OSPAR QSR 2023.

OSPAR QSR 2023 will not include an attempt to assess the cumulative effects of every possible pressure and impact combination, but instead will focus on undertaking a cumulative effects assessment that is integrated with the OSPAR common Indicator Assessments and their associated data[327]. Bow-ties are being constructed to summarise and expand the content from the assessment sheets for each OSPAR common indicator[328]. Figure 5.97 shows an example of a bow-tie for the seafloor damage indicator (BH3). Once the work to construct bow-ties for each indicator is complete, linkages between related parameters will be established, such as linking pressures, hazards or effects depending on the nature of the relationships and the confidence in the associations.

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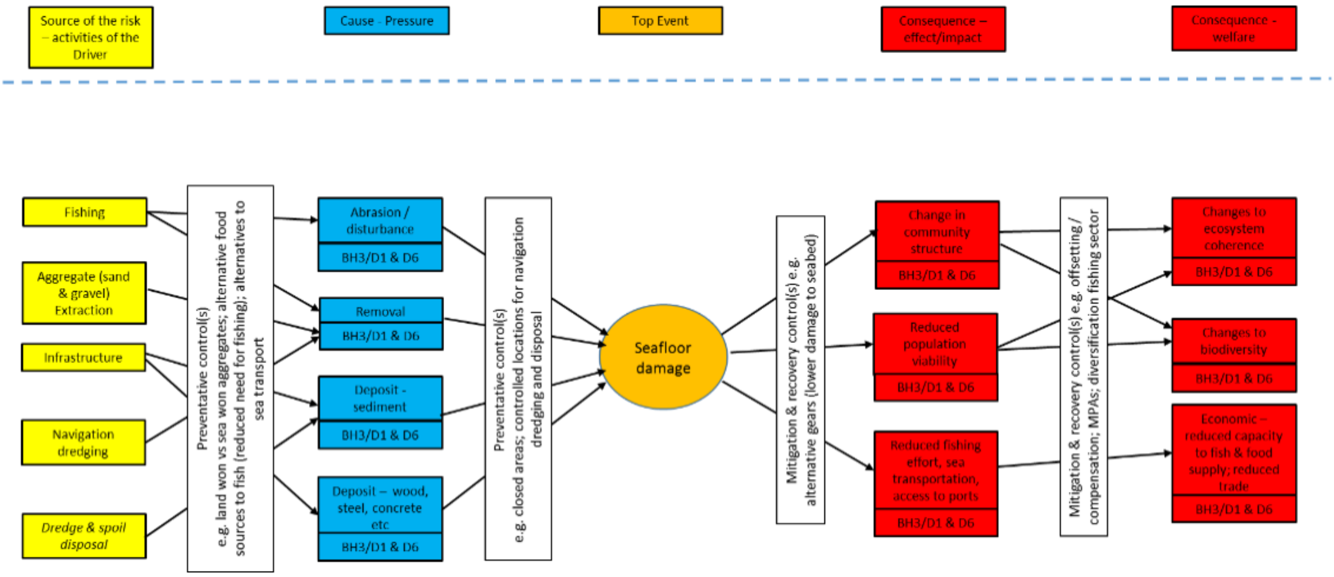
[327] https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/chapter-6-ecosystem-assessment-outlook-developing-approach-cumul/

[328] https://www.ospar.org/work-areas/cross-cutting-issues/ospar-common-indicators

Figure 5.97: OSPAR seafloor damage bow-tie

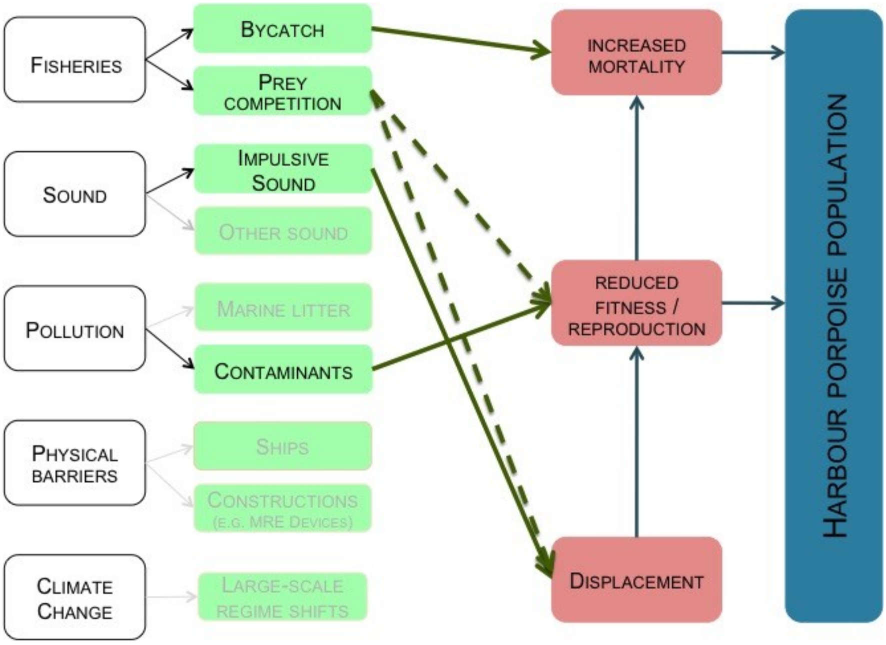


Source: https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/chapter-6-ecosystem-assessment-outlook-developing-approach-cumul/

Case studies investigating effects from human activities on the harbour porpoise are currently being progressed to test and describe the practical application of the cumulative effects approach for QSR 2023. The first of these presents a general framework of the way cumulative effects of all (most relevant) pressures for the harbour porpoise population could be assessed. The pressure-effect relationships in the case study are supported by a review of the literature and the knowledge base within OSPAR committees and thematic work streams which rationalised the associations to identify the most important relationships shown by the bold, continuous and dashed arrows (Figure 5.98). The pressures suspected to have a strong impact on the harbour porpoise population in the North Sea and for which enough quantitative information is available to estimate the effect on the population were identified as: fisheries bycatch (increased mortality), impulsive underwater sound (habitat loss), and pollutants (reduced fitness / impaired reproduction). The second case study constructed this framework in a more detailed and quantified manner for the cumulative effects of impulsive noise on the harbour porpoise population of the North Sea (based on Heinis & de Jong 2015).

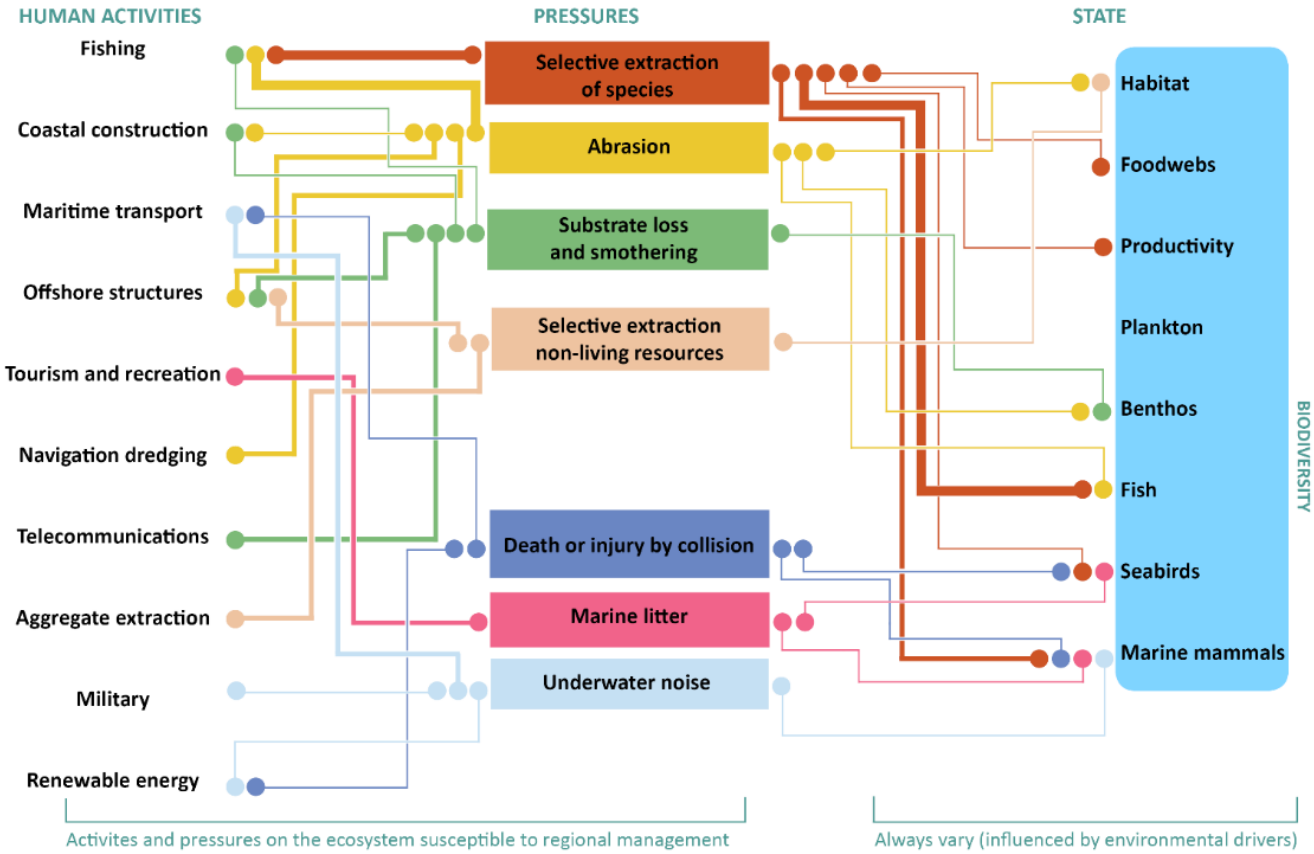
The ICES Working Group on Cumulative Effects Assessment in Management has developed a cumulative effects assessment framework to provide science advice as guidance for the implementation of ecosystem-based management. The framework reflects a step-wise process that aligns the prioritisation of key pressures through causal pathways within defined assessment boundaries. An algorithm has been developed to calculate impact risk scores reflecting vulnerability of the ecosystem to human activities (ICES 2022). WGCEAM undertook a case study for the North Sea (and the Gulf of St Lawrence) to test the framework with semi-quantitative and quantitative data and improve the framework where needed (see Piet *et al.* 2021). The short-term contribution of the WGCEAM outputs into the ecosystem advice provided by ICES is by providing an improved methodology to construct the wire diagrams (or human activity-pressure-ecosystem state component network figures) that are at the basis of the ICES Ecosystem overviews. The relevant diagram for the Greater North Sea is indicated in Figure 5.99.

Figure 5.98: Main sources, pressures and exposure pathways for harbour porpoise population



Source: https://oap.ospar.org/en/ospar-assessments/intermediate-assessment-2017/chapter-6-ecosystem-assessment-outlook-developing-approach-cumul/

Figure 5.99: Greater North Sea ecoregion overview with the major regional pressures, human activities, and ecosystem state components



Note: The width of lines indicates the relative importance of main individual links (the scaled strength of pressures should be understood as a relevant strength between the human activities listed and not as an assessment of the actual pressure on the ecosystem). Climate change affects human activities, the intensity of the pressures, and some aspects of state, as well as the links between these. Source: ICES (2021a).

The approach adopted for assessment of cumulative effects within this SEA has developed over successive SEAs, reflecting experience, consultation responses and guidance from a range of sources within the UK, EU and internationally. Stakeholder consultation has emphasised the importance of cumulative effects within the overall process. It is clear from the ongoing national and international initiatives summarised above that CEA approaches have developed significantly in recent years. The SEA process will review the ongoing development of these initiatives and look to factor them into the assessment at an appropriate time.

5.16.2 Definitions

The terminology and methodology applied to the application of cumulative effects assessment has to date been various. However, all have had the intention of achieving an assessment of multiple pressures on one or a range of receptors (Judd *et al.* 2015). An overall definition of cumulative effects has been variously modified from that of Cooper (2004), and by Judd *et al.* (2015) as, "...*a systematic procedure for identifying and evaluating the significance of effects from multiple pressures and/or activities on single or multiple receptors. Cumulative effects assessment provides management options, by quantifying the overall expected effect caused by multiple pressures and by identifying critical pressures or pressure combinations and vulnerable receptors. The analysis of the causes (source of pressures), pathways, interactions and consequences of these effects on receptors is an essential and integral part of the process*."

Considering the above, it can be broadly stated that the intent of the consideration which follows is to define, at a strategic level and in keeping with the level of definition in the draft plan/programme, the potential for cumulative effects for the range of activities covered by the draft plan/programme (Section 2), and informed by the assessments in Section 5, using an understanding of potential pathways of effect for broader activities taking place on the UKCS. These pathways are understood from a range of sources, including previously produced matrices on "pressures" (see above), and the assessment is more widely informed by other work undertaken at a UKCS scale e.g. that for the updated assessment of good environmental status (Defra 2019b).

The assessment recognises the limits of spatial specificity included in the draft plan/programme, due to a combination of its exploratory nature (oil and gas, gas storage and carbon dioxide storage), and commercial viability and interest (marine renewables, hydrogen production). However, the overall spatial consideration may be taken to indicate, at a strategic level, the theoretical areas of resource for renewable technologies but does not imply any areas of preference or likely deployment. Similarly, the assessment recognises the limitations of spatial data (resolution, availability) and understanding of individual or cumulative impacts for particular species of receptors. Where cumulative effects are also an inherent part of wider discussions of particular sources of effect (e.g. noise, physical presence) the following summarises wider discussions elsewhere which are cross-referenced.

The approach used here builds on previous OESEAs, recognising other work mentioned above, and a number of terms are defined below which are used to describe the nature of cumulative effects identified, these include: secondary, cumulative and synergistic. Though these are not defined by the SEA Regulations, ODPM (2005) notes that the terms are, to some extent, not mutually exclusive and that often the term cumulative effects is taken to include secondary and synergistic effects but there are important nuances to these terms. Additionally, incremental effects are defined, which are used to distinguish those effects resulting from activities which may be carried out under the proposed plan together with activities carried out under previous plans. This definition is extended below to include activities (oil, gas, gas storage, carbon dioxide storage, offshore wind farm and other marine renewables, hydrogen production) which may be carried out under the proposed draft plan/programme.

Cumulative effects are considered in a broader context, to be potential effects of activities resulting from implementation of the plan which act additively or in combination with those of other human activities (past, present and future); in an offshore SEA context notably fishing, shipping (including crude oil transport) and military activities, including exercises (principally in relation to noise) – i.e. what could be described as the other major "industrial" uses of the sea.

Secondary effects comprise indirect effects which do not occur as a direct result of the proposed activities, but as a result of a more complex causal pathway (which may not be predictable).

Incremental effects have been considered within the SEA process as effects from licensing exploration and production activities (including gas and carbon dioxide storage), and leasing OWF and marine renewable developments; which have the potential to act additively with those from other licensed/leased activity.

Synergistic effects occur where the joint effect of two or more processes is greater than the sum of individual effects – in this context, synergistic effects may result from physiological interactions (for example, through inhibition of immune response systems) or through the interaction of different physiological and ecological processes (for example through a combination of contaminant toxicity and habitat disturbance).

In contrast to other elements of the plan, to some extent, all potential sources of effect (i.e. disturbance, emissions and discharges) resulting from oil and gas activity within an area with a long (40 year) history of exploration activity are cumulative, insofar as they are incremental to previously existing sources (although the net trend of overall source level may be a reduction, due to improved environmental management and/or declining production levels, and in the coming years, cessation of production and decommissioning).

Therefore, effects are considered secondary, incremental, cumulative or synergistic only if:

- the physical or contamination "footprint" of a predicted project overlaps with that of adjacent activities;
- or the effects of multiple sources clearly act on a single receptor or resource (for example a fish stock or seabird population);
- or if transient effects are produced sequentially.

Although the sequential effect concept is considered by the SEA mainly in the context of acoustic or other physical disturbance, a different use of the term sequential effect has been developed primarily in the context of visual impact (e.g. for onshore wind farms, from the point of view of a moving observer: SNH 2012).

The SEA Directive (Annex II) also requires, as a criterion for determining the likely significance of effects, consideration of environmental problems relevant to the plan or programme (see Section 4 and Appendix 1). On the assumption that environmental "problems" are a result of some anthropogenic effect, this section of the SEA document considers the potential interactions between these problems and any activities arising from the proposed licensing/leasing.

Those potentially significant effects, which are also considered to be cumulative, are assessed below.

5.16.3 Underwater noise

The potential effects of underwater noise associated with the draft plan/programme are considered at length in Section 5.3; this includes cumulative impact considerations of the most high intensity noise emitting activities of pile-driving and seismic survey.

Cumulative effects on marine mammals resulting from the proposed licensing/leasing are considered likely. Activity levels are likely to be concentrated in Regional Seas 1, 2 and 6, with additional oil and gas activity likely in Regional Seas 8/9, but there is the potential for oil and gas licences to be awarded in any area of the UKCS. Consideration of this likely activity, in combination with propagation ranges for noise, concluded that it is likely that multiple sources (including seismic surveys and pile-driving) will occur at the same time, that both activities may extend throughout much of the year, and be audible to marine mammals over a large proportion of their range. The JNCC guidelines[329] on the deliberate disturbance of marine European Protected Species also suggest that for most cetacean populations in UK waters, disturbance, in terms of the Habitats Regulations or Offshore Marine Regulations (e.g. the *Conservation of Offshore Marine Habitats Species Regulations 2017*), is unlikely to result from single, short-term operations, e.g. a seismic vessel operating in an area for 4-6 weeks, or the driving of a dozen small diameter piles. Such activities would most likely result in temporary disturbance of some individuals, which on its own would not be likely to result in significant effects on the local abundance or distribution. Non-trivial disturbance, which would constitute an offence under the Regulations, would most likely result from more long-term noisy activities in an area, chronically exposing the same animals to disturbance or displacing animals from large areas for long periods of time.

Evidence obtained over the last 10 years or so has shown that harbour porpoise are more sensitive to underwater noise than previously thought. Comparison of modelling frameworks designed to analyse the long-term consequences to harbour porpoise of disturbance associated with large scale wind farm construction in the North Sea suggest a high degree of uncertainty in extrapolating from individual to population effects. Nonetheless, these exercises have raised the theoretical possibility for temporal and spatial combinations of large seismic surveys and pile-driving operations to result in significant population disturbance.

Looking forward, project timelines with respect to consented wind farms indicate that a number of pile driving operations could take place continuously in the North Sea over the next decade or more – primarily in the central and southern North Sea. Noting the effect of the new deemed marine licence condition is a requirement for those projects to produce and implement a Site Integrity Plan (SIP) before the commencement of any offshore activities with the potential to adversely affect the Southern North Sea SAC. The SIP must contain suitable measures to stay within the thresholds for underwater noise as set out in the SNCB guidance[330]. The vast majority of seismic survey effort on the UKCS has been undertaken in the developed (in terms of oil and gas) areas of the northern and central North Sea, the Scottish continental shelf and the Faroe-Shetland Channel, and projections of recoverable reserves continue to identify the central North Sea as the area with the largest reserve base and with a significant exploration potential. Therefore, the central and southern North Sea may represent areas with the most potential for incremental underwater noise effects with respect to pile driving activities and

[329] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/50006/jncc-pprotocol.pdf

[330] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/889842/SACNoiseGuidanceJune2020.pdf

seismic survey (note that in many cases, reprocessing of existing seismic data can avoid the requirement for new deep geological survey).

Previous SEAs have recommended consideration of the establishment of criteria for determining limits of acceptable cumulative impact; and for subsequent regulation of cumulative impact. The SEA recognises the advances made in this respect through the establishment of the indicator on low- and mid- frequency impulsive sounds under the Marine Strategy Framework Directive. While criteria have not yet been defined, the establishment of a database to collate occurrences of "noisy activities" (the Marine Noise Registry) represents the necessary precursor.

Incremental Simultaneous and sequential seismic surveys and pile-driving

Cumulative Seismic survey, pile-driving noise and broadband impulse noise, for example military sonars and continuous mobile sources (e.g. shipping)

Synergistic None known

Secondary None known

5.16.4 Physical damage/change to features and habitats

Potential sources of physical disturbance to the seabed, and damage to biotopes are associated primarily with the construction phase of potential plan activities. Some sources are common across many aspects of the plan (e.g. anchoring of vessels, rigs and installations; pipeline and cable installation; rock dumping; seabed dredging and levelling; piling of foundations; placement of jack up rigs and suction caisson foundations) with others more specific (e.g. placement of foundations and walls associated with tidal lagoon construction). The physical presence of operating structures in the water column (e.g. offshore wind turbines, tidal stream and wave devices as well as tidal barrages or lagoons) may also cause indirect or secondary disturbance to the seabed through alterations to water movements and associated sedimentation patterns or scour. The scale of direct damage to features and habitat loss associated with long-term placement of structures on the seabed is generally in proportion to the size of the object, and the duration of effect is equal to the operational lifespan of the structure – or may be indefinite if complete removal is not feasible or cost-effective. In the case of scour-related effects, the scale may be significantly greater than that of the fixed structure.

The assessment (Section 5.4) indicates that much of the physical disturbance associated with construction activities is largely temporary (e.g. elevated suspended sediment concentrations over a period of a number of hours associated with seabed preparation activities) and localised (e.g. to the seabed footprint of jack up vessels, anchoring scars, cable corridors). The physical placing of a structure on the seabed, the installation of scour protection, cabling and anchor structures all result in direct loss of habitat and sedentary species within the footprint (and any working area) of the structure. Physical habitat recovery and benthic recolonisation of the working area around the foundations after installation is likely to occur, again with the timescale dependent on the sedimentary regime, dispersal of individuals and seabed preparation methods. In terms of floating structures the physical footprint of the anchors on the seabed and therefore direct disturbance is likely to be small, depending on whether embedment anchors, piles or suction caissons are used, but spread out over a potentially large area (in the case of catenary structures), with large areas included in the overall device footprint that are essentially undisturbed.

The likely future scale of offshore wind development along with on-going development of Round 3 related projects, Round 1 & 2 projects and extensions, and ScotWind leasing means that further extensive cable laying operations are required to transfer the generated power from the OWF to the mainland. There has been a clear increase in the average lengths of inter-array and export cables installed as the offshore windfarm development rounds have progressed with most recent projects representing a marked increase over previous rounds. For example, the average lengths of inter-array and export cabling for Round 2 projects is 105 and 84km respectively, which has increased to 203 and 199km for Round 3 projects completed to date. For the purposes of EIA, cable installation corridors of recent Round 3 projects are typically 10-15m wide but wider corridors have been included where pre-clearance activities such as sandwave clearance and boulder clearance are required (e.g. between 20 and 30m wide). It should be noted that export cabling to date have taken a radial approach to connections, which are point-to-point connections between an individual wind farm project and its connection with the grid. This lack of coordination is being addressed through the OTNR (Section 5.14), the final outputs of which are expected in 2023.

Where cable and pipeline routes interact with other activities using the seabed (e.g. in the southern North Sea) then deep burial (e.g. as advised in the East Marine Plans) or extensive protection may be required, which may potentially cause greater disturbance to the seabed and associated biotopes (in addition to the introduction of new hard substrate to otherwise sedimentary environments).

Habitat change from the deposition of hard substrates (including rock and concrete mattresses) in sedimentary habitats, particularly associated with offshore wind farm cable protection but also as a result of oil and gas pipeline installation and decommissioning, has become a recent cause of concern, particularly for southern North Sea sandbank MPAs. High level advice with respect to sandbank habitats in relation to potential cable routes associated with the Round 4 seabed leasing (Natural England & JNCC 2019) indicates that these habitats are often found in high – medium energy environments and have the potential to recover from cabling activities pressures relatively quickly. However, where features are dynamic, the introduction of hard substrate (such as cable protection) is often required causing the pressures physical change to another seabed or sediment type and therefore likely loss of extent of the existing habitat. The advice notes that it is particularly important in MPAs designated for sandbank features to consider these pressures in the context of other operations within the site, as many sandbank MPAs are already impacted by these pressures therefore reducing their capacity to withstand further impacts. Currently, a number of Round 3 projects in the southern North Sea are required to implement a package of benthic compensation measures for potential impacts, resulting from the deployment of cable protection, to Annex I sandbank habitat.

A recent review of rock and other protective material use in offshore oil and gas operations on the UKCS (BEIS 2021h), provided spatial analysis of Environmental and Emissions Monitoring System (EEMS) returns to estimate material placed on the UKCS between 2011 and 2016. Whilst the data was heavily caveated, the analysis indicated that the southern North Sea had the greatest percentage of the total area impacted by deposits, at just over 700,000 m^2 or 0.00102% of the total area, which was attributed to its smaller total geographical area and relatively high number of oil and gas installations; the mobile nature of the seabed sediments leading to the requirement for stabilisation/protection material around oil and gas infrastructure. Almost half of the total area impacted by seabed deposits (primarily rock) in the southern North Sea was located within existing sandbank MPAs. The use of rock protection to cover pipeline ends and to remediate any hazardous free spans in the decommissioning of oil and gas installations in this area is also of relevance.

Cable placement and trenching, both within the array and export cables, may have a large spatial extent of disturbance, but will be of short duration and habitats will recover rapidly over buried cables. Detailed site survey will inform the final routes of cables and pipelines and will allow developers to avoid particular seabed features, sensitive habitats and areas of archaeological importance. There is also the potential to avoid impacts to sensitive features through micro siting/routing of cables although the capacity to bend round relevant features will be limited by the physical nature of the cable.

To date, only one lagoon project has gone through the planning process with a development consent order granted for the Tidal Lagoon Swansea Bay project in June 2015 (a correction order was issued in October 2015). However, it is uncertain whether this, or other tidal range projects (e.g. including former proposals including Tidal Lagoon Cardiff, Tidal Lagoon Newport and the West Somerset Tidal Lagoon) will be developed. Given that tidal range schemes have the potential to significantly impact the physical environment and permanently change physical hydrography and sedimentation characteristics, the degree of incremental physical change could be substantial.

Potential cumulative effects from plan activities are possible where the 'footprints' of physical disturbance overlap incrementally with those of other plan activities or cumulatively with other non-plan activities (e.g. fishing, aggregate extraction, dredge disposal). The aspect of the plan with the greatest potential for cumulative effects is the ongoing and future development of offshore wind given the large scale development proposed over the next decade and the relative localised nature of much of this in the central and southern North Sea, an area also used extensively by other industries. The strategic-level footprint of physical disturbance associated with the construction of the consented offshore wind development will be limited both spatially and temporally. The potential for significant incremental and cumulative physical damage/change effects is further reduced by the naturally dynamic environment of the southern North Sea which is adapted to re-suspension and sedimentation events. In a UKCS context, the contribution of all other sources of disturbance are minor in comparison to the direct physical effects of fishing, and it can be argued that the positive effect of fisheries exclusion offsets any negative effects of the draft plan activities, but a corollary of this is fisheries displacement. On balance, however, the spatial extents of both positive and negative effects are probably negligible for most seabed habitats.

Incremental Physical footprint incremental to existing offshore activity – minor increment from oil and gas and gas storage and carbon dioxide (and hydrogen) transport and storage in existing hydrocarbon reservoirs; higher from OWF and potentially wave, tidal stream and gas and carbon dioxide (and hydrogen) storage in "other" geological formations (e.g. saline aquifers), although data is currently poor; very high for tidal range

Cumulative Cumulative effects dominated by trawling. The disturbance effect of oil and gas and OWF, wave and tidal stream development is likely to be offset by fishing exclusion, however, this could lead to displacement.

Synergistic None known

Secondary Possible changes to water movements and associated sedimentation patterns or scour.

5.16.5 Consequences of energy removal

Numerous studies on the hydrodynamic effects of energy removal have now been undertaken to provide an indication of the nature and scale of energy removal effects. Results are typically site-specific and connecting those changes to other aspects of the physical environment (e.g. sediment dynamics) requires additional work. While offshore wind farms are a more mature technology than wave and tidal devices, evidence on their potential to remove energy and have broadscale effects on hydrographic processes is not well development and requires further modelling work, including from a cumulative perspective with other sources of energy removal or change, and informed by realistic future scenarios of deployment, that also account for impacts of climate change.

The impacts of energy extraction by multiple wave and tidal installations on the marine environment are not well understood, due to the fact that these devices are still at a relatively early stage of development. At present it is not clear how applicable scaling-up of impacts from observations on individual or small clusters of devices to commercial scale arrays is. A number of modelling studies have investigated the impacts of different array spacings and arrangements, predominantly on the wake effect and subsequent power availability for both wave and tidal stream technologies, with varying recommendations depending on placement, device type and physical characteristics of the site. Additionally, studies have started to look at the related implications for sediment dynamics.

Modelling studies have shown that the impacts of energy removal from tidal stream, tidal range and wave arrays may also extend significant distances from deployment sites (e.g. González-Santamaría *et al.* 2012, Shapiro 2011, Wolf *et al*. 2009, Zhou *et al*. 2014b, Angeloudis & Falconer 2017). It is therefore possible that the siting and installation of one marine energy type might reduce the energy availability for other marine energy types, potentially in the far field. One example is the Puget Sound, USA where modelling has suggested that extracting power from near to the outlet to the Pacific Ocean (with the strongest current speeds) would reduce the tidal range in all the other basins in the estuary. Power extraction from the Tacoma Narrows (further upstream, with lower current speeds and therefore lower power generation capacity) would however not significantly affect the range in other basins apart from the main basin (Polyagye *et al.* 2008), leaving more areas available for subsequent energy generation schemes. Similarly the tidal regime and water depth within parts of the wider Bristol Channel and Irish Sea (areas with potential for deployment of other tidal stream or tidal range) may similarly be affected by the placement of a barrage across the Severn from Cardiff to Western-super-Mare (Fairley *et al*. 2014, Zhou *et al.* 2014b).

It may generally be concluded that there are limited and localised impacts from single or pilot scale deployments of tidal stream and wave devices, and the current scale of offshore wind farm deployment. The extent of any cumulative effects of multiple devices on the biogeochemical cycles of UK waters is not well understood, and would require an understanding of the potential range of effects from wind farms, tidal stream and wave arrays and tidal range, both locally and in the far-field (and cumulatively), together with the likely range of potential impacts from climate change, along realistic timescales and scenarios of deployment for such technologies.

Incremental Current scale of wave and tidal stream devices provide little information on incremental effects, although modelling evidence suggests the array layout will have a significant effect especially on the incremental overlap of energy removal on subsequent devices within an array. Future wind leasing may have incremental effects on stratification and wave energy, but more work is required to understand the potential scale of this.

Cumulative Likely to be minimal at significant distances from devices and arrays, although evidence base is very limited. There is the potential for far-field effects and device siting should be informed by modelling of an appropriate scale.

Synergistic Unquantified but potentially significant in relation to wave and tidal devices (including for tidal range) whereby additional devices cumulatively remove more energy from the water column than the sum of the same number of single devices.

Secondary Unquantified – but potential impact on other users (e.g. surfing communities, other marine renewables) from the reduction in wave height downstream of devices

5.16.6 Physical presence

The physical presence of structures in the marine environment is not expected to increase significantly following further oil and gas, gas storage and carbon dioxide storage licensing. Major new surface installations are not expected, and may future developments may be entirely subsea and make use of existing facilities for process and export. The future licensing of offshore wind renewables is expected to have the largest spatial footprint, generating the greatest source of impact. The potential for interactions both from other marine users and relevant ecological receptors (e.g. birds and marine mammals) with offshore oil and gas infrastructure (whether positive or negative) is likely to be insignificant; in part because the number of existing surface facilities is relatively small (of the order of a few hundred and due to decline in the coming years due to decommissioning and use of existing export infrastructure by subsea developments) and because the majority are at a substantial distance offshore, in relatively deep water. However, the larger numbers of individual surface or submerged structures in offshore wind development, the presence of rotating turbine blades and considerations of their location and spatial distribution (e.g. in relation to coastal breeding or wintering locations for waterbirds), indicate a higher potential for incremental physical presence effects.

While evidence from a number of studies has clearly presented the potential for bird displacement in relation to certain species, specifically from offshore wind farm and most notably red-throated diver, there is a lack of available evidence on how this translates to mortality and any population level effect. The draft plan/programme is not spatially defined beyond the remit of leasing for reserved matters, and therefore it is challenging to attribute cumulative effects to the draft plan, as the receptors which could be affected are widely distributed. The potential for further incremental effects from offshore wind deployment that could arise from the draft plan, with those wind farms already operational, consented or which could be consented before the plan were adopted, may be significant, particularly in certain areas of the southern North Sea and Irish Sea.

All activities and developments covered by the draft plan/programme require site-specific information gathering and stakeholder consultation to inform consenting decisions, but in view of the particular sensitivity of the coastal zone (including birds but also a wide range of other receptors), proposed developments within territorial waters must be sited appropriately – some developments may not be compatible with a nearshore location.

Given the likely scale of wave and tidal stream developments that be associated with this draft plan/programme, they are unlikely to represent a significant cumulative impact to coastal receptors. However, the very specific hydrographic conditions required for tidal stream devices which may overlap with important foraging areas for birds and marine mammals indicates that potential cumulative effects may arise in the future as array sizes increase or more arrays are planned.

Incremental Small increment from oil and gas, CO_2 and gas storage, hydrogen production and marine renewables to existing exclusion zones and obstructions, visual intrusion and disturbance; potentially significant increment from offshore wind farms. Displacement, barrier effects and collision risk to birds potentially significant at a local or regional level; no current evidence of significance to bird populations at a strategic level.

Cumulative Exclusion and snagging risks are cumulative to those resulting from natural obstructions, shipwrecks and other debris. Extent of cumulative effect associated with oil and gas, CO_2 and gas storage licensing round is negligible. Potential cumulative displacement, barrier and collision effects on birds.

Synergistic No conclusive data

Secondary No conclusive data

5.16.7 Landscape/seascape

In view of existing offshore wind farm developments which have been consented or are in planning, and those which are preliminary, the bulk of offshore wind to be installed in the coming years will be at a distance from the coast where visual effects are not expected to be significant with the exception of works at the landfall, much of which is temporary in nature. Section 5.15 has highlighted that a significant resource for offshore wind remains in the offshore area for both fixed and floating turbine foundations, and given the projected cost reductions for this technology in the near-term, there is the potential that turbines could be sited further from shore to mitigate a range of effects (including on coastal seascapes), but it is accepted that where appropriately sited, wind farm development could take place in nearshore waters. Additionally, Section 5.15 highlights the increasingly constrained nature of the resource for fixed wind in nearshore areas, such that future development is much more likely to be further from shore. The limits of effects which could be significant for highly valued landscapes for wind farms of up to 350m blade tip, assuming perfect visibility, are highlighted in Section 5.8 and 5.15 following White Consultants (2020). While not reflecting strict areas where development should not take place, the limits indicate that much of the estimated remaining fixed and floating wind resource is beyond such distances.

It is difficult to resolve the local implications on seascape from developments at a strategic level, though in the areas of the East Irish Sea, Thames, Wash and eastern Channel, the concentration of wind farms and/or their proximity to the coast, has the potential to lead to the seascapes of these areas being dominated or at least influenced to a moderate degree by this use of the sea in the future – this is already being reflected in seascape character area descriptions, such as those for north Wales (Section 5.8). Such industrial uses of the sea have until recently characterised areas in offshore waters (for example, see the marine character area descriptions for the East Marine Plan areas) – the cumulative effects of further offshore renewables leasing are considered more likely due to their primarily (to date) nearshore location, vertical scale and lateral extent, with several technologies including tidal stream and tidal range having their resources in nearshore locations. Some aspects of ancillary development including port expansion could be incremental as this may take place in areas previously used by the offshore oil and gas or other industries, and may be in keeping with the character of these areas. Landfalls are relevant to this SEA as they are associated with export cables, and also pipelines relating to oil and gas, gas storage and hydrogen production, though effects of relevance to the draft plan/programme are largely temporary. As noted in Section 2.2.1 and 5.15, the Offshore Transmission Network Review (OTNR) is ongoing, and seeks to try to reduce the potential number of landfalls and related effects through greater coordination.

Resources for wave, tidal and wind technologies tend not to overlap and therefore it is unlikely that different renewable technologies will compete for space, or generate a scenario where there are cumulative effects from different types of renewable technologies. Where this might occur, is in views down certain estuaries or from certain headlands should tidal stream or range devices interrupt open sea views in the nearshore, which are then overlain with, for instance, offshore wind turbines further offshore.

Other activities which may result from the draft plan/programme which could lead to cumulative visual impacts include gas and carbon dioxide storage, and offshore hydrogen production, and any element of the plan relating to landfall activities, though this would need to be assessed at the local level as landfall sites for these could be various and are not determined as part of this SEA. It is unlikely that any significant new oil and gas surface infrastructure will be commissioned from future seaward licensing associated with this draft plan/programme, and in the foreseeable future as UKCS reserves decline.

Incremental In certain previous offshore wind leasing areas, incremental effects are characterised by successive developments of offshore wind farms which are intervisible with the coast and one another. Though more recent (e.g. Round 3) leasing areas are typically further from the coast and therefore have less potential for visual impacts, further intervisibility with future wind sites and existing sites could lead to significant incremental effects. Tidal stream, tidal range and wave devices have a low surface elevation but may incrementally add to offshore lighting and ship movements for maintenance. Tidal range developments have long project lifetimes and are effectively permanent.

Cumulative The location of wind, wave and tidal energy resources are such that there is unlikely to be any significant cumulative effects between these technologies. With regard to gas storage and CCS, any new surface infrastructure may generate cumulative visual effects, but these are likely to be small and at some distance offshore given the key resources for these technologies. Tidal range schemes are inherently shore connected and therefore will have visual effects which may act cumulatively with other changes at the coast, for example loss of intertidal area from sea-level rise, and are effectively permanent.

Synergistic No conclusive data

Secondary No conclusive data

5.16.8 Marine discharges

Total produced water discharge from UKCS oil production was 129 million m^3 in 2020, with an average oil in water content of 17.8mg/l (OGUK 2021[331]). In comparison with this, the potential discharge from new developments following the proposed rounds will be negligible since it is expected that the bulk of produced water will be reinjected rather than discharged. Through OSPAR, the UK is committed to a presumption against discharge from new developments.

[331] https://oeuk.org.uk/wp-content/uploads/woocommerce_uploads/2021/12/OGUK-Environment-Report-2021-27ywy6.pdf

Environmental effects of produced water discharges are limited primarily by dispersion, to below No Observed Effect Concentrations (NOECs) in close proximity to the discharge point. Synergistic interactions are possible between individual components, particularly PAHs, specific process chemicals (especially those which are surface-active, including demulsifiers), and other organic components. However, given the anticipation that the bulk of produced water from new field developments will be reinjected rather than discharged, and that such discharges as are made will be treated to required quality standards[332], the scope for incremental, cumulative or synergistic effects is remote.

Previous discharges of WBM cuttings in the UKCS have been shown to disperse rapidly and to have minimal ecological effects. Dispersion of further discharges of mud and cuttings could lead to localised accumulation in areas where reduced current allows the particles to settle on the seabed. However, in view of the scale of the SEA area, the water depths and currents, and probability of the reinjection (or disposal on land) drill cuttings from any major field development, this is considered unlikely to be detectable and to have negligible incremental or cumulative ecological effect.

OWF developments have limited planned discharges, although some chemicals are routinely used, the majority of these are generally used within closed systems, and do not result in operational discharges; selected and used in line with best practice the effects of this chemical usage is considered to have negligible environmental effect.

Hydrocarbon gas storage, carbon dioxide storage and offshore hydrogen production and storage activities share many of sources of marine discharges as oil and gas activities (e.g. drill muds and cuttings, cementing and other chemicals associated with drilling, completion operations; discharge of chemicals during pipeline pre-commissioning operations, and operational chemical use). Discharge of saline aquifer water may occur for pressure relief during carbon dioxide injection but rapid dispersion of the brine can be engineered or would occur naturally. Given the limited extent of hydrocarbon gas storage, CO_2 storage and hydrogen production/storage (noting hydrogen storage is unlikely before 2030), activities likely from future leasing and licensing and the controls in place, incremental effects from marine discharges will not be significant.

Incremental Produced water: incremental contribution of produced water is dependent on the extent of reinjection but noting the presumption against new produced water discharges, the scale of discharge and effects will be negligible. WBM drilling discharges generally disperse widely and significant accumulations do not occur. It is therefore possible that discharge footprints will overlap, although the ecological effects will be undetectable. Potential "sinks" may occur in areas of sediment accumulation although this is considered unlikely to be detectable.

Cumulative Principal cumulative sources of major contaminants, including hydrocarbons and metals, are shipping (including wrecks) and atmospheric inputs. Cumulative sources of particulate contaminants include aeolian dust and sediment disturbance from trawling, although these are negligible in the context of natural suspended particulate loads.

Synergistic Synergistic effects of chemical contaminants in produced water and drilling discharges are conceivable, although substantive data is almost entirely lacking and it is

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[332] The current performance standard for dispersed oil in water for produced water, is 30mg/l, with the average dispersed from UK oil and gas production for 2020 (17.8mg/l) well below this.

considered unlikely that significant synergistic effects would result from chemicals used in exploration and production, or renewable energy operations.

Secondary None known

5.16.9 Wastes to land

In view of the relatively small number of wells predicted, and the establishment of a licensing mechanism to allow interfield cuttings reinjection, and the relatively small waste generated for onshore disposal from the OWF sector, it is considered unlikely that major incremental or cumulative landfill requirement will result from proposed licensing/leasing. Given the level of activity predicted for hydrocarbon gas storage, CO_2 storage and hydrogen production, and while the wastes generated may be comparable in type to oil and gas, the overall volumes generated are expected to be lower, major incremental or cumulative landfill requirement for these industries is also considered unlikely.

The oil and gas industry has entered a decommissioning phase for a number of North Sea and other fields. The expected lifetime of OWF turbines is 20 to 25 years and 40 years for cables and other associated infrastructure. BEIS guidance[333] indicates a general presumption in favour of the whole of all disused installations being removed and subsequently taken back to land for reuse, recycling, incineration with energy recovery or disposal at a licensed site. Therefore, although decommissioning activity has commenced for oil and gas infrastructure, potential cumulative effects associated with the disposal of infrastructure from both industries is some way off given the relative age of the offshore wind industry.

Incremental Incremental return of general oilfield and renewable operational wastes insignificant; incremental return of drilling wastes also unlikely to represent a significant contribution to onshore waste disposal requirements.

Cumulative Not quantified

Synergistic None known

Secondary None known

5.16.10 Atmospheric emissions

Atmospheric emissions from offshore oil and gas exploration and production activities may contribute to reduction of local air quality (Section 5.11). Greenhouse and acid gas emissions from these sources effectively contribute to a mixed regional or global "pool" and can therefore be considered cumulative (Section 5.12).

Upstream emissions from offshore oil and gas exploration and production are largely from power generation in diesel or gas turbines to operate offshore facilities, and flaring and venting. Additionally, vessels supporting the offshore industry (e.g. survey, supply, support, construction) and helicopters contribute to the emissions from upstream offshore oil and gas activities.

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333 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/916912/decommissioning-offshore-renewable-energy-installations-energy-act-2004-guidance-industry__1_.pdf

Further offshore exploration and production would result in an increment to these sources of greenhouse gas emissions, but this must now be undertaken in keeping with the OGA Strategy which has been placed in the context of the net zero target, and further licensing may be subject to periodic climate compatibility checkpoints. Production from the UKCS is set to decline and be less than the UK's demand throughout the transition to net zero, and there is some advantage of domestic production throughout this period both in terms of the carbon intensity of UKCS production, which is as an average generally less than imported hydrocarbons (other than, for example, those from adjacent states such as Norway), and security of supply.

Flaring from existing UKCS facilities has been substantially reduced relative to past levels, largely through continuing development of export infrastructure and markets, together with gas cycling and reinjection technologies. In addition, offshore oil industry emissions are subject to an Emissions Trading Scheme. New developments will generally flare in substantial quantities only for emergency pressure relief, with "zero routine flaring" now considered a realistic design target for new developments, additionally, flaring and venting will continue to be driven down, going beyond the World Bank's "Zero routine flaring by 2030" initiative (to which the UK is a signatory). Other than start-up flaring, subsea tie-back developments will generally have little effect on host installation flaring.

Atmospheric emissions associated with offshore renewables are largely from their manufacture and deployment, with maintenance involving less intensive boat-based visits. Cumulative effects from an increase in port capacity or the increased utilisation of ports with existing capacity could lead to local air quality effects if unabated, particularly in existing problem areas. However, there have been recent changes in the permitted sulphur content of marine fuels, amongst other plans to decarbonise the shipping sector. For example, and as part of the Clean Maritime Plan, large ports (handling cargo in excess of 1mt per year) in England are being asked to produce Port Air Quality Strategies[334] to establish a minimum level of understanding of air quality in ports, and to reflect actions that the port is taking to address emissions under their control. Additionally, the Transport Decarbonisation Plan was published in July 2021 which included commitments and actions to decarbonise the UK transport system, including the marine sector[335]. The increased deployment of offshore renewables towards 2030 and beyond will, in association with CO_2 storage, hydrogen production, in the wider energy and greenhouse gas reduction policy context of the UK, cumulatively make a contribution to both greenhouse gas emissions reductions and air quality improvement.

Operational air quality effects of CO_2 storage are unlikely to be significant and should not pose any cumulative effects.

Incremental Incremental emissions resulting from internal combustion for power generation by installations, vessels and aircraft, flaring for pressure relief and gas disposal, and fugitive emissions during tanker loading.

Cumulative Greenhouse and acid gas emissions effectively contribute to a mixed regional or global "pool" and are therefore considered to be cumulative. On a global scale, cumulative contributions of emissions resulting from predicted activities and developments will be negligible in comparison to the influence of onshore sources.

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334 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815665/port-air-quality-strategies.pdf

335 https://www.gov.uk/government/publications/transport-decarbonisation-plan. Also see the call for evidence on the deployment of shore power: https://www.gov.uk/government/consultations/use-of-maritime-shore-power-in-the-uk-call-for-evidence

Synergistic	None known
Secondary	None known

5.16.11 Accidental events

Accidental events (with environmental consequences) that could potentially occur on offshore E&P, and gas storage facilities (including hydrocarbon gas, carbon dioxide and hydrogen), and associated support vessels, include oil and chemical spills and gas releases, although large volume oil spills are only possible from oil exploration, production or export facilities and large releases of CO_2 are only possible from CO_2 storage (Section 5.13). Marine renewable energy developments generally have a negligible inventory of oils and chemicals, and spill risks are accordingly mostly associated with construction and operational maintenance; or with navigational safety risks to other (not OWF-related) vessel traffic.

Although the consequences of a major oil spill could be severe, in both ecological and economic terms, the incremental risk associated with the predicted level of activity is moderate or low. The increasing numbers of offshore installations in UK waters, and in particular the number and spatial footprint of large wind farms, will affect the relative risk of vessel collision. This risk is expected to be mitigated *inter alia* by siting of developments so that they do not impinge on major commercial navigation routes or significantly increase collision risk. – for example see related policy in the Marine Plans, in particular for English inshore and offshore waters and the Welsh National Marine Plan. With this caveat, the predicted scale of activity that could follow adoption of the draft plan/programme would not have a significant influence on the cumulative risk.

Regulatory mechanisms already in place require developers, vessel and facility operators to develop effective oil spill mitigation measures, covering organisational aspects and the provision of physical and human resources which will minimise incremental risks. Times to beach, under worst case trajectory modelling conditions, are relatively short in some areas (Regional Seas 1 and 6) and effective contingency planning and local resources are therefore necessary to allow the deployment of response measures where appropriate.

In terms of cumulative risk, there is little doubt that due to scale and consequence, the major risk of significant oil spills is associated with tanker transport of crude oil and refined products. While some control and response measures have been implemented, for example following the Donaldson inquiry into the *Braer* incident, and as a result of the Deepwater Horizon incident in the Gulf of Mexico, the residual risk remains relatively high (in comparison to other oil spill sources). A major well blowout can also result in significant release to sea of oil; however, the probability of such events occurring, and thus influencing cumulative risk, is extremely low.

As context, it may be noted that overall, although the acute effects of oil spills can be severe at a local scale, the cumulative effects of around a century of oil spills from shipping – and over forty years of oil and gas development – do not appear to have resulted in wide-scale or chronic ecological effects. It is therefore concluded that the limited incremental effects of predicted activity, assuming that effective risk management practices continue to be implemented, will be minimal.

The anticipated scale of hydrocarbon gas, and CO_2 storage and hydrogen production activity may be reasonably expected to demonstrator scale projects. Considering the scale of likely development, even a large CO_2 leak, when regionally integrated, is likely to be insignificant when compared with that from continued non-mitigated atmospheric CO_2 emissions and the subsequent acidification of the marine system. Consequently, significant cumulative effects from accidental events associated with these industries are not expected.

Incremental	Hydrocarbons from oil spills will be incremental to (minor) offshore exploration and operational discharges; however, it is considered very unlikely that oil spill footprints will overlap given the spill frequency associated with predicted activities.
Cumulative	There are a range of cumulative sources of hydrocarbons to the area. Depending on magnitude, accidental spills represent a minor to major contribution to overall regional inputs of oil.
Synergistic	None known
Secondary	None known

5.16.12 Summary and conclusion

A challenge in assessing cumulative impacts in relation to the draft plan/programme lies in the findings that the majority of potential effects identified are of small magnitude, largely sub-lethal and for mobile species; largely associated with behavioural changes. Such effects are difficult to measure in the field and are even more complicated to predict because of numerous other factors which are contributing to overall spatial and temporal variability. To use marine mammals as an example, the most relevant effect from the draft plan/programme is the increase in underwater noise from piling and seismic activity with the consequent risk of disturbance, given that injurious effects are mitigated for. Current attempts at addressing acoustic cumulative effects have focused on the "incremental" effects of plan activities, and while the understanding is that they are unlikely to have an effect at the population level, the uncertainties in these assessments remain very large. The next step in a more complete cumulative assessment would be to combine the effects of noise disturbance with all other pressures, including direct mortality from by-catch, effects from changes in prey distribution (from fishing and climate change), chronic exposure to contaminants etc. These interactions are likely to be even more complex than those that have been modelled so far; the scale at which they act may also vary so that some interactions can occur at certain temporal and spatial scales but not at others. Currently, predicting these kinds of interactions remains highly uncertain and quantitatively dubious. Instead, this should lead to further recommendations of regional scale targeted monitoring efforts to be able to have confidence in the assessment of trends for key ecosystem components.

5.16.13 Potential for transboundary effects

The OESEA4 covers a range of activities, some of which could take place in all UK waters, and others which are considered only for England and Wales. Transboundary effects are therefore possible with all neighbouring states whose waters abut the UK. These are France, Belgium, the Netherlands, Germany, Denmark, Norway, the Faroes and the Republic of Ireland. Since activities from this draft plan/programme may occur in UK waters and including adjacent to the majority of median lines, the sources of potentially significant environmental effects with the additional potential for transboundary effects include:

- Underwater noise
- Marine discharges
- Atmospheric emissions

- Impact mortality on migrating birds and bats
- Accidental events – oil spills and major carbon dioxide releases

All of the five aspects above may be able to be detected physically or chemically in the waters of neighbouring states.

The scale and consequences of environmental effects in adjacent state territories due to activities resulting from adoption of the draft plan/programme will be less than those in UK waters and are considered unlikely to be significant.

5.17 Consideration of alternatives

5.17.1 Introduction

The reasonable alternatives to the plan/programme were described in Section 3.8 and are:

1. Do not proceed further licensing and/or leasing for one or more aspects of the draft plan/programme:
    a. Not to undertake any further seaward oil and gas licensing rounds
    b. Not to licence and lease areas of the UKCS for carbon dioxide storage
    c. Not to licence and lease areas of the UKCS for hydrocarbon gas storage
    d. Not to proceed with further renewables leasing, including rounds for offshore wind or individual leasing for wet renewables
    e. Not to proceed with any leasing or licensing requirements needed for offshore hydrogen production, transport and storage offshore[336]
2. To proceed with a leasing and licensing programme
3. To restrict the areas offered for leasing and licensing temporally or spatially

The assessment of these three alternatives is based on the consideration of effects in Sections 5.3-5.16. It is presented below by SEA topic and consists of a two stage process for each topic, which includes:

- Consideration of sources of potentially significant effect (as described in Section 5.2) with a brief explanatory narrative, including comments where effects are considered irreversible
- Consideration of OESEA4 objectives and guide phrases (as described in Section 3)

The consideration of sources of potentially significant effect uses the key below. Note that a "?" denotes where there is uncertainty:

	Potential moderate / high positive impact on topic
	Potential minor positive impact on topic
?	Neutral impact on topic
	Potential minor negative impact on topic
	Potential moderate / high negative impact on topic

[336] Note that legislative changes may be required to facilitate hydrogen transport and storage in geological formations, see Section 2.2.2 and Section 2.5.6.

5.17.2 Alternative 1: Not to proceed further licensing and/or leasing for one or more aspects of the draft plan/programme

Biodiversity, habitats, flora and fauna

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect					Narrative
	a	b	c	d	e	
Physical damage to biotopes from infrastructure construction, vessel/rig anchoring etc (direct effects on the physical environment)						The footprint of effect associated with all the elements of the draft plan/programme is considered to represent a negligible incremental effect, with effects in most areas reversible over time. Under each sub-alternative, the remaining aspects of the draft plan/programme would proceed and physical damage to biotopes would result from these, with a likely minor negative impact on this topic. The introduction of hard substrates (including rock and concrete mattresses) in sedimentary habitats, particularly associated with offshore wind farm cable protection but also as a result of oil and gas pipeline installation and decommissioning, has become a recent cause of concern, particularly for southern North Sea sandbank MPAs. Therefore not proceeding with these elements of the plan would reduce certain site-specific concerns but ongoing strategic initiatives such as the Offshore Transmission Network Review may offer a means to facilitate the planned large-scale offshore wind farm development.
Behavioural and physiological effects on marine mammals, birds and fish from seismic surveys						Seismic surveys are principally associated with oil & gas exploration and development, with seismic also likely to be used to define and monitor gas storage reservoirs including CO_2 and hydrogen. Seismic surveys may generate high source levels with significant potential for propagation with associated behavioural and physiological effects reported for marine mammals, birds and fish (see Section 5.3). Not proceeding with sub-alternative 1a) would result in a neutral impact on this topic as deep geological seismic survey for future oil and gas would not proceed. For each of the gas storage (1b and 1c) sub-alternatives, the remaining aspects of the draft plan/programme would proceed and minor negative behavioural and physiological effects would result. These activities will be subject to environmental requirements (noise assessment) and other regulatory controls at the project specific level, e.g. presence of MMO/PAM operatives.

Potentially significant effect	Nature of effect a	b	c	d	e	Narrative
Behavioural and physiological effects on marine mammals, birds and fish from other geophysical surveys						Other geophysical surveys include the use of echosounders, side-scan sonars and sub-bottom profilers which may be used by all aspects of the plan to provide information on the surface or shallow seabed. Sound levels generally drop off quickly with distance due to high frequency (>10kHz) and high directionality of these systems, but not all systems have been adequately characterised. Under each sub-alternative, the remaining aspects of the draft plan/programme would proceed and potential behavioural and physiological effects would result from these, with a likely minor negative impact on this topic. Plan activities will be subject to environmental requirements and other regulatory controls at the project specific level, which may include noise assessments where relevant.
Behavioural and physiological effects on marine mammals, birds and fish associated with construction phase noise[337]						The aspect of the draft plan/programme most likely to generate significant effects is piling for offshore wind (1d), and therefore, not proceeding with this aspect of the plan is most likely to have a moderate-high positive impact on this topic. Generation of construction phase noise also applicable to oil and gas and to a lesser extent from wave and tidal, principally through piling of infrastructure to the seabed; for wave and tidal in practice, piling is unlikely to occur extensively, although the information on underwater noise associated with wave and tidal energy device construction remains relatively limited. Negligible incremental effect from hydrocarbon gas and CO_2 storage in depleted reservoirs. Plan activities will be subject to environmental requirements (noise assessment) and other regulatory controls at the project specific level, e.g. presence of MMO/PAM operatives.
Behavioural and physiological effects on marine mammals, birds and fish associated with operational noise				?		Negligible operational noise from OWF; source levels from oil and gas production and hydrocarbon gas and CO_2 storage (e.g. gas compression) relatively low therefore local effects only. Potential for noise associated with operation of wave and tidal stream devices, although limited information.
Behavioural and physiological effects on marine mammals, birds and fish associated with decommissioning noise						Should any aspect of the plan not proceed, noise associated with decommissioning (of future developments) will not occur in relation to it. Noise emissions associated with decommissioning of all aspects of the plan are likely to be similar in nature to those generated during construction and installation, with the exception of an absence of extensive pile-driving (OWF) and seismic survey (oil and gas) noise. Noise from decommissioning can also result from the use of explosives, principally from oil and gas.

[337] May include piling noise, and the detonation of unexploded ordnance (UXO).

Potentially significant effect	Nature of effect					Narrative
	a	b	c	d	e	
The introduction and spread of non-native species						Possibility of effects mitigated by adherence to ballast water guidance. Presence of all energy foundations/infrastructure in water column (OWF (fixed and floating), wave/tidal, O&G, CCUS, gas storage and hydrogen production),will result in biofouling to some extent, and may result in localised increase in species diversity, but, given the natural widespread presence of hard substrates, such as glacial dropstones, unlikely that foundations/ structures will facilitate the spread of non-natives to the point where they become invasive. Under each sub-alternative, the remaining aspects of the draft plan/programme would proceed, with a likely minor negative impact on this topic. Section 5.4.6 recommends that the volumes of rock used, for example, in cable armouring, foundation scour protection and pipeline protection and upheaval buckling prevention, must be the minimum required to provide the necessary protection in order to minimise permanent habitat change.
Behavioural disturbance to fish, birds and marine mammals etc from physical presence of infrastructure and support activities						Not proceeding with alternative 1d, principally OWF, would result in an overall neutral effect for this topic, as the future leasing of renewables is likely to have the largest spatial footprint and potential to cause behavioural disturbance (e.g. displacement, particularly of birds). Plan activities will be subject to environmental requirements (EIA/HRA) and other regulatory controls at the project specific level. Mitigation is possible, including through the timing and phasing of activities. Negligible incremental effect from oil and gas, gas and CO_2 storage in depleted reservoirs, and hydrogen production, which are considered to have similar support activity requirements, and on a much smaller spatial scale than OWF.
Collision risks to birds				?		The aspect of the draft plan/programme most likely to generate significant effects is offshore wind; mortality rates being variable, depending on location. Therefore, not proceeding with this aspect of the plan (1d) would, overall, have a neutral effect for this topic, as effects from other aspects of the plan are considered likely very minor. Significant effects at a strategic level are as yet, not fully understood. Collision risk to diving birds from wet renewables also has the potential to generate significant effects, however, there is limited information to quantify the risk.
Collision risks to bats				?		Principally associated with OWF; negligible incremental effect from oil and gas, gas and CO_2 storage in depleted reservoirs and hydrogen production. Limited information to quantify risk.
Collision risks to water column megafauna (e.g. fish, marine mammals).				?		The aspect of the draft plan/programme most likely to generate significant effects is wet renewables (1d); mortality rates being variable, depending on location, although potential effect as yet not fully understood.

Potentially significant effect	Nature of effect a	b	c	d	e	Narrative
Barriers to movement of birds						Principally associated with offshore wind, but also tidal range (impact on foraging areas for waterbirds), and given the planned scale of future offshore wind development and the very low likelihood of effects from other aspects of the plan, proceeding with alternative 1d is likely to overall have a neutral impact on this topic. The most significant effect from barrier to movement is in terms of additional energy expenditure, and local movements, within and between breeding and feeding areas. Effect of additional energy expenditure at a population level, not yet understood. Potential impact from additional energy expenditure on annual regional/global migrations considered low. The loss of intertidal areas as a result of tidal range development may have a significant impact on foraging areas for waterbirds causing a barrier to birds from profitable feeding areas.
Barriers to movement of fish and marine mammals				?		Principally associated with marine renewables given the potential for multiple devices within the water column; significance of effect variable depending on location, but unlikely to be significant at a strategic level given the likely scale of development in the near to medium term. Under each sub-alternative, the remaining aspects of the draft plan/programme would proceed, with a likely minor negative impact on this topic.
						Tidal range schemes, in particular barrages, considered to represent the largest scale of potential effect. These may have a very large spatial footprint, which could be permanent if these are not removed and represent a significant barrier to the movement of migratory and estuarine fish within the local area. Effects potentially irreversible. Therefore not proceeding with this particular element of the plan would have a minor negative or at best neutral impact on this topic given the relatively small scale of effect considered for other aspects of the plan.
Changes/loss of habitats from major alteration of hydrography or sedimentation (indirect effects on the physical environment)				?		Section 5.5 concludes that there are limited and localised impacts from single or pilot scale deployments of tidal stream and wave devices, and current levels of offshore wind deployment, but scaling those impacts up to commercial wave and tidal arrays and the number of wind turbines that could be required to meet net zero target in the UK sector and adjacent north west European states, potentially has some significant issues.

Potentially significant effect	Nature of effect a	b	c	d	e	Narrative
				?		Tidal barrages have far reaching, large scale impacts that potentially change the energy balance, physical hydrography and associated ecology of the estuary/river basin permanently. For this reason and because individual estuary/embayments are so different the SEA recommends that detailed site specific data gathering and assessment is required before decisions can be taken on the acceptability or otherwise of a development (Section 5.5). The infancy of tidal lagoon technology means that further work is needed to understand the nature and extent of impacts, especially in relation to far-field and cumulative effects, though the modelling studies to date specifically for the Swansea Bay lagoon have indicated that it would be unlikely to generate far-field hydrodynamic effects. Not proceeding with this particular element of the plan could minor negative on this topic in view of the other aspects of the plan proceeding.
Potential for effects on flora and fauna of produced or treated water and drilling discharges						Principally associated with oil and gas exploration and production (1a) but drilling may also be required for the injection of gas (including CO_2 and hydrogen into storage reservoirs). Shallow drilling may also be needed to secure facilities to the seabed. Such drilling would not be expected to result in the volume of material associated with the drilling of wells. Drilling discharges are limited to water based muds, with oil-based mud and associated cuttings only discharged if treated down to <1% oil content. Discharges of WBM cuttings in the North Sea and other dispersive environments have been shown to have minimal ecological effects. There is the presumption that produced and treated water from future oil and gas developments on the UKCS will be reinjected and not discharged. Under each sub-alternative, the remaining aspects of the draft plan/programme would proceed, with a likely minor negative impact on this topic.
EMF effects on electrosensitive species				?		EMFs generated by subsea power cables associated primarily with renewables (1d) may interact in a negative way with sensitive marine species, especially benthic and demersal organisms through effects on predator/prey interactions, avoidance/attraction and other behavioural effects, effects on species navigation/orientation capabilities and physiological and developmental effects. However, whilst there is considerable uncertainty, the risk of ecological impacts is low given the scale of renewables deployment, at least in the short to medium term.
The nature and use of antifouling materials						Under each sub-alternative, the remaining aspects of the draft plan/programme would proceed, with a likely minor negative impact on this topic. Renewable energy technologies may use antifouling coatings, paints or surfaces to prevent the accumulations of excessive loads of algae and encrusting fauna; chemicals used in antifouling in UK and European waters are strictly controlled and significant effects would not be anticipated.

Potentially significant effect	Nature of effect a	b	c	d	e	Narrative
Accidental events – major oil or chemical spill						Overall risk of a major oil or chemical spill from future oil and gas exploration and production considered low; regulations in place for safety and environmental operational controls and requirements for emergency response plans and resources to be in place before offshore activities are undertaken. Future licencing for offshore renewables and gas storage (including CO_2 and hydrogen) are not considered to represent a significant source of accidental releases where navigational risks and geological characterisation have been fully considered.
Accidental events – major release of carbon dioxide		?				Future leasing for the storage of carbon dioxide (1b) represents the greatest potential risk for a major release of carbon dioxide, although data from existing long term storage (e.g. Sleipner >20 years) continues to show full containment, therefore risk of loss of containment from future leasing is considered to be low. Potential for significant effects likely to be localised and temporary. Negligible effect from other aspects of the draft plan/programme.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Contributes to conservation of the biodiversity and ecosystems of the United Kingdom and its seas.
- Avoids significant impact to conservation sites designated at an International and National level (e.g. Ramsar, SACs, SPAs, MCZs, MCMPAs, and SSSI).
- Avoids significant impact to, or disturbance of, protected species and loss of habitat.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
Plan activities do not lead to the loss of biological diversity, the degradation in the quality and occurrence of habitats, and the distribution and abundance of species.	With appropriate regulatory control and the implementation of best practice, plan activities related to these sub-alternatives are unlikely to lead to significant loss of biological diversity. Habitats Regulations Assessments screenings at both strategic and project-level will consider the potential of proposed leasing/licensing and subsequent activities to affect the site integrity of relevant sites. Effects on MCZ/MPAs will be assessed at activity consenting and licensing stage.			Assessments (mainly HRA) undertaken for recent southern North Sea OWF projects have concluded that for certain species from certain colonies (kittiwake, lesser black-backed gull), additional cumulative wind farm capacity would result in adverse effects that require compensatory measures. Similarly, the introduction of cable protection as part of OWF development in sedimentary habitats and associated loss of habitat, has become a cause of concern, particularly for southern North Sea sandbank MPAs, requiring as yet undefined compensatory measures. It should be noted that in all cases the assessments are predicated on a high degree of precaution. Not proceeding with these elements of the	As for 1a-c.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
				plan would reduce some concerns with respect to the impact of OWF development but ongoing SEA research and strategic initiatives such as the Offshore Transmission Network Review and recommended strategic reviews of potential compensatory mechanisms (Section 5.4), and of regional seabird populations and relevant pressures (Section 5.6), may facilitate the planned large-scale offshore wind farm development.	
Plan activities do not cause adverse effects on marine ecosystems/valued ecosystem components.	With appropriate regulatory control and the implementation of best practice, plan activities are unlikely to lead to significant adverse effects on marine ecosystems.			Given the potential for considerable localised (at the scale of the estuary) ecological impacts associated with tidal range schemes, not proceeding with this element of the plan would reduce the potential for the plan to cause adverse effects on marine	As for 1a-c.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
				ecosystems/valued ecosystem components.	
Plan activities contribute to the ecological knowledge of the marine and coastal environment through survey and discovery.	Site surveys associated with plan activities may contribute to ecological knowledge, provided that they are suitably archived and made widely available				
Plan activities do not lead to disruption in habitat and species connectivity.	With appropriate regulatory control and the implementation of best practice, plan activities are unlikely to lead to significant disruption in habitat and species connectivity.			The large number of individual structures in OWF developments, the presence of rotating turbines, and their potential location (e.g. in relation to foraging areas for coastal seabird breeding colonies and wintering locations for waterbirds), indicate a higher potential to disrupt connectivity between important habitats (e.g. feeding, breeding areas). Similarly, tidal range schemes may disrupt habitat connectivity for wintering waterbirds and migratory fish species. Not proceeding with this element of the plan would reduce the potential for the plan to disrupt habitat and species connectivity.	As for 1a-c.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
				It is noted that the evidence base often used to determine connectivity (mean maximum (+1SD) foraging range) may be highly precautionary).	
Plan activities do not lead to the introduction of noise at levels which adversely affect the marine environment, including by leading to significant effects on conservation sites and sensitive species.	Seismic surveys may generate high source levels with significant potential for propagation with associated behavioural and physiological effects reported for marine mammals, birds and fish (see Section 5.3). Under each sub-alternative, the remaining aspects of the draft plan/programme would proceed and the introduction of noise would result from these (noting that seismic survey associated with oil and gas exploration likely to be spread across a wider geographical area than more localised seismic for storage operations). Not proceeding with any of the sub-alternatives would reduce the level of noise introduced by that particular sub-alternative but not from the others. With appropriate regulatory control and the implementation of best practice, the potential introduction of noise at levels which may adversely affect the marine environment will be minimised. Habitats Regulations Assessments/ screenings at both strategic and project-level will consider the potential of proposed leasing/licensing and subsequent activities to affect the site integrity of Natura 2000 sites.			Piling noise associated primarily with OWF construction (but used to a lesser extent for other elements of the draft plan) has the potential for behavioural and physiological effects for marine mammals, birds and fish (see Section 5.3). With appropriate regulatory control and the implementation of best practice, the potential introduction of noise at levels which may adversely affect the marine environment will be minimised. Habitats Regulations Assessments/ screenings at both strategic and project-level will consider the	As for 1a-c.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
				potential of proposed leasing/licensing and subsequent activities to affect the site integrity of Natura 2000 sites.	
Plan activities do not lead to the introduction of non-native species at levels which adversely alter marine ecosystems.	The draft plan will not lead to the introduction of non-native species at levels which adversely alter marine ecosystems. Ballast water from shipping/rigs likely to represent the main potential source of non-native species although implementation of The International Convention for the Control and Management of Ships Ballast Water and Sediments, and related IMO guidance, should minimise risk. Increased local species diversity may be associated with hard foundations although this is unlikely to cause significant ecosystem effects.				
The plan recognises the ecosystem importance of land-sea coupling, for instance its role in species migration.	With appropriate regulatory control and the implementation of best practice, these sub-alternatives are unlikely to involve activities that will disrupt the ecosystem importance of land-sea coupling.			Tidal range aspects of the plan may represent the most significant threat to fish migration. OWF developments may displace birds from migratory routes but this is unlikely to be significant.	As for 1a-c.
The plan promotes the achievement of good ecological/environmental status for water bodies and marine sub-regions as outlined at a European Level.	The objectives of the WFD (coastal and estuarine waters) and the MFSD (marine) to promote the achievement of good status for water bodies are an integral part of the environmental management context within which the draft plan is set (see Section 2.2).				
Conclusion	Not proceeding with leasing/licensing would marginally improve the potential for the draft plan/programme to achieve its biodiversity objectives.			Not proceeding with leasing of renewables, particularly OWF and tidal range would significantly improve the potential of the draft plan/programme	As for 1a-c.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
				to achieve its biodiversity objectives.	

Geology, substrates and coastal geomorphology

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect					Narrative
	a	b	c	d	e	
Physical effects of anchoring and infrastructure construction (including pipelines and cables), operation and maintenance, and decommissioning on seabed sediments and geomorphological features (including scour)						Should any aspect of the plan not be progressed, the physical effects of any related activity would not occur. Under each sub-alternative, the remaining aspects of the draft plan/programme would proceed and physical effects would result from these, with a likely minor negative impact on this topic. Of all aspects of the plan, offshore wind farms are considered likely to represent the largest source of physical effect, and therefore out of all the options, 1d is likely to result in the greatest reduction in effect from the draft plan/programme being adopted.
Sediment modification and contamination by particulate discharges from drilling etc or resuspension of contaminated sediment						This source of effect is predominantly associated with oil and gas exploration and production, but drilling is also required for the injection of hydrocarbon gas, carbon dioxide, or hydrogen (noting hydrogen storage is unlikely before 2030) under different aspects of the plan. Not proceeding with those aspects of the plan would result in a neutral effect on the topic, however, as under each sub-alternative all other aspects of the plan proceed, a minor negative effect will remain for each. Additionally, depending on local geological conditions, shallow drilling may be required to secure all types of facilities to the seabed for all options, with offshore wind farms likely having the largest "footprint" in relation to this. Such drilling would not be expected to result in the volume of material and chemical use and discharge, associated with the drilling of wells.
Effects of reinjection of produced water and/or cuttings and carbon dioxide						This would result in a permanent change to geological formations, and is only relevant to alternatives 1a, 1b and 1c.
Onshore disposal of returned wastes – requirement for landfill						Waste generation is principally associated with oil and gas exploration (e.g. contaminated cuttings), though the installation, operation and decommissioning of all aspects of the draft plan/programme would generate wastes to be returned to shore. In all instances, the preference for the return of such wastes would be re-use or recycling with only small proportions going to landfill (see Section 5.10).
Post-decommissioning (legacy) effects – cuttings piles, footings, foundations, *in situ* cabling etc						Decommissioning of facilities to be installed following further leasing and licensing should be more easily removed than, for example, some of the large oil and gas platforms historically used, but would be subject to the prevailing legal and policy framework at the time of their decommissioning. For most oil and gas facilities, and all renewables, there is a presumption of full removal on decommissioning.

Potentially significant effect	Nature of effect					Narrative
	a	b	c	d	e	
Changes to sedimentation regime and associated physical effects						Of all aspects of the plan, only renewables are considered to have the potential to alter the sedimentary regime in any significant way through cumulative local and far-field effects, with tidal range technologies, and in particular barrages, considered to represent the largest source of potential effect.
Accidental events – risk of sediment contamination from oil spills						There is a low risk of occurrence of major spills, predominantly related to oil exploration and production, and a very low risk of spills related to navigation for offshore wind, wave and tidal energy.
Accidental events – blow out impacts on seabed						There is a low risk of a blow out associated with oil and gas exploration, and gas storage.
Offshore disposal of seabed dredged material						While most recently a concern relating to seabed preparation and levelling for offshore wind farms at certain locations, it may also be required for export pipeline installation associated with oil and gas production, gas storage, carbon dioxide storage, and the export of hydrogen gas. Resulting sediment plumes would be temporary and significant deposition localised to the disposal location.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Protects the quality of the seabed and its sediments, and avoids significant effects on seabed morphology and sediment transport processes.
- Protects the integrity of coastal and estuarine processes.
- Avoids significant damage to geological conservation sites and protects important geological/geomorphological features.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
Activities arising from the plan do not adversely affect the quality and character of the geology and	Further oil and gas licensing is likely to generate only	Leasing/licensing for carbon dioxide or gas storage are likely to generate only localised effects. There is greater potential for new		Not proceeding with renewables leasing will reduce the	Offshore hydrogen production is likely to generate only

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
geomorphology of seabed or coastal sediments.	localised effects. Not proceeding with licensing would marginally reduce the overall physical effects of the draft plan/programme.	pipelines with this aspect of the plan compared to further oil and gas licensing. Not proceeding with leasing/licensing would marginally reduce the overall physical effects of the draft plan/programme.		potential for effects on geology and geomorphology, however, for most activities the effects are likely to only be locally significant, but caution is required in the planning of scaled up wave and tidal stream arrays and tidal range schemes, particularly given the relative permanency of the latter. Not proceeding with leasing would have the largest impact on reducing the overall physical effects of the draft plan/programme.	localised effects. There is greater potential for new pipelines with this aspect of the plan compared to further oil and gas licensing. Not proceeding with offshore hydrogen would marginally reduce the overall physical effects of the draft plan/programme.
Plan activities do not lead to changes in seafloor integrity which could adversely affect the structure and function of ecosystems.	Most aspects of the plan will result in relatively limited and temporary changes to the seabed which will not have a significantly adverse effect on associated ecosystems. Tidal range schemes may have a much greater impact on the seafloor which could adversely affect the structure and function of ecosystems. Alternative 1d would, therefore, likely result in the lowest level of effect.				
Plan activities avoid adverse effects on designated geological and geomorphological sites of international and national importance.	Most aspects of the plan are unlikely to affect sites of national or international importance, however the potential is there to do so, and detailed site specific survey should inform any proposal. As above, the aspect of the draft plan/programme most likely to generate effects is renewables due to their potential scale of future deployment, and in the case of tidal range, relative permanence, such that most sub-alternatives are likely to have marginal effect on sites other than potentially 1d.				
Conclusion	Not proceeding with leasing/licensing would marginally reduce the overall physical effects of the draft plan/programme.			Not proceeding with leasing would likely result in a significantly lower level of potential physical effect on	As per 1a-1c

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
				geology and geomorphology, including features of conservation interest.	

Landscape/seascape

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect					Narrative
	a	b	c	d	e	
Potential effects of development on seascape including change to character (interactions between people (and their activities) and places (and the natural and cultural processes that shape them))						Should any aspect of the plan not proceed, landscape and seascape effects will not occur in relation to it. As noted in Section 5.8, the aspect of the draft plan/programme most likely to generate significant effects is offshore wind, and therefore, not proceeding with that aspect of the plan is most likely to produce lower levels of effect. This should be read in conjunction with the conclusions of Section 5.8.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- To accord with, and contribute to the delivery of the aims and articles of the European Landscape Convention and minimise significant adverse impact on seascape/landscape including designated and non-designated areas.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
Activities do not adversely affect the character of the landscape/seascape.	Further oil and gas licensing, and leasing/licensing for gas storage (including carbon dioxide) is unlikely to result in significant effects on landscape/seascape in view of the location of prospective areas, and the likely small scale of future development. Not adopting these aspects of the plan is unlikely to alter the significance of the effect of			Not proceeding with further renewables leasing is the most likely sub-alternative to reduce the levels	Hydrogen development is likely to be small scale offshore initially. Not adopting this aspect

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
	the overall draft plan/programme on the character of landscape and seascapes, particularly as the greatest source of such effect is likely to be from renewables, which will proceed under all alternatives other than 1d.			of potential effect of the plan to being very minor.	of the plan is unlikely to alter the significance of the effect of the overall draft plan/programme on the character of landscape and seascapes, particularly as the greatest source of such effect is likely to be from renewables, which will proceed under all alternatives other than 1d.
The plan helps to conserve the physical and cultural visual resource associated with the land and sea.	Not adopting these aspects of the plan is unlikely to alter the significance of the effect of the overall draft plan/programme on the physical and cultural resource of landscape and seascapes, particularly as the greatest source of such effect is likely to be from renewables, which will proceed under all alternatives other than 1d.			Not proceeding with further renewables leasing is the most likely sub-alternative to reduce the levels of potential effect of the plan on the physical and cultural resource.	Not adopting this aspect of the plan is unlikely to alter the significance of the effect of the overall draft plan/programme on the physical and cultural resource of landscape and seascapes, particularly as the greatest source of such effect is likely to be from renewables, which will proceed under all alternatives other than 1d.
Conclusion	It is not considered likely that adoption of these alternatives will significantly alter the effects of the plan on landscape and seascape, particularly as the greatest source of such effect is likely to be from renewables, which will proceed under all alternatives other than 1d.			The risk of effects on landscape and seascape, both from individual	As for sub-alternatives 1a-1c. It is not considered likely that adoption of

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
	This should be read in conjunction with the controls in relation to landscape/seascape effects and conclusions of Section 5.8.			developments and from cumulative effects with renewables and other offshore activity is greatest from further renewables leasing, and so selection of alternative 1d would be expected to result in the lowest level of effect from the draft plan/programme on this topic. This should be considered in the context of the conclusions of Section 5.8.	this alternative will significantly alter the effects of the plan on landscape and seascape.

Water environment

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect a	b	c	d	e	Narrative
Contamination by soluble and dispersed discharges including produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction						This source of effect is predominantly associated with oil and gas exploration and production (noting the general presumption that produced water from future oil and gas developments on the UKCS will be reinjected and not discharged), but drilling and saline discharges may be produced during the construction and management of hydrocarbon gas, carbon dioxide, or hydrogen storage (although the effect of these are unlikely to be significant if appropriate mitigation followed). Not proceeding with those aspects of the plan would result in a neutral effect on the topic, however, as under each sub-alternative all other aspects of the plan proceed, a minor negative effect will remain for each. Additionally, depending on local geological conditions, shallow drilling may be required to secure all types of facilities to the seabed for all options, with offshore wind farms likely having the largest “footprint” in relation to this. Such drilling would not be expected to result in the volume of material and chemical use and discharge, associated with the drilling of wells.
Changes in seawater or estuarine salinity, turbidity and temperature from discharges (such as aquifer water and halite dissolution) and impoundment						Consented discharges of aquifer water etc are principally associated with gas, CO_2 and hydrogen storage, and are unlikely to have a significant impact. Of all aspects of the plan, only tidal range schemes have the potential to significantly change seawater or estuarine water properties through impoundment. Therefore not proceeding with further leasing for offshore renewables (1d) will potentially result in fewer effects on seawater properties.
Energy removal from wet renewable devices, and offshore wind farms						The scale of potential impact for the alternatives reflects that non-renewable aspects of the draft plan/programme will not result in large-scale energy removal. Not proceeding with further leasing for offshore renewables (1d) will potentially result in fewer effects on hydrographic processes.
Accidental events - contamination of the water column by dissolved and dispersed materials from oil and chemical spills or gas releases						There is a low risk of occurrence of major spills, predominantly related to oil exploration and production, and a very low risk of spills related to navigation for offshore wind, wave and tidal energy. CO_2, gas and hydrogen storage developments are not considered to represent a significant source of contamination from spills or accidental releases where navigational safety risks have been fully considered and where there is knowledge of the reservoir or aquifer properties. Overall risk of significant contamination associated with oil exploration and development considered low with reported spills primarily of very small quantities of oil.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Protects estuarine and marine surface waters, and potable and other aquifer resources.
- Avoid significant impact on flood and coastal risk management activities.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
Plan activities do not result in concentrations of contaminants at levels giving rise to pollution effects.	Further oil and gas licensing and leasing/licensing for gas storage (including carbon dioxide), is likely to generate only localised and temporary pollution effects. Not proceeding with leasing/licensing would marginally reduce the potential for pollution effects associated with the draft plan/programme.			The majority of chemicals used are in closed systems and therefore not discharged under normal circumstances. Not proceeding with further renewables would not affect the potential for pollution effects as these primarily associated with other aspects of the plan.	Hydrogen development is likely to be small scale offshore initially. Not adopting this aspect of the plan is unlikely to alter the potential for pollution effects associated with the draft plan.
Plan activities do not result in permanent alteration of hydrographical conditions which adversely affect coastal and marine ecosystems.	n/a	n/a	n/a	Not proceeding with further renewables leasing will mean no further changes to hydrographic processes from this aspect of the draft plan/programme.	n/a
Plan activities do not result in adverse effects on saline and potable aquifer resources.	n/a	Potential adverse effects on saline and potable aquifer resources only likely during the construction and management of hydrocarbon gas, carbon dioxide, or hydrogen storage in saline aquifers (although the effect of these are unlikely to be significant given appropriate control measures). Not		n/a	Hydrogen development is likely to be small scale offshore initially. Not adopting this aspect of the plan is unlikely to alter the potential

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
		proceeding with leasing/licensing would marginally reduce the potential of the draft plan to have adverse effects on aquifer resources.			for adverse effects on aquifer resources.
Conclusion	The risk of pollution effects on the water environment, both from individual developments and from cumulative effects with other offshore activity is greatest from further oil and gas licensing (although as noted this is likely to be limited), and so not proceeding with further oil and gas licensing will result in the lowest level of effect from the draft plan/programme on this topic. This should be considered in the context of the conclusions of Section 5.9.	Leasing/licensing for gas storage (including carbon dioxide) is unlikely to result in significant effects on the water environment where navigational safety risks have been fully considered and where there is knowledge of the reservoir or aquifer properties. Not adopting these aspects of the plan is therefore unlikely to alter the overall effect of the draft plan/programme on the water environment.		The risk of pollution effects from renewables is unlikely given the closed nature of most systems where chemicals are used. Tidal range schemes have the potential to significantly change seawater or estuarine water properties through impoundment. Therefore not proceeding with further renewables leasing will not alter the overall effect of the plan with respect to water pollution but could have a positive effect with respect to estuarine areas identified as a tidal range resource.	Hydrogen development is likely to be small scale offshore initially. Not adopting this aspect of the plan is unlikely to alter the potential for adverse effects on the water environment associated with the draft plan.

Air quality

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect a	b	c	d	e	Narrative
Local air quality effects resulting from vessel and power generation exhaust emissions, flaring and venting						All aspects of the draft plan will have associated vessel emissions but these will likely decrease in the future as part of implementation of the Clean Maritime Plan. With the exception of renewables, power generation emissions make the largest contribution to draft plan emissions, particularly oil and gas but will likely decrease significantly alongside future GHG emission reduction efforts (e.g. electrification and zero routine flaring and venting).
Air quality effects of a major gas release or volatile oil spill						Offshore renewables and gas storage (including CO_2) are not considered to represent a significant source of accidental releases where navigational risks and geological characterisation have been fully considered. Overall risk of a major gas release or oil spill associated with oil exploration and development considered low.
Potential for effects on human health associated with reduced local air quality resulting from atmospheric emissions associated with plan activities						The offshore nature of most of the draft plan activities reduces the potential for air quality effects on human health. The potential expansion of ports to facilitate mainly OWF, but possibly also other renewables development, may have implications for local air quality in these areas. Construction of tidal range schemes could produce significant cumulative effects at a local level through emissions from shipping and road haulage transport, or production of dust.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Avoids degradation of regional air quality from plan related activities.

Guide phrases	Alternatives 1a	1b	1c	1d	1e
The plan contributes to the achievement of air quality targets outlined in the Clean Air Strategy 2019, Cleaner Air for Scotland 2, and other strategies of devolved administrations.	Not proceeding with further oil and gas licensing will have a negligible effect on overall draft plan atmospheric	Not proceeding with gas and CO_2 storage will have a minimal effect on overall draft plan atmospheric emissions as the emissions associated with the likely scale of storage operations over the short to medium term are		Offshore renewables deployment, and in particular offshore wind, is expected to make a significant contribution to the UK	Not proceeding with hydrogen storage will have a minimal effect on overall draft plan atmospheric emissions as the

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
	emissions and associated air quality given the limited scale of exploration and production activity likely to result from licensing. Continued decommissioning of ageing infrastructure and strategies in place to decarbonise upstream oil and gas (e.g. shift towards electrification and zero routine flaring) will contribute towards achieving reductions in air quality target emissions.	unlikely to represent significant sources of atmospheric emissions.		Government's programme to decarbonise energy supply which would also represent a positive contribution to the achievement of air quality targets. An increase in port facilities or uptake of existing port capacity could lead to an increase in emissions which could contribute to the perpetuation, or creation, of Local Air Quality Management Areas although Port Air Quality Strategies offer a means to minimise this contribution.	emissions associated with the likely scale of storage operations over the short to medium term are unlikely to represent significant sources of atmospheric emissions.
Emissions from plan activities do not contribute to, or result in, air quality issues which adversely affect human health or the wider environment.	Emissions from oil & gas and gas storage (including CO_2 storage) are not expected to directly contribute to emissions which may lead to detrimental air quality and resultant health effects given their likely scale in the short to medium term and primarily offshore location.			The expansion of port activities (as above) has the greatest potential to produce effects at the local level although Port Air Quality Strategies may offer a means to minimise this contribution.	Emissions from hydrogen storage are not expected to directly contribute to emissions which may lead to detrimental air quality and resultant health effects given their likely scale in the short to medium term and offshore location.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
Conclusion	Emissions from oil & gas and gas storage (including CO_2 storage) are not expected to directly contribute to emissions which may degrade regional air quality given their likely scale in the short to medium term and primarily offshore location. Any new developments as a result of plan implementation will need to align with ongoing emission reduction strategies.			Offshore renewables deployment, and in particular offshore wind, is expected to make a significant contribution to the UK Government's programme to decarbonise energy supply which would also represent a positive contribution to the achievement of air quality targets.	Emissions from hydrogen storage are not expected to directly contribute to emissions that degrade regional air quality their likely scale in the short to medium term and offshore location.

Climate and meteorology

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect					Narrative
	a	b	c	d	e	
Contributions to net greenhouse gas emissions						a: emissions from oil and gas exploration and production will make a minor contribution to the wider greenhouse gas emissions of the UK, and not adopting this aspect of the plan would limit these domestic emissions. In the absence of a corresponding change in demand for oil and gas, a greater proportion would need to be imported. It is therefore considered that alternative 1a would either be neutral, as it would have no effect on the demand for hydrocarbons in the UK, or potentially minor negative due to the higher emissions intensity of most imports (refer to Section 5.12 where this is discussed in greater detail). b: should no further leasing/licensing for offshore carbon dioxide storge take place, emissions associated with the appraisal, installation and commissioning of facilities would be eliminated, however, it is unlikely the objectives of the plan would be met for this aspect, with wider implications for the UK to meet its net zero targets. c: contributions to emissions may be lower should no further leasing/licensing for hydrocarbon gas storage take place on the UKCS due to emissions associated with the construction and operation of such a site, however, the risk of enhancing imports from such an option may have a similar outcome for gas as alternative 1a. d: not proceeding with further renewables leasing would not meet the objectives of this aspect of the plan, and severely limit the UK Government's ability to achieve related policy goals, and the scale of deployment that is likely to be needed to reach net zero (for example as indicated by the CCC, see Section 2.5). While not proceeding with this aspect of the plan would eliminate emissions associated with the construction, installation and maintenance of devices, the limited payback periods for renewables (see Section 5.12) means not proceeding is likely to contribute to emissions overall. e: should offshore hydrogen production not proceed, emissions associated with the installation, operation and maintenance of these facilities will not occur, however, the draft plan/programme will not contribute to any production targets towards 2030 and beyond, and there may be a missed opportunity to store energy generated in periods of high renewables production and low demand. In the event this activity is moved onshore, the outcome may be neutral.

Potentially significant effect	Nature of effect a	b	c	d	e	Narrative
Reduction in net greenhouse gas emissions						a: the demand for oil and gas is being dealt with through a range of measures that are not considered in this SEA, however, projections of demand for hydrocarbons, and production of these from the UKCS, shows both a decline towards 2050 and a significant gap between the demand and production. If no further licensing was undertaken on the UKCS, and in the absence of any indication that demand will reduce more quickly than projected (and also recognising the need for hydrocarbons as feedstocks and not just fuel), the UK would need to import more oil and gas, with it being highly likely that these imports would have a higher upstream carbon intensity than that which would have been produced domestically (e.g. as the foundations for decarbonising upstream emissions have already been set for the UK in the NSTD, OGA Strategy, Net Zero Strategy etc., see Section 5.12). It is therefore considered that alternative 1a would either be neutral, as it would have no effect on the demand for hydrocarbons in the UK, or minor negative due to the higher emissions intensity of imports. b: should no further leasing/licensing for offshore carbon dioxide storge take place, emissions associated, it is unlikely the objectives of the plan would be met for this aspect, with wider implications for the UK to meet its net zero targets. c: there may be a net reduction in greenhouse gas emissions should no further leasing/licensing for hydrocarbon gas storage take place on the UKCS due to emissions associated with the construction and operation of such a site, however, the risk of enhancing imports from such an option may have a similar outcome for gas as alternative 1a. d: not proceeding with further renewables leasing would not been the objectives of this aspect of the plan, and severely limit the UK Government's ability to achieve related policy goals, and the scale of deployment that is likely to be needed to reach net zero (for example as indicated by the CCC, see Section 2.5). e: should offshore hydrogen production not proceed, the draft plan/programme will not contribute to any production targets towards 2030 and beyond, and there may be a missed opportunity to store energy generated in periods of high renewables production and low demand. In the event this activity is moved onshore, the outcome may be neutral.
Effects on blue carbon						In all cases, not proceeding with an element of the draft plan/programme will mean there is less seabed disturbance, such that any effect on the blue carbon stored in seabed sediments can be discounted, but only for that aspect. While the greatest effect is likely to be generated by the aspect of the plan likely to have the largest footprint (renewables, alternative 1d), there is a likely minor negative effect under all alternatives.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Minimises greenhouse gas emissions.
- Resilience to climate change.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
The plan contributes to decarbonisation in the energy sector, and the achievement of targets relating to greenhouse gases at a national and international level, which include the UK's Net Zero target, related carbon budgets, and the Nationally Determined Contribution under the Paris Agreement.	In the context of hydrocarbon demand, over which the draft plan/programme has no control, and the policies and strategies in place to decarbonise further upstream oil and gas activities[338], not proceeding with further licensing could either have no effect on decarbonising the energy sector, or it may be negatively affected by higher carbon intensity imports. This must be read in conjunction with Section 5.12.	Carbon dioxide storage is a key component of the UK Government's plan to deliver net zero, and a key piece of policy context related to the objectives of the plan. Not proceeding with carbon dioxide storage offshore would likely compromise the ability of the UK to meet its future carbon budgets.	As noted above, not proceeding with this aspect of the plan is regarded to have either a neutral effect, or depending on whether greater imports are required, a minor negative effect.	Offshore renewables deployment, and in particular offshore wind, is expected to make a significant contribution to the UK Government's programme to decarbonise energy supply. If further leasing were not pursued, the scale of deployment set out in the net zero strategy or projected towards 2050 (e.g. by the CCC) could not be met.	Should offshore hydrogen production not proceed, there could be a lost opportunity for the plan to contribute to wider decarbonisation of energy supply.
Plan activities recognise the potential impact of climate change during their lifetime, in relation to their potential impact on coastal change, flood risk, or other climate change adaptation. Plan activities	n/a, if no further licensing was undertaken, these aspects of the plan would not need to individually make such considerations.				

[338] Refer to Section 5.12, and in particular, the conclusions and recommendations.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
recognise the potential for climate change related impacts to affect them, and take this into account in their design.					
Conclusion	In the absence of a change in projected demand for hydrocarbons which is in keeping with scenarios that meet net zero, it cannot be definitively concluded whether further licensing will result in higher carbon dioxide emissions overall. There remains some advantage to domestic production by reducing its emissions intensity to well below that of imports.	Without further leasing/licensing for carbon dioxide storage, it will be challenging for the UK to meet policy objectives consistent with the sixth carbon budget and beyond.	The effect on this topic of not proceeding with gas storage leasing/licensing is considered to be marginal.	Without further leasing for renewables, it will be challenging for the UK to meet policy objectives consistent with the sixth carbon budget and beyond.	The effect on this topic of not proceeding with offshore hydrogen production is considered to be marginal in the short term, but it could hamper any longer term targets for such production.

Population and human health

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect a	b	c	d	e	Narrative
Potential for effects on human health associated with reduced local air quality resulting from atmospheric emissions associated with plan activities						The offshore nature of most of the draft plan activities reduces the potential for air quality effects on human health. The potential expansion of ports to facilitate mainly OWF, but possibly also other renewables development, may have implications for local air quality in these areas. Construction of tidal range schemes could produce significant cumulative effects at a local level through emissions from shipping and road haulage transport, or production of dust.
Potential for effects on human health associated with discharges of naturally occurring radioactive material in produced water						Of potential relevance to oil and gas and gas storage but unclear whether pressure control for CO_2 or hydrogen storage could result in discharges of NORM in produced water. However, with respect to oil and gas, the concentrations of radionuclides in water and sediments surrounding platforms are low and there is no evidence of a pathway that could lead to significant accumulation in fish, and consequently effects on human health are not predicted.
Accidental events – potential food chain or other effects of major oil or chemical spills or gas release						Offshore renewables and gas storage (including CO_2) are not considered to represent a significant source of accidental releases where navigational risks and geological characterisation have been fully considered. Overall risk of a major gas release or oil spill associated with oil exploration and development considered low.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Has no adverse impact on human health and wellbeing.
- Avoids disruption, disturbance and nuisance to communities.

Guide phrases	Alternatives 1a	1b	1c	1d	1e
Plan activities do not result in, or contribute to the contamination of fish and other seafood for human consumption at levels which	Discharges from plan activities will be subject to regulatory controls at the project level, and are not expected to contribute to the contamination of fish or seafood for human consumption. Therefore, not proceeding			Not proceeding with further leasing for renewables would have a neutral impact	As for 1a, b and c.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
exceed those established by Community legislation or other relevant standards.	with licensing or leasing of any of these aspects of the draft plan would have a minimal effect.			as the majority of chemicals used are in closed systems and therefore not discharged under normal circumstances.	
Plan activities avoid adverse effects on physical and mental health.	Plan activities will be subject to Health and Safety requirements and other regulatory controls at the project specific level which will minimise the potential for adverse effects on physical and mental health. Therefore not proceeding with a particular aspect of the plan will not significantly change the potential for adverse effects.				
Plan activities avoid adverse nuisance to communities, for instance through noise or vibration.	Those aspects of the plan with the potential to cause nuisance to communities include the onshore decommissioning of oil and gas infrastructure and the construction of tidal lagoons. However, as above, these activities will be subject to Health and Safety requirements and other regulatory controls at the project specific level which will minimise the potential for adverse nuisance to communities. Therefore not proceeding with a particular aspect of the plan will not significantly change the potential for adverse effects.				
Adverse effects on the quality or access to areas used for recreation (e.g. amenity, sailing, surfing), are minimised or avoided.	Not proceeding with further oil and gas licensing and licensing/leasing of gas storage (including CO_2) will have a negligible effect on the quality or access to recreation areas given the likely limited scale of potential activities and their offshore nature. Existing leasing/licensing measures and regulatory controls (e.g. EIA) provide a suitable level of control with regard to the location of activities.			Not proceeding with renewable aspects of the plan could have a positive effect on the quality or access to recreation areas due to the spatial scale of development and the location-specific nature of areas used for recreation. Existing leasing/licensing measures and regulatory controls (e.g. EIA) provide a suitable level of control with regard to the location of activities.	As for 1a, b and c.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
Conclusion	Plan activities will be subject to Health and Safety requirements and other regulatory controls at the project specific level which will minimise the potential for adverse effects on human health and wellbeing, as well as the potential for disturbance and nuisance to communities. Therefore not proceeding with a particular aspect of the plan will not significantly change the potential for adverse effects.				

Other users and material assets (Infrastructure, Other Natural Resources)

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect					Narrative
	a	b	c	d	e	
Positive socio-economic effects of contributing to greenhouse gas reduction						All aspects of the plan have their objectives set within the context of net zero. Should no further seaward oil and gas licensing proceed (1a) there is a risk that there is a greater reliance on imports that have not been produced in basins targeting net zero upstream emissions, though this may decrease over time, and with a lower socio-economic benefit for the UK. Additionally, not proceeding with further licensing reduces the UK's security of supply. Similarly, not proceeding with carbon dioxide storage (1b), renewables leasing (1d) and offshore hydrogen production (1e) would all represent a loss of the potential socio-economic benefits from the part offshore energy can play in the energy transition, including a loss of jobs and related skills. Similar arguments can be made for hydrocarbon gas storage (1c) as for not proceeding with future seaward licensing for oil and gas exploration and production; not proceeding with this aspect of the draft plan/programme may have a neutral effect at best or a possible minor negative effect.
Interactions with fishing activities (exclusion, displacement, seismic, gear interactions, "sanctuary effects")						Offshore oil and gas (1a), gas storage (1c) (including CCS, 1b) facilities, and the likely scale of that for hydrogen production (1e), are generally small and will likely have a low density across the UKCS, with many recent oil and gas developments entirely subsea and with limited fisheries exclusion. The effect on fisheries of these in the context of the likely scale of leasing/licensing from adoption of the draft plan/programme is considered so small as to be effectively neutral. Offshore wind farms cover larger areas and floating wind farms may preclude certain types of fisheries entirely. Not proceeding with further renewables leasing (1d) would result in a lower level of displacement for fisheries from the plan overall, to the point that it would have a neutral effect.

Potentially significant effect	Nature of effect					Narrative
	a	b	c	d	e	
Other interactions with shipping, military, potential other marine renewables and other human uses of the offshore environment						Similar to above, the relative scale and potential for interaction make offshore renewables, and in particular offshore wind, more likely to result in interactions with other users. Not proceeding with that aspect of the plan would therefore be expected to have neutral effect on reducing interactions with other users. This should be read in the context of the range of planning/marine plan policy, guidance and statutory means of securing mitigation to avoid or reduce conflicts (see Section 5.7).
Accidental events – socio-economic consequences of oil or chemical spills and gas releases						Further oil and gas licensing contains the greatest risk of a large oil or chemical spill and related socio-economic effects, and not proceeding with that aspect of the plan (1a) would likely produce a neutral impact, or a very low likelihood of a minor negative impact from the other aspects of the plan being considered. The likelihood of spills from the other aspects of the plan are very low, particularly for renewable energy and hydrogen production, such that alternatives 1b and 1e, are likely to have a minor negative effect as under all of these further oil and gas licensing proceeds.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Balances other United Kingdom resources and activities of economic, safety, security and amenity value including defence, shipping, fishing, aviation, aggregate extraction, dredging, tourism and recreation against the need to develop offshore energy resources.
- Safety of Navigation.
- Reduces waste.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
Plan activities integrate with the range of other existing uses of the marine environment.	Mitigation between plan activities and existing users is already controlled through a range of licensing and leasing conditions, regulatory controls, and decisions related to individual applications should be made in accordance with relevant planning and marine plan policy. Alternative 1d has the least impact as renewable present the greatest potential for				

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
	conflict with certain other uses of the sea such as fisheries, and while work is ongoing[339], between carbon dioxide storage and offshore wind. The co-location of activities could take place where it is deemed appropriate. Greater activity coordination should be expected through marine planning in the future.				
Plan activities do not result in adverse effects on marine assets and resources.	Plan activities should not sterilise areas of potential future use (e.g. potential carbon dioxide stores or key areas of renewable resources) or compromise those presently in use (e.g. aggregate extraction areas) through inappropriate siting. Policies of the marine plans reflect this and where possible, all developments should seek to avoid, minimise or mitigate impacts on other resources, or justify why impacts are outweighed by the benefits. As above, the alternative with least potential for spatial conflict is 1d.				
Plan activities avoid adverse effects on, and contribute to the maintenance of, safe navigation, including recognised shipping routes, traffic separation and existing and proposed port operations.	Potentially significant impacts could arise (at a strategic level) from offshore wind and other marine renewables due to their spatial scale and the location-specific nature of certain resources, though activities would not take place in specified IMO routeing areas. Marine plan policies identify additional areas which should be avoided where possible, or entirely, and when combined with existing leasing/licensing measures and regulatory and planning controls (e.g. consent to locate) there is a suitable level of control with regard to the location of activities.				
Properties and quantities of waste and litter resulting from plan activities do not cause harm to the coastal and marine environment.	Through existing regulatory controls, offshore waste is returned to shore and disposed of appropriately.				
Conclusion	Plan activities have the potential to negatively impact existing users of the sea. There is the potential for co-location of activities where it is appropriate. Activities will not generate waste related impacts at sea or at the coast, nor will they impact upon present or potential marine resources. At a strategic level, the lowest level of impact is likely if Alternative 1d proceeded, noting the controls already referred to above (also see Section 5.7 and 5.15).				

339 https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/energy/offshore-wind-and-ccus-co-location/

Cultural heritage

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect					Narrative
	a	b	c	d	e	
Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc. and impacts on the setting of coastal historic environmental assets and loss of access.						Should any aspect of the plan not proceed, related physical disturbance would not occur and the setting of assets would not be affected. Adopting alternative 1d is most likely to result in the smallest scale of effect, as the future leasing of renewables is likely to have the largest spatial footprint and related physical disturbance, generating the greatest amount of physical effect, and is also most likely to affect the setting of heritage assets (however refer to Section 5.8 and the separate consideration against landscape/seascape above, and also Section 5.4). For all alternatives, there remains a potential minor negative effect on this topic.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Protects the historic environment and cultural heritage of the United Kingdom, including its setting.
- Contributes to archaeological knowledge.

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
Activities avoid adverse effects on the character, quality and integrity of the historic and/or cultural landscape, including those sites which are designated or registered, and areas of potential importance.	Not proceeding with any aspect of the plan definitively avoids adverse effects on historic/cultural landscapes. Of all the alternatives, 1d, not to proceed with further renewables leasing, is most likely to positively affect this objective, as they are likely to be the largest source of effect on all forms of landscape/seascape.				
Plan activities contribute to the archaeological and cultural knowledge of the marine and coastal environment through survey and discovery.	There would be no contribution to furthering knowledge. Of all the alternatives, 1d, not to proceed with further renewables leasing, is most likely to negatively affect this objective, as the large areas of survey coverage and prospective offshore wind areas to date, have been useful in generating new information to interpret. Historical oil and gas seismic data has also led to the characterisation of palaeolandscapes in the North Sea, however these data are generally not collected with any focus on the historic environment.				

Guide phrases	Alternatives				
	1a	1b	1c	1d	1e
Conclusion	As above, the greatest positive, and potentially negative, impact would be option 1d.				

5.17.3 Alternative 2: To proceed with a leasing and licensing programme, and Alternative 3: To restrict the areas offered for leasing and licensing temporally or spatially

Biodiversity, habitats, flora and fauna

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect		Narrative
	2	3	
Physical damage to biotopes from infrastructure construction, vessel/rig anchoring etc (direct effects on the physical environment)			The footprint of effect associated with all the elements of the draft plan/programme is considered to represent a negligible incremental effect, with effects in most areas reversible over time. The introduction of hard substrates (including rock and concrete mattresses) in sedimentary habitats, particularly associated with offshore wind farm cable protection but also as a result of oil and gas pipeline installation and decommissioning, has become a recent cause of concern, particularly for southern North Sea sandbank MPAs. Effects in most areas reversible over time; mitigation may be possible through identification and avoidance of biotopes where this is not the case.
Behavioural and physiological effects on marine mammals, birds and fish from seismic surveys			Seismic surveys are principally associated with oil & gas exploration and development, with seismic also likely to be used to define and monitor gas storage reservoirs including gas, CO_2 and hydrogen, although the predicted level of activity is low. Seismic surveys may generate high source levels with significant potential for propagation with associated behavioural and physiological effects reported for marine mammals, birds and fish (see Section 5.3). These activities will be subject to environmental requirements (noise assessment) and other regulatory controls at the project specific level, e.g. presence of MMO/PAM operatives.

Potentially significant effect	Nature of effect 2	Nature of effect 3	Narrative
Behavioural and physiological effects on marine mammals, birds and fish from other geophysical surveys			Other geophysical surveys include the use of echosounders, side-scan sonars and sub-bottom profilers which may be used by all aspects of the plan to provide information on the surface or shallow seabed. Sound levels generally drop off quickly with distance due to high frequency (>10kHz) and high directionality of these systems, but not all systems have been adequately characterised. Plan activities will be subject to environmental requirements and other regulatory controls at the project specific level, which may include noise assessments where relevant.
Behavioural and physiological effects on marine mammals, birds and fish associated with construction phase noise[340]			The aspect of the draft plan/programme most likely to generate significant effects is piling for offshore wind. Generation of construction phase noise also applicable to oil and gas and to a lesser extent from wave and tidal, principally through piling of infrastructure to the seabed; for wave and tidal in practice, piling is unlikely to occur extensively, although the information on underwater noise associated with wave and tidal energy device construction remains relatively limited. Negligible incremental effect from hydrocarbon gas and CO_2 storage in depleted reservoirs. Plan activities will be subject to environmental requirements (noise assessment) and other regulatory controls at the project specific level, e.g. presence of MMO/PAM operative.
Behavioural and physiological effects on marine mammals, birds and fish associated with operational noise			Negligible operational noise from OWF; source levels from oil and gas production and hydrocarbon gas and CO_2 storage (e.g. gas compression) relatively low therefore local effects only. Potential for noise associated with operation of wave and tidal stream devices, although limited information.
Behavioural and physiological effects on marine mammals, birds and fish associated with decommissioning noise			Noise emissions associated with decommissioning of all aspects of the plan are likely to be similar in nature to those generated during construction and installation, with the exception of an absence of extensive pile-driving and detonation of UKO (OWF) and seismic survey (oil and gas) noise. Noise from decommissioning can also result from the use of explosives, principally from oil and gas. Plan activities will be subject to environmental requirements (noise assessment) and other regulatory controls as part of the decommissioning programme process.
The introduction and spread of non-native species			Possibility of effects mitigated by adherence to ballast water guidance. Presence of all energy foundations/infrastructure in water column (OWF (fixed and floating), wave/tidal, O&G. CCUS, gas storage and hydrogen production),will result in biofouling to some extent, and may result in localised increase in species diversity, but, given the natural widespread presence of hard substrates, such as glacial dropstones, unlikely that foundations/ structures will facilitate the spread of non-natives to the point where they become invasive.

[340] May include piling noise, and the detonation of unexploded ordnance (UXO).

Potentially significant effect	Nature of effect 2	3	Narrative
Behavioural disturbance to fish, birds and marine mammals etc from physical presence of infrastructure and support activities			The aspect of the draft plan/programme most likely to generate significant effects is offshore wind, as the future leasing of renewables is likely to have the largest spatial footprint and potential to cause behavioural disturbance (e.g. displacement, particularly of birds). Plan activities will be subject to environmental requirements (EIA/HRA) and other regulatory controls at the project specific level. Mitigation is possible, including through the timing and phasing of activities. Negligible incremental effect from oil and gas, gas and CO_2 storage in depleted reservoirs, and hydrogen production, which are considered to have similar support activity requirements, and on a much smaller spatial scale than OWF.
Collision risks to birds	?	?	The aspect of the draft plan/programme most likely to generate significant effects is offshore wind; mortality rates being variable, depending on location. Significant effects at a strategic level are as yet, not fully understood. Collision risk to diving birds from wet renewables also has the potential to generate significant effects, however, there is limited information to quantify the risk. Plan activities will be subject to environmental requirements (EIA/HRA) and other regulatory controls at the project specific level. Negligible incremental effect from oil and gas, gas and CO_2 storage in depleted reservoirs, and hydrogen production.
Collision risks to bats	?	?	Principally associated with OWF; negligible incremental effect from oil and gas, gas and CO_2 storage in depleted reservoirs and hydrogen production. Limited information to quantify risk.
Collision risks to water column megafauna (e.g. fish, marine mammals).	?	?	The aspect of the draft plan/programme most likely to generate significant effects is wet renewables; mortality rates being variable, depending on location, although potential effect as yet not fully understood.
Barriers to movement of birds	?	?	Principally associated with OWF, with the other aspects of the draft plan having a negligible effect. The most significant effect from barrier to movement is in terms of additional energy expenditure, and local movements, within and between breeding and feeding areas. Effect of additional energy expenditure at a population level, not yet understood. Potential impact from additional energy expenditure on annual regional/global migrations considered low.
			The loss of intertidal areas as a result of tidal range development may have a significant impact on foraging areas for waterbirds causing displacement of birds.
Barriers to movement of fish and marine mammals	?	?	Principally associated with marine renewables given the potential for multiple devices within the water column; significance of effect variable depending on location, but unlikely to be significant at a strategic level given the likely scale of development in the near to medium term.

Potentially significant effect	Nature of effect 2	Nature of effect 3	Narrative
			Tidal range schemes, in particular barrages, considered to represent the largest scale of potential effect. These may have a very large spatial footprint, which could be permanent if these are not removed and represent a significant barrier to the movement of migratory and estuarine fish within the local area. Effects potentially irreversible.
Changes/loss of habitats from major alteration of hydrography or sedimentation (indirect effects on the physical environment)	?	?	Limited and localised impacts from single or pilot scale deployments of tidal stream and wave devices, and current levels of offshore wind deployment, but scaling those impacts up to commercial wave and tidal arrays and the number of wind turbines that could be required to meet net zero target in the UK sector and adjacent north west European states, could result in significant issues
			Tidal barrages have far reaching, large scale impacts that potentially change the energy balance, physical hydrography and associated ecology of the estuary/river basin permanently. The infancy of tidal lagoon technology means that further work is needed to understand the nature and extent of impacts, especially in relation to far-field and cumulative effects, though the modelling studies to date specifically for the Swansea Bay lagoon have indicated that it would be unlikely to generate far-field hydrodynamic effects.
Potential for effects on flora and fauna of produced or treated water and drilling discharges			Principally associated with oil and gas exploration and production but drilling may also be required for the injection of gas (including CO_2 and hydrogen into storage reservoirs). Shallow drilling may also be needed to secure facilities to the seabed. Such drilling would not be expected to result in the volume of material associated with the drilling of wells. Drilling discharges are limited to water based muds, with oil-based mud and associated cuttings only discharged if treated down to <1% oil content. Discharges of WBM cuttings in the North Sea and other dispersive environments have been shown to have minimal ecological effects. There is the presumption that produced and treated water from future oil and gas developments on the UKCS will be reinjected and not discharged.
EMF effects on electrosensitive species			EMFs generated by subsea power cables associated primarily with renewables may interact in a negative way with sensitive marine species, especially benthic and demersal organisms through effects on predator/prey interactions, avoidance/attraction and other behavioural effects, effects on species navigation/orientation capabilities and physiological and developmental effects. However, whilst there is considerable uncertainty, the risk of ecological impacts is low given the scale of renewables deployment, at least in the short to medium term.
The nature and use of antifouling materials			Renewable energy technologies may use antifouling coatings, paints or surfaces to prevent the accumulations of excessive loads of algae and encrusting fauna; chemicals used in antifouling in UK and European waters are strictly controlled and significant effects would not be anticipated.

Potentially significant effect	Nature of effect		Narrative
	2	3	
Accidental events – major oil or chemical spill			Spills are principally associated with oil and gas exploration and development. There is a low risk of significant event under both alternatives.
Accidental events – major release of carbon dioxide			Spill type principally associated with storage of CO_2. There is a low risk of significant event under both alternatives.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Contributes to conservation of the biodiversity and ecosystems of the United Kingdom and its seas.
- Avoids significant impact to conservation sites designated at an International and National level (e.g. Ramsar, SACs, SPAs, MCZs, MCMPAs, and SSSI).
- Avoids significant impact to, or disturbance of, protected species and loss of habitat.

Guide phrases	Alternatives	
	2	3
Plan activities do not lead to the loss of biological diversity, the degradation in the quality and occurrence of habitats, and the distribution and abundance of species.	Aspects of the plan that could result in physical damage/change have the potential to affect sites and species of biological importance, and as such, detailed site specific surveys should be conducted to assess the occurrence of important features. With appropriate regulatory control and the implementation of best practice, plan activities are unlikely to lead to significant loss of biological diversity. Habitats Regulations Assessments screenings at both strategic and project-level will consider the potential of proposed leasing/licensing and subsequent activities to affect the site integrity of protected sites. Effects on relevant site (i.e. SACs, SPAs, NCMPAs, MCZs) will be assessed at activity consenting and licensing stage.	Restricting the plan spatially or temporally may allow a precautionary approach to be taken. For example, some areas with relevant interests may either not be leased/licensed until adequate information is available, or be subject to strict controls (e.g. sound exposure limits) on potential activities in the field.

Guide phrases	Alternatives	
	2	3
Plan activities do not cause adverse effects on marine ecosystems/valued ecosystem components.	With appropriate regulatory control and the implementation of best practice, plan activities are unlikely to lead to significant adverse effects on marine ecosystems. Tidal range aspects of the plan may represent the most significant threat to marine ecosystems/valued ecosystem components.	Restricting the areas offered spatially or temporally may facilitate protection of marine ecosystems/valued ecosystem components.
Plan activities contribute to the ecological knowledge of the marine and coastal environment through survey and discovery.	There is the potential for site investigations/surveys, in particular for large-scale renewable arrays to contribute positively to ecological knowledge of an area, provided that they are suitably archived and made widely available.	Site surveys associated with plan activities may contribute to ecological knowledge, albeit on a more restricted basis than for alternative 2
Plan activities do not lead to disruption in habitat and species connectivity.	Principally associated with OWF; significance of effect variable depending on location and significance at a strategic level remains unclear. Large tidal range schemes considered to have a potential significant effect.	Restricting the plan spatially or temporally may allow a precautionary approach to be taken thereby minimising the risk of disruption in habitat and species connectivity
Plan activities do not lead to the introduction of noise at levels which adversely affect the marine environment, including by leading to significant effects on conservation sites and sensitive species.	With appropriate regulatory control and the implementation of best practice, the potential introduction of noise at levels which may adversely affect the marine environment will be minimised. Habitats Regulations Assessments/ screenings at both strategic and project-level will consider the potential of proposed leasing/licensing and subsequent activities to affect the site integrity of protected sites.	Restricting the plan spatially or temporally may allow a precautionary approach to be taken. For example, some areas with relevant interests may either not be leased/licensed until adequate information is available, or be subject to strict controls on potential activities in the field.
Plan activities do not lead to the introduction of non-native species at levels which adversely alter marine ecosystems.	The draft plan will not lead to the introduction of non-native species at levels which adversely alter marine ecosystems. Ballast water from shipping/rigs likely to represent the main potential source of non-native species although implementation of The International Convention for the Control and Management of Ships Ballast Water and Sediments, and related IMO guidance, should minimise risk. Increased local species diversity may be associated with hard foundations	Restrictions on areas licensed are unlikely to reduce potential for introduction and spread of non-native species (as described in Alternative 2). However, it is considered that the draft plan will not lead to the introduction of non-native species at levels which adversely alter marine ecosystems.

Guide phrases	Alternatives	
	2	3
	although this is unlikely to cause significant ecosystem effects	
The plan recognises the ecosystem importance of land-sea coupling, for instance its role in species migration.	Tidal range aspects of the plan may represent the most significant threat to fish migration. OWF developments may cause some displacement of birds from annual migratory routes although, from an energy expenditure perspective, this is unlikely to be significant given appropriately careful siting considerations.	Restricting the areas offered spatially or temporally may facilitate protection of important migratory routes (e.g. for diadromous fish returning to rivers.
The plan promotes the achievement of good ecological/environmental status for water bodies and marine sub-regions as outlined at a European Level.	The objectives of the WFD (coastal and estuarine waters) and the MFSD (marine) to promote the achievement of good status for water bodies are an integral part of the environmental management context within which the draft plan is set (see Section 2.2).	Restricting the plan spatially or temporally will facilitate attainment of the objectives as will allow a precautionary approach to be taken. Relevant areas may either not be leased/licensed until adequate information is available, or be subject to strict controls on potential activities in the field. Given the paucity of information on infield effects of some aspects of the draft plan, a precautionary approach is recommended.
Conclusion	Habitats Regulations Assessments/ screenings, and the protected sites (SAC, SPA, NCMPA, MCZ) assessment during consenting/licensing process, in combination with initiatives and commitments relating to the WFD and MSFD, through adherence to regulatory controls and best practice with respect to environmental management, will ensure that the biodiversity, habitats, flora and fauna objectives are met.	Restricting the plan spatially or temporally will facilitate attainment of the objectives and will allow a precautionary approach to be taken. Relevant areas may either not be leased/licensed until adequate information is available, or be subject to strict controls on potential activities in the field. Given the paucity of information on infield effects of some aspects of the draft plan, a precautionary approach is recommended

Geology, substrates and coastal geomorphology

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect 2	3	Narrative
Physical effects of anchoring and infrastructure construction (including pipelines and cables), operation and maintenance, and decommissioning on seabed sediments and geomorphological features (including scour)			The footprint of effect associated with all the elements of the draft plan/programme is considered to represent a negligible incremental effect, with effects in most areas reversible over time. Effects may be irreversible if deployed structures and materials not recovered, though these are likely to be buried pipelines and protection materials on decommissioning (subject to the guidance and legislation at the time), which are unlikely to significantly affect the broadscale geological character of the UKCS.
			Tidal range schemes may have a very large spatial footprint which could be effectively permanent. Larger barrage schemes are likely to result in widescale and permanent changes to the sedimentary regime of estuaries they enclose, with potential for far-field effects, well beyond the area of development.
Sediment modification and contamination by particulate discharges from drilling etc or resuspension of contaminated sediment			Predominantly associated with oil & gas exploration and development. Some drilling required for carbon dioxide, hydrocarbon gas and hydrogen storage, and in some circumstances, shallow drilling for the foundations of offshore wind, wave and tidal stream devices, and jackets or other structures associated with oil and gas or hydrogen production facilities. The regulation of discharges relating to these activities, and experience to date, suggests limited scope for significant effects, with any effect highly localised around the drilling location.
			Significant effects associated with the construction of tidal range schemes, which have long (multiple years) construction periods.
Effects of reinjection of produced water and/or cuttings and carbon dioxide			Permanently affects geological storage sites which must retain injected materials in perpetuity. Significant effects on the geology and geomorphology of the UKCS are not considered likely.
Onshore disposal of returned wastes – requirement for landfill			Associated principally with oil and gas exploration and development and gas storage. Offshore wind, wave, tidal and carbon dioxide storage (and also likely hydrogen production and transport) have limited waste production other than decommissioning.

Potentially significant effect	Nature of effect 2	 3	Narrative
Post-decommissioning (legacy) effects – cuttings piles, footings, foundations, *in situ* cabling etc			Some structures/foundations below seabed level may be left after decommissioning, with potential for future exposure by sediment processes within the area. The terms of these being left are controlled both internationally (e.g. under UNCLOS and the OSPAR Convention) and nationally (e.g. current BEIS decommissioning guidance) which seek to limit the potential for effects, largely on other users (see below) of leaving materials on the seabed. Effects may be irreversible, but the nature of future development related to this draft plan/programme and the legislative and policy context within which it must take place will not, for example, result in contaminated cuttings piles, with new projects considering the mode of decommissioning through their design, with future complete removal more likely.
			Tidal range schemes are unlikely to be removed. Effects may be irreversible.
Changes to sedimentation regime and associated physical effects			Localised effects associated with changes to hydrography of the area expected for wind, wave and tidal stream, but potentially negligible at distance, although information is limited and large-scale deployment of all technologies could result in broadscale effects on hydrography and related sedimentary regime.
			Tidal range schemes will permanently alter physical conditions, with effects potentially detectable over wide areas, particularly for larger tidal barrage schemes. Effects may be irreversible.
Accidental events – risk of sediment contamination from oil spills			Low risk of occurrence of major spills, predominantly related to oil exploration and production. Very low risk of spills related to navigation for offshore wind, wave and tidal.
Accidental events – blow out impacts on seabed			Low risk of a blow out associated with oil & gas exploration and gas storage.
Offshore disposal of seabed dredged material			Associated principally with seabed preparation and levelling for offshore wind in certain locations. Resulting sediment plumes are temporary and significant deposition localised to disposal location.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Protects the quality of the seabed and its sediments, and avoids significant effects on seabed morphology and sediment transport processes.
- Protects the integrity of coastal and estuarine processes.
- Avoids significant damage to geological conservation sites and protects important geological/geomorphological features.

Guide phrases	Alternatives	
	2	3
Activities arising from the plan do not adversely affect the quality and character of the geology and geomorphology of seabed or coastal sediments.	There is the potential for cumulative impacts of device ‘footprints’, especially relating to scour effects, cabling and pipeline laying. Some significant local scale sediment effects are expected for wave and tidal stream devices although these are potentially negligible at larger distances, with the scale of effect dependant on location, setting and physical conditions. Tidal range causes permanent large scale changes to the geomorphology of an area. The siting of renewables requires site- and device-specific modelling at a relevant scale.	As per alternative 2
Plan activities do not lead to changes in seafloor integrity which could adversely affect the structure and function of ecosystems.	Most aspects of the plan will result in relatively limited and temporary changes to the seabed which will not have a significantly adverse effect on associated ecosystems. There is the potential for adverse effects to be concluded in relation to conservation sites in unfavourable condition where installation and operation of marine energy developments could generate incremental effects (e.g. as noted in relation to recent wind farm applications). Such effects should be avoided wherever possible to avoid the need to consider compensatory measures. Depending on their scale and location, tidal range schemes may have a large impact on the seafloor which could adversely affect the structure and function of ecosystems.	As per alternative 2.
Plan activities avoid adverse effects on designated geological and geomorphological sites of international and national importance.	Aspects of the plan that could result in physical damage/change have the potential to significantly affect sites of geological and geomorphological importance, and as such, detailed site specific surveys should be conducted to assess the occurrence of important features and the likely impact of any proposal. There is the potential for site investigations, in particular for large-scale renewable arrays to contribute to positively geological and geomorphological knowledge of an area.	As per alternative 2.
Conclusion	Most aspects of the plan will have only small scale and temporary impacts on the geology and sediments of an area. Where significant levels of development, particularly	As per alternative 2.

Guide phrases	Alternatives	
	2	3
	from offshore wind farm, are proposed in areas exposed to significant other uses (e.g. aggregate extraction marine disposal) or with particular sensitivity, without appropriate planning and mitigation, there is the potential for significant effects, including cumulative effects, on seabed morphology and sediment transport processes. Tidal range schemes have the potential to adversely affect all of the objectives.	

Landscape/seascape

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect		Narrative
	2	3	
Potential effects of development on seascape including change to character (interactions between people (and their activities) and places (and the natural and cultural processes that shape them))			There will be visual effects associated with all offshore developments arising from the draft/plan programme. The significance of seascape impacts is largely dependent upon the sensitivity/capacity of individual seascapes, the specific nature of a given development, and the potential for cumulative or incremental effects between plan activities, and other existing and proposed marine activities. The most significant effects are considered to relate to offshore wind, however, future projects are more likely to be further from shore, with a reduced potential for significant effects compared to early wind farm proposals, particularly as the area of fixed foundation wind resource has become diminished.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- To accord with, and contribute to the delivery of the aims and articles of the European Landscape Convention and minimise significant adverse impact on seascape/landscape including designated and non-designated areas.

Guide phrases	Alternatives	
	2	3
Activities do not adversely affect the character of the landscape/seascape.	In the absence of appropriate planning and project level mitigation there is the potential for incremental, cumulative effects between existing and future offshore wind farms, and in-combination effects with other elements of the draft plan/programme and existing activities. There is, however, a range of assessment guidance and planning policy in place that handles issues relating to seascape and marine development.	The spatial and temporal restriction of plan activities in relation to seascape concerns alone may conflict with the wording of existing policy relating to this topic, and as recommended in Section 5.8 (also see Section 6), information informing future bidding areas and related applications through the leasing process, should consider the potential for significant effects at the earliest stage of project planning.
The plan helps to conserve the physical and cultural visual resource associated with the land and sea.	Plan activities have the potential to generate negative impacts on the physical and cultural resource, as they introduce an industrial element, the character and scale of which will not be compatible with certain areas. Current controls, marine and planning policy and accordance with assessment guidance should provide a suitable level of mitigation.	The spatial restriction of certain plan activities may reduce the potential visual impact at the coast and at sea in certain locations. In addition, current controls, marine and planning policy and assessment guidance should provide a suitable level of mitigation.
Conclusion	Plan activities have the potential to have a significant adverse impact on the landscape/seascape objective. Most activity will take place at sufficient distance offshore that seascape impacts at the coast will be confined to ancillary development, and these will be largely temporary. The recent trend of wind farms being sited further from shore, the emergence of floating turbines and their projected deployment at commercial scale, means there is scope for continued siting at distance from shore, but the appropriateness of wind farm locations in relation to landscape/seascape is highly site specific. In the absence of mitigation at the project level, those activities most likely to take place within close proximity of the coast (tidal range and stream) could adversely impact the objective.	As for alternative 2. Consideration is required at the project level as to the appropriateness of the siting of a particular development, both in isolation and in combination with existing and potential future developments. Existing controls and planning policy, including the requirement to undertake a SVIA, should provide a suitable level of mitigation provided that cumulative impacts considerations are made and the latest available guidance followed.

Water environment

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect 2	3	Narrative
Contamination by soluble and dispersed discharges including produced water, saline discharges (aquifer water and halite dissolution), and drilling discharges from wells and foundation construction			Associated principally with oil & gas exploration and development; gas and CO_2 storage but also possibly hydrogen storage, and OWF foundations. Presumption against produced water discharges for new developments; drilling discharges limited to WBM. Effect of saline discharges unlikely to be significant if appropriate mitigation followed.
Changes in seawater or estuarine salinity, turbidity and temperature from discharges (such as aquifer water and halite dissolution) and impoundment			Principally associated with gas and CO_2 storage, and tidal range. Consented discharges of aquifer water etc unlikely to have a significant impact although accidental release events may be significant (see below).
			Tidal range schemes have the potential to significantly change seawater properties through impoundment.
Energy removal from wet renewable devices, and offshore wind farms			Unlikely to be significant for wave and tidal stream given the likely small array scale of potential projects, although this is location specific and will need project level assessment, including in-combination with other relevant projects where these exist.
			The increasing deployment of offshore wind has the potential to result in cumulative changes, though the ability to model this, including in the context of climate change remains limited. Alternative 3 may result in a reduced scale of effect, but as effects are location specific conclusions are not definitive, and the outcome for alternatives 2 and 3 are regarded to be similar.
			Tidal range schemes have the potential for significant energy removal downstream with wide ranging effects on currents, turbidity etc. Location specific modelling is required to understand the significance of any effect.
Accidental events - contamination of the water column by dissolved and dispersed materials from oil and chemical spills or gas releases			Low risk of occurrence of major accidents. CO_2, hydrogen and gas storage developments are not considered to represent a significant source of accidental spills where navigational safety risks have been fully considered and where there is knowledge of the reservoir properties. Overall risk associated with oil exploration and development considered low.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Protects estuarine and marine surface waters, and potable and other aquifer resources.
- Avoid significant impact on flood and coastal risk management activities.

Guide phrases	Alternatives	
	2	3
Plan activities do not result in concentrations of contaminants at levels giving rise to pollution effects.	With the appropriate regulatory controls and mitigation in place, regular and planned activities resulting from the draft plan should not give rise to pollution effects. Accidental events (e.g. oil/chemical spill), whilst unlikely could lead to pollution effects.	Restricting the areas offered spatially or temporally may protect areas at particular risk from accidental pollution events.
Plan activities do not result in permanent alteration of hydrographical conditions which adversely affect coastal and marine ecosystems.	Tidal range schemes could permanently alter hydrographic conditions which could adversely affect coastal and marine ecosystems as well as impact flood and coastal risk management activities. Given the demonstrator or small commercial array scale of likely wave and tidal stream projects these are unlikely to significantly affect ecosystems although this will be location- and technology-specific and therefore are better assessed at a project level. The consideration of cumulative effects from the siting of many large scale wind farms in UK and adjacent state waters may need consideration in the coming years, and needs project-specific input or realistic deployment scenarios.	Restricting the areas offered for tidal range schemes, or optimising their location and layout, may limit the potential for alteration of hydrographical conditions. Given the small scale of likely wave and tidal stream projects, these are unlikely to significantly affect ecosystems, although this will be location- and technology-specific, and therefore is better assessed at a project level rather than imposing strategic restrictions. Similarly, as per alternative 2, the potential for effects on hydrography of widescale European offshore wind deployment may need consideration in the coming years, but needs project-specific input or realistic deployment scenarios.
Plan activities do not result in adverse effects on saline and potable aquifer resources.	With the appropriate regulatory controls and mitigation in place, regular and planned activities resulting from the draft plan (primarily associated with gas, CO_2 and hydrogen storage) should not give rise to adverse effects on aquifers.	Restricting the areas offered spatially or temporally may increase protection of particular areas at risk from pollution events.
Conclusion	With the appropriate regulatory controls and mitigation in place, regular and planned activities resulting from the draft plan will not have a significant adverse impact on surface waters, potable and other aquifer resources. Tidal range schemes have the potential to adversely affect estuarine and marine waters as well as impact	Restricting the areas offered spatially or temporally may increase protection of particular areas at risk from pollution events. Restricting the areas offered for tidal range schemes may limit the potential for alteration of hydrographical conditions and could facilitate

Guide phrases	Alternatives	
	2	3
	(potentially both positively and negatively) flood and coastal risk management activities.	attainment of positive flood and coastal risk management objectives.

Air quality

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect		Narrative
	2	3	
Local air quality effects resulting from vessel and power generation exhaust emissions, flaring and venting			All aspects of the draft plan will have associated vessel emissions but these will likely decrease in the future as part of implementation of the Clean Maritime Plan. With the exception of renewables, power generation emissions make the largest contribution to draft plan emissions, particularly oil and gas but will likely decrease significantly alongside future GHG emission reduction efforts (e.g. electrification and zero routine flaring and venting).
Air quality effects of a major gas release or volatile oil spill			Offshore renewables and gas storage (including CO_2) are not considered to represent a significant source of accidental releases where navigational risks and geological characterisation have been fully considered. Overall risk of a major gas release or oil spill associated with oil exploration and development considered low.
Potential for effects on human health associated with reduced local air quality resulting from atmospheric emissions associated with plan activities			The offshore nature of most of the draft plan activities reduces the potential for air quality effects on human health. The potential expansion of ports to facilitate mainly OWF, but possibly also other renewables development, may have implications for local air quality in these areas. Construction of tidal range schemes could produce significant cumulative effects at a local level through emissions from shipping and road haulage transport, or production of dust.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Avoids degradation of regional air quality from plan related activities.

Guide phrases	Alternatives	
	2	3
The plan contributes to the achievement of air quality targets outlined in the Clean Air Strategy 2019, Cleaner Air for Scotland 2, and other strategies of devolved administrations.	All aspects of the draft plan will have associated vessel emissions but these will likely decrease in the future as part of implementation of the Clean Maritime Plan. With the exception of renewables, power generation emissions make the largest contribution to draft plan emissions, particularly oil and gas but will likely decrease significantly as part of GHG emission reduction efforts (e.g. electrification and zero routine flaring and venting).	Restricting the areas offered spatially or temporally could reduce the contribution to atmospheric emissions from different aspects of the plan, thereby contributing to the achievement of air quality targets.
Emissions from plan activities do not contribute to, or result in, air quality issues which adversely affect human health or the wider environment.	Emissions from oil & gas and gas storage (including CO_2 and hydrogen storage) are not expected to directly contribute to emissions which may lead to detrimental air quality and resultant health effects given their likely scale in the short to medium term and primarily offshore location. The expansion of port activities has the greatest potential to produce effects at the local level although Port Air Quality Strategies may offer a means to minimise this contribution. Construction of tidal range schemes could produce significant cumulative effects at a local level through emissions from shipping and road haulage transport, or production of dust.	Restricting the areas offered spatially or temporally could reduce the potential for air quality issues particularly with respect to those parts of the plan that could contribute to the perpetuation, or creation, of Local Air Quality Management Areas (e.g. port expansion and construction of tidal range schemes).
Conclusion	Emissions could lead to local air quality effects around ports from which operations associated with plan activities are concentrated, particularly in existing problem areas. Emissions offshore are unlikely to significantly contribute to national totals, or to human health or wider environmental effects, and are otherwise controlled through appropriate regulation.	As for Option 2.

Climate and meteorology

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect 2	Nature of effect 3	Narrative
Contributions to net greenhouse gas emissions			The upstream emissions associated with future offshore oil and gas exploration and production must be in keeping with commitments made through the North Sea Transition Deal and the OGA Strategy, such that new projects must assist the Secretary of State in meeting the net zero target. Additionally, any further licensing round may be contingent on the outcome of periodic climate compatibility checkpoints, and any project will have to undertake EIA which will include an assessment of any related emissions. This applies under either chosen alternative. Restricting the spatial and temporal issuance of licences for oil and gas exploration and production consistent with the outcome of the periodic climate compatibility checkpoints, and the UK's carbon budget, would lessen the effect of that aspect of the draft plan/programme on this topic.
Reduction in net greenhouse gas emissions			The SEA does not consider the end use of either hydrocarbon production or electricity production from renewables, however, the draft plan/programme positively contributes to the policy objectives making a contribution to the UK Government's targets in relation to the deployment of further offshore wind farms, carbon dioxide storage and hydrogen production (e.g. the Net Zero Strategy), and therefore the sixth carbon budget and beyond.
Effects on blue carbon			There is evidence that disturbance of seabed sediments can result in the loss of stored carbon in seabed sediments. Given the global and regional scale of some of the climatic and hydrographic factors influencing the flux of carbon within the marine environment (e.g. increasing atmospheric CO_2 and ocean acidification, storms, increasing water temperature), the generally localised and temporary physical disturbance to sediments caused by activities covered by the draft plan are unlikely to lead to a significant depletion of carbon stocks. Therefore, whilst there is considerable uncertainty, the scale of effects on blue carbon in relation to future activities associated with the draft plan/programme is considered minimal when taken in the context of the wider contribution to renewable energy targets and objectives relating to these.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Minimises greenhouse gas emissions.
- Resilience to climate change.

Guide phrases	Alternatives	
	2	3
The plan contributes to decarbonisation in the energy sector, and the achievement of targets relating to greenhouse gases at a national and international level, which include the UK's Net Zero target, related carbon budgets, and the Nationally Determined Contribution under the Paris Agreement.	The objectives of the draft plan/programme are firmly set within the legislative and policy context detailing the transition to low carbon energy sources (see Section 2.2), including deployment of technologies which contribute to scenarios consistent with, for example, those indicated by the CCC which could provide a pathway to net zero by 2050.	As for alternative 2. A coordinated approach to deployment of new technologies is required in order to both help attain the relevant objectives of the draft plan/programme while not compromising other existing marine resources and activities (see below in relation to other users and material assets).
Plan activities recognise the potential impact of climate change during their lifetime, in relation to their potential impact on coastal change, flood risk, or other climate change adaptation. Plan activities recognise the potential for climate change related impacts to affect them, and take this into account in their design.	Given their large scale and expected long life, tidal range schemes have the potential to change the nature of the coastal environment and its ability to respond to flooding and other aspects of potential climate change, both negatively and positively. New projects should be consistent with planning policy and marine plan policies in relation to demonstrating their resilience to climate change.	As per alternative 2.
Conclusion	Plan/programme activities will make a significant contribution towards meeting deployment targets for technologies covered by the draft plan/programme, and beyond. Though oil and gas activities do not confer any climate change mitigation, future licensing may be contingent on the outcome of periodic climate compatibility checkpoints, and any subsequent activities will need to be consistent with the OGA Strategy, North Sea Transition Deal, the elimination of flaring and venting by 2030, or earlier, and also be subject to EIA where the impacts of upstream emissions will be considered.	The spatial restriction of certain activities could reduce the overall potential of the draft plan/programme to contribute towards reduced net UK GHG emissions.

Population and human health

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect 2	3	Narrative
Potential for effects on human health associated with reduced local air quality resulting from atmospheric emissions associated with plan activities			The offshore nature of most of the draft plan activities reduces the potential for air quality effects on human health. The potential expansion of ports to facilitate mainly OWF, but possibly also other renewables development, may have implications for local air quality in these areas. Construction of tidal range schemes could produce significant cumulative effects at a local level through emissions from shipping and road haulage transport, or production of dust.
Potential for effects on human health associated with discharges of naturally occurring radioactive material in produced water			Of potential relevance to oil and gas and gas storage but unclear whether pressure control for CO_2 or hydrogen storage could result in discharges of NORM in produced water. However, with respect to oil and gas, the concentrations of radionuclides in water and sediments surrounding platforms are low and there is no evidence of a pathway that could lead to significant accumulation in fish, and consequently effects on human health are not predicted.
Accidental events – potential food chain or other effects of major oil or chemical spills or gas release			Offshore renewables and gas storage (including CO_2 and hydrogen) are not considered to represent a significant source of accidental releases where navigational risks and geological characterisation have been fully considered. Overall risk of a major gas release or oil spill associated with oil exploration and development considered low.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Has no adverse impact on human health and wellbeing.
- Avoids disruption, disturbance and nuisance to communities.

Guide phrases	Alternatives 2	3
Plan activities do not result in, or contribute to the contamination of fish and other seafood for human consumption at levels which exceed those established by	Discharges from plan activities are subject to regulatory controls at the project level, and are not expected to contribute to the contamination of fish or seafood for human consumption.	As for alternative 2, though discharges may be reduced in line with a potentially smaller number of developments, subject to any spatial restrictions.

Guide phrases	Alternatives	
	2	3
Community legislation or other relevant standards.		
Plan activities avoid adverse effects on physical and mental health.	Plan activities will be subject to Health and Safety requirements and other regulatory controls at the project specific level.	As for alternative 2, though spatial and temporal restriction will reduce the number of people potentially affected by plan activities.
Plan activities avoid adverse nuisance to communities, for instance through noise or vibration.	As above.	As above.
Adverse effects on the quality or access to areas used for recreation (e.g. amenity, sailing, surfing), are minimised or avoided.	Potentially significant effects could arise (at strategic level) from OWF and other marine renewables due to spatial scale and the location-specific nature of areas used for recreation. Existing leasing/licensing measures and regulatory controls (e.g. EIA) provide a suitable level of control with regard to the location of activities.	As for alternative 2, though spatial and temporal restriction will reduce the number of people potentially affected by plan activities.
Conclusion	Plan activities should not contribute to wider adverse effects on physical and mental health, subject to project level assessment.	Plan activities should not contribute to wider adverse effects on physical and mental health, subject to project level assessment.

Other users and material assets (Infrastructure, Other Natural Resources)

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect 2	3	Narrative
Positive socio-economic effects of contributing to greenhouse gas reduction			The draft plan/programme contributes to renewables deployment, carbon dioxide storage and hydrogen production as part of the transition to low carbon energy sources. The economic consequences of transitioning to a low carbon economy are understood to be significantly less than those associated with impacts of climate change (see Section 5.12).
Interactions with fishing activities (exclusion, displacement, seismic, gear interactions, "sanctuary effects")			Potential significant effects (at strategic level) arise mainly from offshore wind farm developments due to their spatial scale. Impacts are location-specific but consideration is needed at an individual project level and cumulatively with other activities that have or could displace fisheries activity.
Other interactions with shipping, military, potential other marine renewables and other human uses of the offshore environment			Potential significant effects (at strategic level) arise mainly from offshore wind farm developments due to their spatial scale. Impacts are location-specific but consideration is needed at an individual project level and cumulatively with other activities that have or could displace other users. At present, there are potential co-location issues with offshore wind farms and carbon dioxide storage sites; planning and marine plan policies should be considered when considering future leasing areas.
Accidental events – socio-economic consequences of oil or chemical spills and gas releases			Spills are principally associated with oil and gas exploration and development, gas storage (including carbon dioxide). There is a low risk of significant event under both alternatives. The restriction of activities spatially could result in a lower risk from major spills.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Balances other United Kingdom resources and activities of economic, safety, security and amenity value including defence, shipping, fishing, aviation, aggregate extraction, dredging, tourism and recreation against the need to develop offshore energy resources.
- Safety of Navigation.
- Reduces waste.

Guide phrases	Alternatives	
	2	3
Plan activities integrate with the range of other existing uses of the marine environment.	Mitigation between plan activities and existing users is already controlled through a range of licensing and leasing conditions, regulatory controls, and decisions related to individual applications should be made in accordance with relevant planning and marine plan policy. The co-location of activities could take place where it is deemed appropriate. Greater activity coordination should be expected through marine planning in the future.	The spatial restriction of certain plan activities would reduce the potential for interactions with other users of the sea, however, existing controls through a range of licensing and leasing conditions, regulatory controls and planning policy provide a basis for such restriction. While the SEA is not prescriptive on this point, a number of recommendations are made in Section 5.15 and Section 6.
Plan activities do not result in adverse effects on marine assets and resources.	Plan activities should not sterilise areas of potential future use (e.g. potential carbon dioxide storage or renewable resource) or compromise those presently in use (e.g. aggregate extraction areas) through inappropriate siting. Policies of the marine plans reflect this and where possible, all developments should seek to avoid, minimise or mitigate impacts on other resources, or justify why impacts are outweighed by the benefits.	As for alternative 2, though further spatial restrictions based on environmental and socio-economic considerations would lead to a reduced likelihood of adverse effects on marine assets and resources.
Plan activities avoid adverse effects on, and contribute to the maintenance of, safe navigation, including recognised shipping routes, traffic separation and existing and proposed port operations.	Potentially significant impacts could arise (at a strategic level) from offshore wind and other marine renewables due to their spatial scale and the location-specific nature of certain resources, though activities would not take place in specified IMO routeing areas. Marine plan policies identify additional areas which should be avoided where possible, or entirely, and when combined with existing leasing/licensing measures and regulatory and planning controls (e.g. consent to locate) there is a suitable level of control with regard to the location of activities.	As for alternative 2. The SEA has highlighted (Sections 5.7 and 5.15), in addition to IMO routeing, a range of indicative navigation routes – suitable shipping traffic surveys would need to be undertaken at the project level to assess the risk to shipping. Spatial restrictions may reduce the overall impact on navigation from plan activities.
Properties and quantities of waste and litter resulting from plan activities do not cause harm to the coastal and marine environment.	Through existing regulatory controls, offshore waste is returned to shore and disposed of appropriately.	As for alternative 2.

Guide phrases	Alternatives	
	2	3
Conclusion	Plan activities have the potential to negatively impact existing users of the sea. There is the potential for co-location of activities where it is appropriate. Activities will not generate waste related impacts at sea or at the coast, nor will they impact upon present or potential marine resources.	As for alternative 2.

Cultural heritage

Consideration of sources of potentially significant effect

Potentially significant effect	Nature of effect		Narrative
	2	3	
Physical damage to submerged heritage/archaeological contexts from infrastructure construction, vessel/rig anchoring etc. and impacts on the setting of coastal historic environmental assets and loss of access.			The risk of damage associated with the footprint of oil and gas, gas storage (including of carbon dioxide), offshore wind farm and other marine renewables anchoring is mitigated through appropriate preparatory survey work. Such survey work has the potential to make positive contributions to identification and interpretation of archaeological remains. Connected with landscape/seascape, the setting of historic assets could be affected by the siting of activities related to the draft plan/programme, though this is reversible in the medium-term. For tidal range schemes, effects may be long term or permanent.

A consideration of the relevant OESEA4 objectives and guide phrases is given below:

- Protects the historic environment and cultural heritage of the United Kingdom, including its setting.
- Contributes to archaeological knowledge.

Guide phrases	Alternatives	
	2	3
Activities avoid adverse effects on the character, quality and integrity of the historic and/or cultural landscape, including those sites which are designated or registered, and areas of potential importance.	The impact of plan activities on the archaeological resource is largely mitigated through statutory controls and project level assessment and reporting in keeping with industry and statutory advisor guidelines, though in the absence of the same level of protection offshore as afforded onshore, site specific surveys would be required to prevent any loss to the marine archaeological resource. The Marine Policy Statement notes that the lack of designation for some sites does not necessarily indicate a level of lower significance.	The outcome is the same as for alternative 2, though certain areas would be avoided though primarily for environmental or socio-economic reasons, which may confer indirect protection to certain areas of interest.
Plan activities contribute to the archaeological and cultural knowledge of the marine and coastal environment through survey and discovery.	Site surveys associated with plan activities may identify new archaeological material and further knowledge in this area, provided that reporting is undertaken in keeping with established codes of practice and commitments made during consenting, such as those secured through written schemes of archaeological investigation.	Site surveys associated with plan activities may identify new archaeological material and further knowledge in this area, albeit on a more restricted basis than for alternative 2.
Conclusion	Preparatory survey work will both help to minimise potential damage to marine archaeological sites, and further knowledge in the area.	As for alternative 2.

6 Recommendations & Monitoring

6.1 Recommendations

The conclusion of OESEA4 is that alternative 3 to the draft plan/programme is the preferred option, with the area offered restricted spatially through the exclusion of certain areas together with a number of mitigation measures to prevent, reduce and offset significant adverse impacts on the environment and other users of the sea. This conclusion has been reached through a consideration of the reasonable alternatives to the draft plan/programme and the potential environmental implications of the resultant activities in the context of the objectives of the draft plan/programme, the SEA objectives, the existing regulatory and other control mechanisms, the wider policy and environmental protection objectives, the current state of the environment and its likely evolution over time, and existing environmental problems.

Substantial progress has been made in implementing the recommendations made in earlier UK Offshore Energy SEAs[341] which, together with a wide range of other initiatives (reflected in this document, particularly Section 5 and Appendix 1) have served to improve understanding of receptors and effects. However, a number of important areas of uncertainty remain and these are summarised below.

A number of recommendations are made arising from the OESEA4 process, for detail see the topic specific assessments in Section 5. Many recommendations apply to all the different elements of the draft plan/programme as there is a large degree of commonality in the potential sources of effect from the different industrial activities. The introduction of marine spatial planning/prioritisation across UK waters is recognised and reflected in the recommendations made in respect of the current draft plan/programme.

The recommendations are listed below under the four categories of: spatial considerations, managing environmental risk, improving the information base, and best practice/mitigation. No implied priority is given to the ordering of the recommendations. Where appropriate, these recommendations reflect the recommendations made in previous BEIS SEAs.

6.2 Spatial considerations

1. Existing and future SPAs, SACs and MCZ/MPA sites are not intended or treated as strict no-go areas for other activities (noting that highly protected marine areas are due to be designated in 2022), competent authorities have a responsibility to secure compliance with the requirements of the Habitats Regulations and Offshore Habitats Regulations, and the Marine and Coastal Access Act 2009. It is recommended that applicants are made aware at the licensing/leasing round stage that sites which are part of the national site network may, subject to the conclusions of any Habitats Regulations or MCZ/MPA Assessment, preclude development, necessitate suitable mitigation measures so as to avoid adverse effects on a designated site or species, or in some circumstance, would require derogation and compensatory measures. This includes making potential applicants aware of the risks to mobile species which may range far from site boundaries

[341] https://www.gov.uk/guidance/offshore-energy-strategic-environmental-assessment-sea-an-overview-of-the-sea-process#sea-recommendations

but are nonetheless subject to protection. This recommendation is linked to others below on managing environmental risk, in particular for ornithology.

2. The importance of territorial waters and adjacent coasts is reflected in numerous, often overlapping designations to protect their scenic, geological, ecological and cultural features, and designations or use for recreational, shellfishery, fishery, navigational, commercial and other activities. The environmental sensitivity of coastal areas is not uniform and the intensity of designations and uses typically declines further offshore away from the coast. All activities and developments covered by the draft plan/programme require site-specific information gathering and stakeholder consultation to inform consenting decisions. In addition to marine spatial plan requirements, the particular sensitivity of the coastal zone must be taken into account during site selection for proposed developments within territorial waters. Some developments may not be compatible with a particular nearshore location, for example adjacent to a World Heritage Site.

3. Important navigation routes were previously identified for the SEA process and as part of the first marine plans in England, primarily in territorial waters, and as part of the Welsh National Marine Plan. In view of the number of offshore wind consents now issued and those projects at a pre-planning stage (including Round 4 projects) in the southern North Sea and eastern Irish Sea, an update to the studies undertaken in 2011 and 2013 on cumulative navigational effects of offshore wind farms, on behalf of the Southern North Sea Offshore Wind Forum, would seem timely. This would ensure an up-to-date understanding on the potential strategic level effects on shipping routes and traffic for future developments to consider, and could form part of future marine planning cycles. Where necessary, important navigation routes could be treated as "Clearways" in the siting and consenting of marine developments. These would require agreement for all waters of the British Isles as well as international coordination for transboundary routes since there are wind farm and other development proposals in the waters of adjacent states.

4. To date, there has been little experience of fisheries adaptation and co-location with offshore wind farms, and at a strategic level caution is required with regard to the siting of a major expansion of offshore infrastructure to ensure fishing activities and skills of local cultural and economic importance are not inadvertently lost, through the prevention or significant hindrance of fishing activity for a generation or more during the lifetime of the developments. While planning policy indicates that developers and decision makers must consider displacement issues, including of fisheries, the cumulative and incremental effect on the fisheries sector from increasing offshore development is not well understood and is challenging to assess. Developments should aim to avoid occupying recognised important fishing grounds in coastal or offshore areas unless there is agreement that successful co-location between the industries can be achieved.

5. Safety zones are either automatically applied, or may be applied for, in the offshore oil and gas sector (and by extension for CCS and gas storage) to ensure the safety of installations and subsea infrastructure. While smaller operational safety zones may be applied around renewables, these are seldom applied. The need for these should be further explored in the context of the potential for multiple anchors to be located at some distance from floating wind turbines and the potential future use of subsea sub-stations.

6. For the area to the west of the Hebrides it is recommended that blocks west of 14 degrees west should continue to be withheld from oil and gas licensing. This recommendation

also applies to the deeper parts of the Southwest Approaches, beyond the shelf break, in waters >200m deep. This is in view of the paucity of information on many potentially vulnerable components of the marine environment, and other considerations. Once further information becomes available, the possible licensing in these areas can be revisited. The potential for collaborative investigations in the areas is recognised reflecting the cost and difficulty of studies in distant, deep waters. However, the potential for future licensing in these (and other) areas may be contingent on the outcome of periodic climate compatibility checkpoints, see recommendation 12 below.

7. It is recommended that leasing/licensing and any subsequent consenting of activities should ensure the minimisation of disruption, economic loss and safety risks to other users of the sea and the UK as a whole. It is recognised that individual projects will be assessed on a case by case basis through the relevant planning process, and will therefore be subject to planning policy which is specific to projects of national significance and/or those of the UK's regional marine plans. Recognising the policy of these plans, and the overarching policy in the UK Marine Policy Statement and the Overarching National Policy Statement for Energy (EN-1) and relevant National Policy Statements, and in addition to those more detailed recommendations above, developments (individually or cumulatively) should aim to:

- avoid impingement on major commercial navigation routes where this could significantly increase collision risk or lead to appreciably longer transit times, this includes within the water column where under-keel clearance could be significantly reduced;
- avoid causing alteration to the ease and safety of navigation in port approaches or reduce the commercial attractiveness of the ports e.g. through increases in vessel insurance premiums;
- avoid potential disruption of existing and potential future aggregate supplies;
- avoid interference with civilian aviation operations necessary to ensure aviation safety, efficiency and capacity, including radar systems, unless the impacts can be mitigated, are deemed acceptable, are temporary or can be reversed;
- avoid jeopardising national security for example through interference with radar systems or unacceptable impact on training areas unless the impacts can be appropriately mitigated or are deemed acceptable in consultation with MoD;
- avoid causing significant detriment to tourism, recreation, amenity and wellbeing as a consequence of deterioration in valued attributes such as landscape, tranquillity, biodiversity and hydrographic features;
- explore opportunities for co-location which could mitigate potential spatial conflicts with existing users.

6.3 Managing environmental risk

8. To date, cumulative and in-combination assessments for wind farms are based on the legally-secured consented wind farm parameters, which for more recent wind farm projects in England and Wales generally reflect a worst case in part related to the application of the Rochdale Envelope approach. The difference in the number of

turbines in a wind farm consent compared to that constructed can be large (approximately one third to one half), such that there is also likely to be a significant difference in the estimated bird mortality between these scenarios. This "headroom" is enhancing the significance of effect concluded for ongoing and future in-combination effects assessment as part of project consenting. Building on work already undertaken as part of The Crown Estate's Offshore Wind Evidence and Change programme[342], it is recommended that further work be undertaken to define the magnitude of the collision risk mortality headroom that exists, to determine whether agreement can be reached on the level of this mortality as a baseline for further offshore wind development for Round 4 and beyond, and that the variation of consents by existing operators to reflect the as-built parameters of projects is encouraged to facilitate a legal basis to draw down the headroom.

9. Evidence suggests that wind farms can result in a high level of displacement for overwintering red-throated diver, though this does not appear to result in complete displacement, and the level of displacement appears to be variable between locations. Evidence is lacking on any related level of mortality and population level effects for wintering sites in the UK. It is recommended that until further information is available on the scale of habitat degradation/loss across operational wind farms in areas designated for red-throated diver, and it is understood how this loss translates into population level effects for the species, future rounds of offshore leasing should avoid impinging on diver habitat, noting that boundaries for sites designated for this feature may not always reflect where diver habitat is located. To support this, and also to clarify the variation in population and distribution within sites between years, it is also recommended that scientifically robust monitoring be undertaken to understand recent site populations and distributions of the species to facilitate the consideration of the issue at a strategic and project level (also see below in relation to improving the marine management information base). Without this new evidence, with the conservation objectives for sites designated for red-throated diver as written and in particular "by maintaining or restoring:…the distribution of qualifying features within the site" could mean that no further windfarm or other development will be possible in or immediately adjacent to such sites. At a wider MPA level such issues require policy level discussion to ensure that the UK's conservation objectives can be met without unnecessarily constraining energy related or other economic activities.

10. A comprehensive strategic review of post-consent wind farm monitoring is required to inform the environmental assessment, consenting of future developments and identification of important evidence gaps.

11. Modelling has suggested the potential for hydrodynamic effects on the North Sea, including on sediment transport and deposition, stratification timing and strength, primary production and effects at higher trophic levels, from the widespread deployment

[342] https://www.marinedataexchange.co.uk/details/3488/2021-womble-bond-dickinson-offshore-wind-evidence-and-change-programme-headroom-in-cumulative-offshore-windfarm-impacts-for-seabirds-a-report-for-the-crown-estate/packages

of offshore renewables in the waters relevant to this SEA and those of other UK constituent countries and adjacent states. This includes from interactions with devices generating electricity directly through energy removal such as tidal stream, tidal range and wave devices, but also from the deployment of wind turbines which have foundations that interact with thermally stratified waters. Currently available models do not account for all potential parameters of effect, are poorly validated, need realistic scenarios of the location, timing and nature of future renewables deployment, and also need to account for the effects of climate change on the marine environment over the same timescales which will also influence, for example, stratification timing and strength. There is a clear need to continue to improve modelling capability and to improve model validation.

12. The final decision on putting in place a climate compatibility checkpoint for further offshore oil and gas licensing and the final design of such a checkpoint were not available at the time of publication of this Environmental Report. However, to be compatible with the wider Government commitment to achieving net zero by 2050 there is a need for any future licensing and related projects to at least meet the targets set in the North Sea Transition Deal on upstream emissions, the net zero flaring by 2030 initiative, and to ensure compliance with the OGA Strategy in assisting the Secretary of State in meeting the net zero target. Other considerations (beyond the remit of this SEA) such as security of energy supply may also influence future decisions by the OGA on the launching of new licensing rounds.

13. Beaked whales are very sensitive to anthropogenic noise (particularly to powerful sonar but potentially also to seismic survey) and their behaviour makes them difficult to observe visually or acoustically as part of implementation of standard seismic survey mitigation procedures. In recognition of this, it is recommended that opportunities to enhance mitigation measures for beaked whales beyond those in the JNCC guidelines for minimising the risk of injury and disturbance to marine mammals from seismic surveys should be considered during deep water seismic survey planning and implemented during operations.

14. A range of chemicals are used in marine renewables developments and during operations, a proportion of which are discharged to sea. On the UKCS all chemicals used in the exploration and production of offshore hydrocarbons (and de facto CCS and gas storage) are controlled through the Offshore Chemical Notification Scheme, reflecting the OSPAR Harmonised Mandatory Control Scheme. Since most of the chemicals used by the renewables industry are similar to those used in the oil and gas industry there seems a logic to standardise their control and reporting (including those chemicals listed by OSPAR for priority action or candidates for substitution), but it is noted that the majority of chemicals used are in closed systems and discharges are likely to be minor.

15. The number of offshore energy structures and associated sacrificial anodes used for corrosion protection has risen in recent years, with concerns raised over the consequent release of aluminium and other metals. To understand the scale of this concern, data on anode use and replacement should be collected and collated by developers, regulators or trade associations, or a study of a representative project be undertaken. Alternative technologies such as impressed current cathodic protection are available. Paint and

coatings for structural protection could reduce anode use, but many of these replacements are plastic based and the implications for their long term use is unknown.

16. The injection of carbon dioxide into saline aquifers for storage is likely to lead to discharge of hypersaline water through water production to control pressure within the aquifer. Brines with the potential to be discharged should be characterised chemically to assist in the engineering of effective treatment and dispersion e.g. through diffusers, and to allow appropriate monitoring of plume dispersion and potential environmental effects in the water column and seabed. Pressure increases in the aquifer resulting from the injection of carbon dioxide may lead to seepage of brines at the seabed via naturally occurring outcrops of the relevant geological formation; appropriate control measures and monitoring should be undertaken where such seepage may occur to reduce the scale of such seepage and to document the scale and effects on the environment.

17. The nature and uses of the range of estuaries and embayments in which tidal range developments have been and may be proposed vary widely. Similarly there is a wide diversity in the type and location of installations proposed to exploit tidal range. Consequently it is recommended that site specific assessments are undertaken before decisions can be taken on potential leasing and the desirability and acceptability of individual projects, and that successive tidal range proposals should consider the potential for local, regional and wider far-field effects to be generated cumulatively. Such assessments will require a broad subject, spatial and temporal consideration e.g. coastal defence trends and plans, local and regional nutrient flows and siltation patterns, feasibility of compensatory measures for effects on the national site network, effects on endangered diadromous fish, and the importance for waterbirds the UK assumes during extreme cold winters.

18. The subject of cumulative effects assessment (CEA) is challenging at project, industry and strategic levels, and is frequently raised by stakeholders as an issue. At all levels of assessment, guidance on the spectrum of certainty and the point beyond which CEA is considered conjectural would be useful.

19. Unlike natural gas and carbon dioxide, there is currently no consenting route for projects transporting hydrogen by offshore pipeline, or its storage in geological formations, and similarly, the consenting route for hydrogen generation offshore requires definition. Both of these points require clarification to help facilitate offshore green hydrogen production, transport and storage.

6.4 Improving the marine management information base

Although the information base continues to improve, there remain a number of subject areas for which information is limited and should be enhanced to support appropriate development site selection and project-specific consenting. These information gaps include aspects of the natural world and human uses, with regional context and long-term trend data notably lacking.

20. Although there has recently been significant boat based and aerial survey effort in coastal waters, there is a general lack of modern survey data on waterbirds in offshore areas. Adequate data on waterbird distribution and abundance is a prerequisite to effective environmental management of activities, for example, in timing of operations to avoid periods of particular sensitivity. A comprehensive analysis of the European Seabirds at Sea (ESAS) database was undertaken to identify possible marine SPAs but gaps in

spatial coverage necessitated the use of interpolation to estimate values for un-surveyed areas. These data, amongst others, also informed a wider seasonal modelling study as part of the Marine Ecosystems Research Programme (MERP), however, while the outputs can usefully inform broadscale understanding, more information will be required to draw conclusions in relation to environmental management. The development of high-precision tracking devices has led to a recent upsurge in bird tracking studies, and for some species several hundreds of individuals have been tracked from numerous colonies around the UK, allowing the marine distribution of some species to be predicted from tracking data. It is recommended that the results of cross-validations of models of marine distribution derived from tracking individual birds with those from at-sea survey are assessed to inform decisions on the nature and location of waterbird distributional research.

21. Deep-diving cetaceans, particularly beaked whales, continue to remain poorly understood due to the challenges associated with their typically offshore distribution and limited time spent at the surface for observation. Should there be potential interest in deep water hydrocarbon exploration to the west of the Hebrides, improved understanding of the ecology and location of important areas for beaked whales should be obtained to underpin assessments of effects and identification of mitigation measures.

22. To support the assessment of potential effects of proposed activities (in conservation sites and beyond), improved understanding of harbour porpoise ecology is needed, along with that of their prey and interspecific interactions (such information will assist in the management of the population(s) in UK waters).

23. Whilst the information base has improved in recent years, further data are required on the spatial scale at which marine mammals and their prey respond to well characterised noise sources, and whether this varies according to individual characteristics, behavioural state or other environmental variables, and whether the scale of effects is sufficient to cause significant adverse effects at an individual or population scale.

24. There is a need for enhanced, strategic level understanding of biodiversity and its patterns in UK waters, in particular for the species (e.g. the bivalve *Arctica*) and features (e.g. habitats characterised as seapens and burrowing megafauna communities or burrowed mud) used as the bases for MCZ/MPA identification and designation, to inform considerations of site integrity and the assessment of proposed activities impinging on sites.

25. While risks to marine life from EMFs associated with submarine power cables are not considered to constitute a major impact, and are regularly not taken beyond the scoping stage in wind farm environmental assessments, there remain significant data gaps with regards to its biological impacts such that a meaningful risk assessment cannot be conducted. Developing standards for appropriate *in situ* measurements of anthropogenic EMF environments, along with increased *in situ* measurements of EMFs and the local geomagnetic field will improve understanding of the factors that influence EMFs, which would complement a modelling study being commissioned as part of the OESEA process. The effects knowledge base needs to be expanded using model species to determine sensitivity thresholds, encounter rates, long-term impact studies and population level impacts. Finally, an understanding of potential cumulative effects will become more important, specifically the impact of potentially encountering

differently oriented power cables, how biological behavioural and physiological effects may interact, and the potential for effects experienced during early life history influence later life stages.

26. The conservation status of sites and their related features are not available for a number of SACs and SPAs or the data informing site status may be old. An up to date understanding of the conservation status of these sites and their features is important, as without it, conclusions on the presence or absence of adverse effects from projects may be erroneous.

27. There is currently little information available on the interaction of birds, marine mammals and fish with surface and submerged wave and tidal devices and the SEA recommends that for the deployment of single devices and small arrays, appropriately focussed surveys of animal activity and behaviour should be undertaken to inform commercial scale deployment risk assessments and consenting. A strategic and coordinated approach to such research is recommended since the results will be of wider application; research results should be made publicly available where ever possible.

28. For some areas there is excellent data on seabed topography and texture from multibeam mapping undertaken under various auspices including by the MCA, BGS and the SEA programme. The NERC Marine Environmental Mapping Programme (MAREMAP) and the scoping study for a UK National Seabed Mapping Programme are noted, however, significant gaps in coverage remain, and continued effort should be focussed on developing comprehensive coverage of the UKCS, prioritising areas of industrial and conservation interest.

29. The information collected by offshore renewables and oil industry site surveys and studies is valuable in increasing the understanding of UK waters. The initiatives such as the Marine Data Exchange and UKBenthos databases ensure that such information is archived for potential future use should be continued and actively promoted during the consenting processes. Similarly, there should be encouragement for the analysis of this information to a credible standard and its wider dissemination, including via the Marine Environmental Data and Information Network (MEDIN).

6.5 Best practice/mitigation

30. The SEA notes post-consent changes made to cable installation techniques, remedial works and additional cable protection which have resulted in habitat disturbance and loss/ modification within MPAs that has not been assessed as part of the consent application process[343]. The SEA recommends that while some flexibility may remain for effects to be considered at the marine licensing stage, which may include changes to the national site network between the date of consent and construction, developers must ensure that realistic levels of impacts and where possible impact location, particularly those associated with cable installation and protection in sensitive MPAs, are assessed as part of their submissions at the consenting stage.

[343] e.g. https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-001240-Natural%20England%20-%20Offshore%20Cabling%20paper%20July%202018.pdf

31. The SEA recommends that the development of appropriate benthic compensatory measures for sandbank and subtidal biogenic reef MPAs with respect to cable protection is reviewed at a strategic level (as supported by JNCC and Natural England[344]) to focus research in this area. Better definition of the nature and extent of existing introduced hard substrates within MPAs designated for sandbanks is required to improve understanding of the conservation status of these qualifying features, and characterise how the static hard substrates interact with the mobile features over time. Previous attempts have not been the catalyst for the collection of specific industry information on hard deposits in relevant MPAs required to reduce uncertainty in this area, or have been limited by available data. As part of future permitting and licensing, data on the nature, scale and location of hard substrate deposition should be recorded and disseminated.

32. Connected with the above, the volumes of rock used, for example, in cable armouring, foundation scour protection and pipeline protection and upheaval buckling prevention, must be the minimum required to provide the necessary protection in order to minimise permanent habitat change and to ensure areas developed as a result of the current draft plan/programme are left fit for other uses after decommissioning. Alternative methods of protection/control (e.g. those that are more easily removed on decommissioning) should be considered to minimise the potential for permanent habitat change.

33. In areas with vulnerable habitats and species such as maerl beds and cold water coral reefs mitigation may be required for physically damaging activities such as rig/vessel anchoring, discharges of drilling wastes and cable, pipeline or umbilical installation (from hydrocarbon, gas storage or renewable energy related activities). Prior to decisions on activity consenting in such areas, developers should provide a detailed assessment and seabed information so that appropriate site specific mitigation can be defined.

34. Given the focus in UK OWF assessments and consent deliberations on various seabirds which feed extensively on sandeels, and in the context of the energy transition towards net zero by 2050, strategic compensation through selective restriction or closure of sandeel fisheries should be given consideration at a policy level.

35. A number of large marine protected areas established for seabed features such as sandbanks are judged to be in unfavourable conservation status. Such sites typically overlap with areas with OWF development potential. The conservation objectives for such MPAs generally advise a restore objective and note “Our confidence in this objective would be improved with longer term monitoring and access to better information on the activities taking place within the site.”.` In the context of the energy transition towards net zero by 2050 and to avoid potentially unwarranted precaution, it is recommended that a programme of strategic investigations is initiated for relevant MPAs to provide the necessary evidence to inform consenting advice and decisions. Such evidence would also allow management and mitigation efforts to focus on the more damaging pressures affecting the sites.

36. Whilst it is recognised that most developers in the marine environment have Health, Safety & Environmental management systems in place, it is recommended that companies involved in the planning, undertaking and control of marine activities resulting

[344] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010080/EN010080-003633-EN010080_Hornse%20Three_SBIP_SNCB%20comments%20letter%20Final.pdf

from the current draft plan/programme operate Environmental Management Systems which are consistent with an international standard.

37. Site surveys for marine developments can identify unexploded ordnance (UXO), which is either left *in situ* or rendered harmless through disposal. Human safety is paramount in such decisions, but the potential to minimise the impacts and cumulative effects of the percussive noise on marine mammals (and other fauna) should be given due weight, in particular in relation to conservation sites established or proposed for seals or cetaceans in areas of relatively high UXO occurrence e.g. the southern North Sea. The preferred approach should be to use low-noise methods for disposal wherever possible, with clear justification provided where such methods are not proposed.

38. Application of net gain to offshore projects is not presently a mandatory requirement, but provisions of the *Environment Act 2021* allow it to be so. In advance of any requirement, further evidence is required to support the potential for offshore energy installations to generate net gain.

6.6 Monitoring

The SEA Regulations require the responsible authority for the draft plan/programme to:

"….monitor the significant environmental effects of the implementation of each plan or programme with the purpose of identifying unforeseen adverse effects at an early stage and being able to undertake appropriate remedial action."

In so doing, the Regulations allow for the responsible authority's monitoring arrangements to comprise or include arrangements established otherwise than for the express purpose of complying with the Regulations e.g. monitoring conducted for other regulatory purposes.

The types of relevant monitoring already undertaken or proposed for this SEA fall into three types:

- Emissions monitoring
- Effects monitoring
- SEA objectives monitoring

Each of these is summarised below.

6.6.1 Emissions monitoring

As required by the various environmental permits and other environmental legislative requirements (see Appendix 3), developers must monitor and report the quantities of solid, liquid and atmospheric emissions, discharges and wastes generated. For the marine renewable energy industry this is required as part of a combined marine licence; for the oil industry, including gas storage, this is reported via the Environmental Emissions Monitoring Scheme and all oil or chemical spills via Petroleum Operations Notice Number 1 (PON 1). As well as monitoring compliance with individual permit conditions the data provides a benchmark which allows performance trends to be monitored over time, and projected increases from a new draft plan/programme to be placed into context. The BEIS Offshore Environmental Inspectorate enforce statutory instruments in support of this, offshore installations are inspected and operators are encouraged to use Best Environmental Practice (BEP) and Best Available Technique (BAT) in all activities. This also applies to carbon dioxide storage facilities, except those in Scottish Territorial Waters where the Scottish Government have responsibility.

6.6.2 Effects monitoring

There has been extensive monitoring of the effects of UK offshore oil and gas activities since 1975, and several regional surveys have been undertaken in recent years under the auspices of BEIS/OGUK Monitoring Committee, Marine Scotland, Cefas and the National Marine Monitoring Programme. Similarly, there are extensive monitoring programmes undertaken in connection with UK offshore wind farm development and operation, through marine licence and other permit conditions. There is also a large body of monitoring work on the effects of oil industry operations and a rapidly growing one for offshore wind farms, from other North Sea states and beyond. Studies include operational effects monitoring at field or regional scales, themed research projects and academic studies. This existing monitoring activity is periodically reviewed as part of the Department's SEA process and to date is considered adequate to understand the evolution of baseline conditions in respect of sediment contamination and biological effects across the SEA areas. For other marine renewable energy generation types, monitoring of effects is in its infancy although the body of information is growing through monitoring required by marine licence and other permit conditions. With the exception of loss of integrity of the geological store, the effects of carbon dioxide transport and storage developments are anticipated to be largely similar to those of offshore hydrocarbon exploration, production and storage. Research studies into the likely effects of large release of carbon dioxide have helped define the scale of potential impacts as well as suitable monitoring methods. Developer initiated and permit required monitoring is expected to provide the basis for effects monitoring of demonstrator and commercial scale developments and their operation. There is the potential for future synergies in the monitoring of marine plans and the OESEA programme.

6.6.3 SEA objectives monitoring

The draft Offshore Energy SEA objectives and indicators were considered during scoping. The agreed objectives and indicators are given in Section 3.5. The SEA indicators will be monitored by the BEIS and the SEA team to track SEA performance over time.

Where unforeseen adverse effects are identified the Department will seek to establish the cause in consultation with the Consultation Bodies/Authorities and other stakeholders. Remedial action will be developed and agreed with relevant parties and implemented as appropriate.

Information on the overall status of the UK seas and trends over time are variously collated for national, European and international initiatives. For example the UK Charting Progress 2 Report was published in 2010. Similarly the last OSPAR Quality Status Report was published in 2010, with an intermediate assessment planned for 2017 and the next QSR scheduled for 2023. Data from the monitoring of the effects of the implementation of this draft plan/programme would be included in future such reports as well as those reporting on the achievement of good environmental status as required by the Marine Strategy Regulations. The conservation status of conservation sites, including SACs, SPAs, MCZs and MPAs, is monitored by the statutory nature conservation agencies, and is reported under the Habitats Regulations (formerly Article 12 and 17 of the Birds and Habitats Directives respectively).

In respect of atmospheric emissions, the Climate Change Committee was set up under the *Climate Change Act 2008* to support the strategic aims of the Department and the devolved administrations and to independently assess how the UK can optimally achieve its emissions reductions goals. The Committee advises Government on the level of carbon budgets and submits annual reports to Parliament on the UK's progress towards targets and budgets to which the Government must respond. The advice from the CCC has been considered in this SEA and would continue to be reviewed against the SEA objectives as part of monitoring.

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