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Energy Innovation Needs Assessment: Offshore Renewable Energy

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Authors

The 2025 Energy Innovation Needs Assessment: Offshore Renewable Energy was commissioned by the Department for Energy Security & Net Zero (DESNZ) and delivered by a consortium led by the Carbon Trust, including Mott MacDonald, UCL and Pengwern Associates.

Carbon Trust was the lead technical author for the offshore renewables sub-theme report.

Views expressed in this report are those of the authors and not necessarily those of the UK Government.

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Abbreviations

AHV	Anchor handling vessel
AR	Allocation Round
CfD	Contracts for Difference
CRI	Commercial readiness index
DCOs	Development Consent Orders
EIA	Environmental impact assessment
EMEC	European Marine Energy Centre
FLOW	Floating offshore wind
GPS	Global Positioning System
HND	Holistic Network Design
HRA	Habitats regulation assessment
HV	High voltage
HVAC	Hight voltage alternating current
HVDC	High voltage direct current
IEA	The International Energy Agency
LCOE	Levelised cost of energy
LRD	Load reduction device
OEM	Original equipment manufacturer
O&G	Oil and gas industry
O&M	Operations and maintenance
OSW	Offshore wind
TLP	Tension leg platform
TRL	Technology Readiness Level

Key findings

The Energy Innovation Needs Assessments (EINAs) have been developed and updated to identify key innovation needs across the UK's energy system, to provide an evidence base for the prioritisation of investment and support for clean energy innovation. This report summarises the analysis and findings from the EINAs across the offshore renewables sub-theme, focusing on fixed-bottom offshore wind (OSW), floating offshore wind (FLOW), and tidal stream technologies.

Energy system modelling to assess the potential impact of innovation in key net zero technologies was conducted using UK TIMES. Technologies were assessed at 3 levels of innovation (low, medium and high) and across three hypothetical scenarios: Minimally Constrained, High Hydrogen and High Diversification.[1] The key results from EINAs system modelling suggests that:

- Offshore wind plays a significant role in driving net zero by 2050 for the UK energy system across all scenarios modelled highlighting it as a critical technology to decarbonise ever increasing demands for electricity generation whilst being the cheapest way of generating power.
- It is closely interconnected with the innovation of other EINA technologies. Technologies that rely on low-carbon electricity downstream, including electrolysis and heat pumps, increase the value of offshore wind and accelerate its deployment in the energy system, whilst BECCS and DACCS innovation sensitivities reduce the need for offshore wind so it is scaled to meet demand accordingly. However, deployment is still high in all scenarios and innovation runs.
- Innovation in offshore wind has the potential to realise significant savings when compared to the low innovation level scenario. Innovation can reduce the cost of achieving net zero by £16.5 billion, in Minimally Constrained, increasing to £21.1 billion, in High Diversification, by 2050.
- Tidal has a limited role in the majority of scenarios in UK TIMES reaching 6 GW of capacity in the technology-specific high innovation level run in High Diversification. This run represents the only instance of tidal energy deployment across all modelled runs. Due to its limited deployment, innovation in tidal stream only creates a cost saving to the overall energy system for the high innovation High Diversification run.

Although fixed-bottom offshore wind is a well-established technology, incremental improvements through innovation, manufacturing, and monitoring could lower the Levelised Cost of Energy (LCOE), increasing the feasibility of deployment to reach Net Zero by 2050. Initial pre-commercial demonstrations of floating offshore wind in the UK (Kincardine, Hywind)

[1] These scenarios do not represent government policy but were selected due to their differing constraints which provide a diverse set of outputs and insights. More information on the scenarios can be found in the Innovation Analysis section of this report and in the EINAs Methodology report.

have provided evidence of higher attainable capacity factors from access to deeper water locations where fixed-bottom solutions are less suitable. Significant work is still needed to cost-effectively scale the technology for commercial use (50 turbines or more). Major investment in both innovation and infrastructure will be needed for further offshore demonstrations of the different floating wind design platforms suitable for varying Metocean (wind, water depth, waves, and seabed) conditions. Specific novel components require de-risking in large-scale offshore tests. Capacity expansions will rely on innovative solutions to reduce costs and increase fabrication rates, reducing potential bottlenecks while maintaining high levels of quality control through process-led mass manufacturing.

Tidal stream faces significant barriers that require major innovation support, including substantial cost reduction and supply chain and infrastructure development to establish a commercial scale industry. Although tidal stream is one of the more expensive forms of offshore renewables, the case for its use rests on its reliable and predictable energy production, which assists in grid stabilisation alongside less predictable renewables.

Table 1 outlines the key innovation priorities for the EINAs offshore renewable technologies included on the basis of potential cost and barrier reduction impacts. Further detail on these, including their implications for cost reduction and technology deployment, timelines and relatively lower impact innovations in the Mapping of innovation needs section of the report.

Table 1: Innovation needs for EINAs offshore renewables technologies

Innovation area	Description
Component and infrastructure development	Integrated assembly techniques: Design and manufacturing techniques that enable large-scale modular assembly in combination with designs that reduce material requirement. Foundation design and optimisation: Automation of fabrication and material optimisation using advanced mass or batch production techniques. Advanced installation and maintenance techniques such as self-hoisting turbines and cranes and autonomous maintenance systems. Increased size and standardised development of turbines.
Grid integration	Improvements in Direct Current (HVDC) networks and smart grids and holistic network design (HND). Sharing infrastructure generation devices to reduce cost and incentivise network upgrades. HVDC substation development for increasingly distant farms. High Voltage (132kV) array cable development, both HVAC and HVDC. Improved system monitoring: accelerometers, GPS sensors measuring motions, optical fibres measuring cable temperatures.

Advanced design, modelling, controls and monitoring	Advanced monitoring and inspection techniques to manage large scale offshore farm complexity. Advanced turbine control systems: Turbine control systems that optimise individual turbines across a wind farm will aid efficiency and prolong the life of assets. Development of control systems specific to offshore renewables technology.
Testing and industry guidelines	Full-scale testing and consolidation of designs for large-scale floating wind concepts and innovations. Validation of concept and test facilitates. Novel component level development qualifications, e.g. mooring solutions, self-hoisting cranes, and dynamic cables.
Energy storage innovation	Alternatives to network connection or surplus demand, e.g. cost-competitive production of low carbon hydrogen and ammonia onsite to provide fuel for shipping.

If offshore renewables are to be deployed on the scale required to reach Net Zero, there are a number of market barriers that could pose a challenge to scale up. These include:

- **Supply chain:** There is a need to expand UK manufacturing capacity. Globally, support vessels for installation, maintenance and decommissioning will be required to enable larger turbine installation. Floating wind and tidal stream will both require specialist components.
- **Skills and training:** Highly skilled workers including scientists, engineers and technicians will be required to meet targets. Currently, the rate of growth of the workforce is slower than the rate required. Workers will be needed in coastal and remote locations where the infrastructure is situated.
- **Regulatory environment:** Consenting time is a major bottleneck to implementing large-scale offshore renewables, due to the lengthy and complicated permitting processes. These processes vary across administrations and technologies and depend on the location and capacity of the proposal. For commercial wind farms, the process from pre-application to final determination of the necessary consents is estimated to take 3-5 years.

The key results from the business opportunities calculator suggest that innovation in offshore wind and tidal stream could contribute the following potential business opportunities:

- GVA growth from approximately £1bn in 2025 to around £5bn by 2050, a growth rate of around 7% per year, driven by the significant expansion in UK and overseas capacity over this period. This result is robust to the different scenarios.
- A corresponding increase in supported employment (direct and indirect jobs) leads to approximately 155,000 jobs supported by 2050. Again, this result is also robust to the different scenarios examined.

- GVA and supported employment are largely driven by fixed offshore wind, but floating offshore wind becomes increasingly important over time as deployment of this technology increases.
- The domestic market is likely to drive growth of GVA and employment in this model over the next decade, with exports markets expected to be an equally, if not more, important driver by 2050.
- As the sector matures and the ratio of new capacity to existing capacity falls, a shift from GVA and jobs being driven by construction activity to increasingly being driven by operation and, more modestly, decommissioning. By 2040, the majority of GVA is supported by OPEX activities across scenarios.
- An employment profile that, by 2050, is predominantly supporting high skilled science, research and engineering and technology professional occupations, as well as director/managerial jobs.

Introduction

The Energy Innovation Needs Assessments

Achieving the UK's ambitious clean power by 2030 mission and Net Zero by 2050 target requires the accelerated scaling and deployment of innovative clean energy technologies. The UK Government has a central role to play in supporting the research, development and deployment of these innovations to achieve global and national climate objectives. The decisions made now in the prioritisation and investment of crucial clean energy technologies will be pivotal to enable progress in the coming years and decades.

The Energy Innovation Needs Assessments (EINAs) have been developed and updated to identify key innovation needs across the UK's energy system, to provide an evidence base for the prioritisation of investment and support for clean energy innovation. The 2025 publications reflect an update on the 2019 exercise, accounting for the significant changes and progress both in the clean energy sector and the wider economy. To complement and build on the UK's Net Zero Research and Innovation Framework, the updated EINAs will inform key decisions on clean energy innovation funding through a structured evidence base that quantifies and assesses the role and scale of opportunities. The evidence enables comparison across technologies and takes account of wider factors that may impact deployment and scale-up.

The methodology followed is detailed in the EINAs Technical Methodology Report and is summarised below.

The EINAs technologies were decided through a prioritisation exercise, taking into account insights from key sector experts and prioritising against key DESNZ criteria. An initial longlist of 190 technologies for analysis was put together based on:

- Previously published global and national scenarios (including the 2019 EINAs)
- DESNZ priorities
- Insights from DESNZ engagement activities
- Input from technical experts

This longlist was then assessed and prioritised to inform a shortlist of EINAs technologies, which were then taken forward for analysis including:

- An assessment of each technology's innovation needs, costs and barriers to deployment.
- Modelling, using the UKTIMES and HighRES models, to assess the impact of different levels innovation in these technologies on the UK's energy system in hypothetical Net Zero scenarios, including on system cost, capacity and energy security.

- Economic analysis, including Gross Value Added (GVA) and employment, of the deployment of the technologies across scenarios and innovation levels.

This report summarises the findings across the offshore renewables sub-theme.

The 2025 EINAs publications have been commissioned by DESNZ and produced by a consortium led by the Carbon Trust, including Mott MacDonald, UCL and Pengwern Associates. Carbon Trust was the lead technical author for the offshore renewables sub-theme report.

Scope and limitations of the EINAs:

The EINAs project is a research exercise to evaluate the potential impact of technological innovations on the UK energy system and Net Zero targets and help inform decisions on clean energy innovation.

A number of technologies were included as part of the prioritisation but were not included in the systems modelling due to limitations of the models used for the EINAs, data availability and resource constraints. The three hypothetical scenarios developed to represent potential routes to Net Zero were selected due to their differing constraints which provide a more diverse set of outputs and insights.

The technologies and scenarios selected do not represent UK Government policy.

The offshore renewable energy sub-theme

Offshore renewables offer a significant opportunity to accelerate the decarbonisation of the UK's energy system. They could play a key role in the provision of clean energy depending on which pathway the UK chooses to take as they can replace current generation technologies. Whilst maturity of these technologies varies by type, there are opportunities for innovation across the offshore renewables value chain to facilitate the scaling of these opportunities. Offshore renewables interact with a number of other priority areas, including networks and energy storage. Technologies in these sub-themes are assessed in the relevant EINAs reports.

A shortlisting and prioritisation exercise was conducted to determine the offshore renewable energy technologies to be modelled and studied in this update of the EINAs. This followed a framework which considered the following factors:

- **Known net zero priority:** Technologies where there is a clear government direction or expert consensus.
- **Energy security:** Technologies necessary for system resilience and to protect against grid and import shocks.
- **UK relevance:** Technologies suitable for UK specific circumstances, and where the UK is likely to have an impact.

- **Technology Readiness Level (TRL) relevance:** Technologies close to commercialisation or likely to be commercially viable by 2040.

The technologies prioritised for assessment within the offshore renewable energy sub-theme are fixed-bottom offshore wind (OSW), floating offshore wind (FLOW), and tidal stream technologies, as detailed in Table 2.

Table 2: EINAs technologies in the offshore renewable energy sub-theme

Technology	Description
Fixed-bottom offshore wind (OSW)	Fixed-bottom offshore wind (OSW) turbines are installed directly on the seabed in shallow waters less than 60m depth. Fixed-bottom OSW was first deployed commercially in northern Europe, and has since expanded into markets including China, Japan and the USA. Fixed-bottom OSW is currently an extensive part of UK and global energy production. The UK is a global leader, with 14.7 GW of OSW operating capacity (as of 2024), accounting for almost 20% of global capacity.[2] Fixed-bottom OSW currently provides over 17% of the UK's electricity.[3] Fixed-bottom OSW is a commercially accepted technology which is constantly developing. Further innovation is needed to reduce costs and improve the lifetime of assets. As offshore turbines reach a larger size and capacity increases, it is essential that innovation development continues at a fast pace across key industry elements, including high voltage cables, standardisation and industrialisation, and vessel development and decarbonisation.
Floating offshore wind (FLOW)	Floating offshore wind (FLOW) refers to turbines installed on floating platforms moored to the seabed. FLOW is usually installed where fixed-bottom OSW installation is not feasible, covering depths from 60m - 1,000m plus. Installing FLOW turbines at these greater depths can unlock more areas for deployment as competition for seabed usage increases and can be advantageous due to the increased and more consistent wind resource available. At present, there are several test and demonstration-scale commercial clusters of varying floating sub-structure designs, including the Tension Leg Platform (TLP) and the semi-submersible floating sub-

[2] Renewable UK (2025) UK wind and global offshore wind: 2024 in review
[3] Renewable UK (2024) Energy bible confirms new renewable power generation records

Technology	Description
	structures. All the current platforms are in relatively shallow water 60-300m. Currently, the most advanced FLOW designs are at an estimated Technology Readiness Level (TRL) of 8-9.[4] Floating wind has yet to consolidate in the same manner as fixed-bottom designs. There are a multitude of floating wind foundation designs at the concept level, but the majority have yet to be demonstrated and are at TRL 4-6. Although there are similarities to fixed-bottom OSW, FLOW requires larger port capacities and further innovation to achieve commercial scale. This will rely on the development of innovative technologies, for example, mooring systems, high voltage dynamic cables and cost-effective floating foundation design.
Tidal stream	Tidal stream could be an important part of the UK's long-term decarbonisation objectives.[5] Tidal stream (sometimes referred to as tidal current) harnesses kinetic energy from fast-flowing current created by tides. The technology typically uses underwater turbines fixed or moored to the seabed to extract energy from moving water driven by tidal currents.[6] Tidal stream technology is at an earlier stage of development, at TRL of 6 – 8, and CRI 1-2, but there are large numbers of competitions for concept demonstrators of varying design. In the UK, the EMEC test centre and Wave Energy Scotland are leading this innovation. Standardisation and industrialisation are key areas that require development for the commercial success of tidal stream.

This report focuses on the three technologies outlined above. Other offshore renewable technologies, including tidal range and wave power, which use tidal barrages/lagoon technology, were included in the initial longlisting have not been prioritised for analysis for the EINAs. Tidal range faces significant barriers to scale up and deployment, including the need for subsidy support, environmental factors and cost concerns due to large initial investment. This reduces the opportunity for early impact on the UK's Net Zero target.[7] Wave energy, often associated with UK tidal stream R&D, has not been prioritised for analysis, due to its lower

[4] IRENA (2024) Floating offshore wind outlook
[5] UK Government (2024) Clean Power 2030: Action Plan: A new era of clean electricity
[6] Serin E, Andres P, Martin R, Shah A, Valero A (2023) Seizing sustainable growth opportunities from tidal stream energy in the UK.
[7] British Hydropower Association (Accessed: 2024) Tidal Range - British Hydropower Association

TRL and remaining uncertainty around the technology's potential to be deployed at large scale. However, some analysis suggests that, with government support and investment, both tidal barrage/lagoon technology and wave energy have the potential to contribute to the UK's Net Zero ambitions.[8], [9]

Offshore renewables in the UK energy system

With access to abundant territorial waters with suitable natural resources, and strong offshore maritime expertise, there is significant potential for offshore renewables to accelerate the decarbonisation of the UK's energy system. The UK has a strong track record in the development and deployment of the fixed-bottom OSW and oil and gas (O&G) industry and can leverage this experience to be a first-mover in emerging offshore renewable markets.

This section introduces each of the technologies assessed in the offshore renewables sub-theme, and an overview of the landscape of the technologies in the UK and their potential future deployment.

Fixed-bottom offshore wind

Fixed-bottom OSW refers to wind turbines that are installed directly onto the seabed. These structures are typically installed in shallow waters in the region shallower than 60m, on monopiles or jacket structures and some gravity based concrete structures. Fixed OSW technology is commercially mature, and the UK is a global leader in the sector. In 2024, fixed OSW currently provided over 17% of the UK's electricity.[10] By the end of 2024, the UK had 14.7 GW of OSW operating capacity, accounting for almost 20% of global capacity (80.9 GW).[11] The UK's capacity is set to double, with a further 16 GW of OSW either in construction or committed in the pipeline.[12] To achieve the Clean Power 2030 mission, the UK will need to reach between 43-50 GW of constructed or contracted OSW capacity by 2030.[13]

The government's Contract for Difference (CfD) scheme incentivises investment through providing OSW developers with protection against changing electricity prices, currently over a 15-year contract. For example, Allocation Round 6 (AR6) saw nine CfD contracts for fixed-bottom offshore wind projects awarded, totalling 4.9 GW.[14] This creates the opportunity for the development of offshore wind projects in designated lease zones in the UK waters by setting a final cleared strike price of £59/MWh for regular OSW and £54/MWh for permitted reduction fixed-bottom OSW (2012 costs, adjusted for inflation to reflect the value of money in 2012 as a

[8] Marine Energy Council (2023) Wave energy to have a key role in realising the UK's net zero ambitions, according to new report
[9] Climate Change Committee (2020) Tidal Lagoon Power response: The Sixth Carbon Budget and Welsh emissions targets Call for Evidence
[10] Renewable UK (2024) Energy bible confirms new renewable power generation records
[11] Renewable UK (2025) UK wind and global offshore wind: 2024 in review
[12] Renewable UK (2025) Offshore wind | RenewableUK
[13] UK Government (2024) Clean Power 2030: Action Plan: A new era of clean electricity
[14] UK Government (2024) Clean Power 2030: Action Plan: A new era of clean electricity

consistent basis for comparison). A methodology was developed by DESNZ, used to create administrative strike prices for CfD AR6.[15]

Offshore wind will be central to a resilient, secure and robust domestic energy supply. Building the UK's OSW operating capacity can reduce the UK's dependence on energy imports and reduce exposure to volatile global energy costs.

Floating offshore wind (FLOW)

Floating wind technology enables wind turbines to be anchored to the seabed via mooring lines to the seabed in deeper waters than fixed-bottom turbines. This unlocks access to new areas of the seabed, which can provide increased geographical diversity of energy supply and provide increase areas for deployment as shallow waters become increasingly constrained. Deeper waters can also enable access to regions where wind patterns are stronger and more reliable, for example they are less affected by land masses, as you move further offshore. This is demonstrated by higher capacity factors (maximum potential output over a given period) for floating wind when compared to fixed-bottom OSW between 35-45%; Hywind Scotland achieved 57.1% in the twelve months to March 2020.[16]

The UK developed the world's first wind farm on floating foundations in 2017, off the coast of Scotland. Currently, the UK's FLOW operating capacity is 77.5 MW, second to Norway's 94MW, with a total global capacity of 245 MW[17]. Norway's capacity is primarily made up of the Hywind Tampen project; eleven 8.6 MW turbines in the Norwegian North Sea which supply electricity to Equinor's oil and gas fields, Snorre and Gullfaks.[18]

The UK has the largest floating wind pipeline in the world based on confirmed seabed exclusivity, with over 25 GW already agreed. The Floating Offshore Wind Taskforce estimates that by 2050, FLOW turbines could provide one-third of the UK's OSW capacity, 175 TWh/year of clean energy - more electricity than natural gas provides today.[19] The CfD Allocation Round 6 (AR6) saw 400 MW of floating wind awarded to Green Volt. If the Green Volt project is able to deliver at the strike price of £139.93/MWh (2012 prices),[20] this would be a crucial stepping-stone to GW-scale projects.[21] The UK is well-placed to lead on the development of FLOW, with a strong history of maritime innovation and significant marine energy resources. There are significant opportunities to benefit from first-mover advantage, creating domestic economic value, jobs and supply chains, while capitalising on a significant decarbonisation opportunity.

Tidal stream

Tidal stream technology (sometimes referred to as tidal current energy) harnesses kinetic energy from fast-flowing current created by tides. Tidal stream technology is suited to areas

[15] UK Department for Energy Security & Net Zero (2023) Methodology used to set Administrative Strike Prices for CfD Allocation Round 6
[16] Energy Numbers (2022) UK offshore wind capacity factors
[17] Renewable UK (2025) UK wind and global offshore wind: 2024 in review
[18] Equinor (2025) Hywind Tampen
[19] Renewable UK (2025) Floating Offshore Wind: Anchoring the next generation offshore
[20] Department for Energy Security and Net Zero (2024) Contracts for Difference (CfD) Allocation Round 6: results
[21] Offshore Renewable Energy Catapult (2024) Allocation Round 6 (AR6) Results and Analysis

where the current is intensified by topographical features such as straits or inlets where the shape of the seabed accelerates currents through the narrowing of channels.[22] Tidal stream technology is at an earlier stage of development than OSW, with key components at TRLs of 4 - 6.[23] There has been some convergence on designs towards underwater turbine concepts. These can be broken down into two main types: fixed and floating, each comprising a range of designs, generally aligning around concepts featuring turbines on a horizontal axis. These are similar to wind turbines, but are smaller in size and capacity, at around 1-2 MW as opposed to 8-12 MW for an OSW turbine. Similar to wind farms, multiple tidal stream devices can be deployed in the same area to form arrays.[24]

A significant advantage of tidal stream as a renewable technology is the consistency and predictability of the tides. Tidal stream therefore holds the potential to complement other, more intermittent, renewables. Increasing tidal stream capacity could reduce network balancing costs by providing predictable and dependable electricity,[25] and reducing the amount of dispatchable gas needed to balance the system.[26,27] As a significant domestic renewable resource (estimates suggest that practical resource could be equivalent to up to 11% of the UK's electricity demand[28]) tidal stream energy can therefore contribute to reducing the UK's reliance on energy imports and exposure to volatile prices in global energy markets.[29]

The first demonstration of tidal stream was in 2002, with a capacity of 150 kW. Since then, there have been several successful tidal demonstrations, primarily in the UK's European Marine Energy Centre (EMEC).[30] The UK is the global leader in tidal stream energy development, having deployed the world's first commercial-scale tidal turbine in 2008. The UK now has around 10 MW of tidal stream generation capacity installed (as of 2023), which represents over half of the world's current operational capacity.[31] In the CfD Allocation Round 6, successful projects were allocated a total capacity of 28 MW with a strike price of £172/MWh (2012 prices).

Tidal stream requires locations with strong currents, which reduces the number of potential UK array locations in comparison to OSW. Potential locations for tidal include the north of Scotland, with significant potential also around north Wales, Northern Ireland, the Channel Islands and the Isle of Wight. The predictable nature of tides and the potential locations

[22] Grantham Research Institute (2023) What is tidal stream energy?
[23] Offshore Renewable Energy Catapult (2024) Tidal stream technology roadmap
[24] Serin E, Andres P, Martin R, Shah A, Valero A (2023) Seizing sustainable growth opportunities from tidal stream energy in the UK
[25] Offshore Renewable Energy Catapult (2022) Quantifying the benefits of tidal stream
[26] Serin E, Andres P, Martin R, Shah A, Valero A (2023) Seizing sustainable growth opportunities from tidal stream energy in the UK
[27] Supergen Offshore Renewable Energy (2023) What are the UK power system benefits from deployment of wave energy and tidal stream generation?
[28] Coles D et al. (2021) A review of the UK and British Channel Islands practical tidal stream energy resource
[29] Serin E, Andres P, Martin R, Shah A, Valero A (2023) Seizing sustainable growth opportunities from tidal stream energy in the UK
[30] European Marine Energy Centre (2025) Tidal devices
[31] Serin E, Andres P, Martin R, Shah A, Valero A (2023) Seizing sustainable growth opportunities from tidal stream energy in the UK

available means the UK is on track to have over 130 MW of tidal stream deployed by 2029.[32] The majority of this will be the first commercial scale tidal arrays, estimated to be deployed in the late 2020s to early 2030s, and research suggested that a potential 6 GW of tidal stream could be installed in the UK by 2050. 33

The main commercial scale demonstration projects in the UK include:[34]

- SIMEC Atlantic Energy and Andritz Hydro: four 1.5 MW turbines installed in Meygen Phase 1, a further 28 MW to be delivered under CfD AR4 by 2027.
- Nova Innovation: Shetland Tidal Array (six 100 kW turbines).
- Orbital Marine Power: Installed second full-scale prototype of 2 MW in 2021, with a further 7.2 MW to be delivered under CfD AR4 by 2027.
- Magallanes Renovables: Installed full-scale prototype of 2 MW in EMEC in 2019, and a further 5.6 MW to be delivered under CfD AR4 by 2026.

[32] European Marine Energy Centre (2024) Six tidal stream projects successful in the UK's latest renewable auctions
[33] Supergen Offshore Renewable Energy (2023) Research and Innovation for Wave and Tidal Stream in the UK and EU: A 2023 Summary
[34] Supergen Offshore Renewable Energy (2023) Research and Innovation for Wave and Tidal Stream in the UK and EU: A 2023 Summary

Offshore renewables: Innovation opportunities

Innovation opportunities in offshore renewables

This section outlines key innovation opportunities to reduce costs, support commercialisation and enable the scale up of offshore wind and tidal stream technology. Key focus areas for innovation are outlined below and mapped along with their likely impact on cost and deployment.

Component, infrastructure and logistics development

Innovation in the technology components and infrastructure will be essential to facilitate the expansion of the offshore energy industry. Some of the key areas for innovation include:

- Vessel design and decarbonisation, and self-hoisting cranes as alternatives to heavy lift vessels.
- Advanced transfer systems to safely transport technicians and equipment to offshore locations.
- Wind generator integration method for larger turbines.
- Mooring equipment for FLOW.
- Robotics: automation of tasks such as inspection and maintenance using autonomous systems.

For FLOW to reach commercial scale, there must be further cost reductions, balanced by the need for security of supply, including system and network resilience to damage (see the EINAs Networks report), both accidental and otherwise. This will require innovation in manufacturing, installation and maintenance, combined with large-scale infrastructure upgrades to ports.

Energy storage

In areas where it may be less practical to transmit electricity directly from offshore renewables to areas of electricity demand, innovation in energy storage or energy transmission vectors could support offshore renewables development. Examples would be hydrogen or the production of ammonia for low-carbon vessel fuel, other battery and network storage. Innovations in these areas are assessed in the Energy Storage, Networks and Hydrogen EINAs reports.

Grid integration

To enable a rapid uptake in offshore renewable energy and reduce grid connection times, grid capacity and integration technologies will need to be enhanced. Innovation in subsea long distance High Voltage Direct Current (HVDC) cables and DC networks will be needed to support the cost-effective transmission of electricity. This could be particularly important for floating wind arrays, which may be located further offshore.

Implementing smart grids, including control systems, and well-designed long-term energy storage will be necessary as a larger percentage of renewable energy is integrated in the grid system, to manage fluctuations in the availability of natural resources (i.e. wind and solar). Integrating multiple sources of renewables may help to balance the energy system by improving correlation between renewable generation and energy demand. Capacity expansion of both the network and new generation will be aided by developing higher voltage and connectors, such as 132 kV array cables, will pave the way for larger capacity next-generation turbines at 14 MW plus.

Advanced design, modelling, controls and monitoring

With continued advances in artificial intelligence (AI), additional analysis and optimisation can be performed for offshore renewable arrays. This can include early initial modelling and accurate mapping of the predicted power yield of an array site location, as well as advanced control system and integrated instrumentation. Increasing the efficiency through remote monitoring and data collection and analysis will be key in reducing costs across all offshore renewables

Decommissioning and end of life

With many of the early installed fixed-bottom wind arrays reaching the end of their lifecycle (~30 years) before 2050, decommissioning and removal of generation equipment creates a significant logistical challenge and could have a significant environmental impact. Well-thought-out innovative approaches for life extension of existing lease areas and infrastructure will be key. These may include repowering or retrofitting new technology, maintenance updates, or improved monitoring solutions. Examples would include methods of integrating newer, large turbines into old lease areas and networks cost-effectively. Well-designed end of life extension could have a significant effect on reducing LCOE for an array/farm and help maintain the UK capacity, reducing the amount of new deployment required to meet Net Zero targets.

Testing and industry guidelines

Innovative cost-reduction technologies will need to be tested at a commercial scale before being implemented in floating wind and tidal stream arrays. There are several renewable test facilities in the UK; the European Marine Energy Centre (EMEC) in Orkney offers test sites for tidal energy and the Offshore Renewable Energy Catapult has several renewables test facilities in Blyth and Levenmouth. Sufficient and appropriate guidelines developed by classification societies are also necessary to accelerate the development of innovations. Standardisation of industry-specific guidance, such as dynamic cable design and testing standardisation, is required across the offshore renewables industry. Clear guidance is needed to define the level of testing required for specific novel technologies, such as onshore versus full-scale offshore tests. Although there are several large-scale test facilities and demonstration projects in the UK, more facilities willing to risk testing novel equipment, as well as funding programs, need to be developed to test full-scale novel technologies offshore capable of reducing offshore renewable costs.[35]

Mapping of innovation needs

This section details key components and areas of technology innovation required to reduce cost and accelerate the deployment of the offshore renewable technologies assessed in this report. This section draws from the previous EINAs offshore renewable research with updated assessments. The table details the direct technology impacts of innovations, as well as the other EINAs technologies that could benefit from innovation in these areas. Each innovation is assessed according to its likely impact on cost reduction and deployment for the relevant technology, with a qualitatively assessed 1 (very low) – 5 (very high) impact rating. Column descriptors within the table are defined as following:

- Technology: technologies where the innovation is applicable.
- Other impacts: other technology families that are indirectly impacted by this innovation.
- Cost reduction: how the innovation opportunity can reduce the overall costs of the technology, rated from 1 (low) to 5 (high).
- Barrier reduction: how the innovation opportunity can contribute to reducing barriers to deployment, rated from 1 (low) to 5 (high).
- Time frame: period over which the innovation could feasibly start to be adopted and have material implications for the UK energy system and Net Zero

[35] European Marine Energy Centre (2025) National floating wind test centre

Table 3: Component, infrastructure and logistics development innovation opportunities

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Turbine size and design: Increased size and standardising development of turbines to increase yield and lower LCOE as fewer turbines will be required. Specific turbines and towers developed for floating wind and mass manufacture of tidal streams are required for commercial scaling.	Fixed-bottom OSW FLOW Tidal stream	4 - Larger turbines have higher energy output, and so fewer turbines are required per offshore array. This reduces costs as less offshore infrastructure, such as cables, is required. There is also potential benefit in cross-industry standardisation of turbine sizes and designs to improve reliability, efficiency of O&M and installation.	4 – Use of fewer, large turbines can reduce production times, easing supply chain pressures, and reduced numbers of turbines require less inspection and maintenance. Turbine scaling will reduce LCOE but could introduce challenges relating to infrastructure. Significant upgrades will be needed to handle larger turbines, e.g. vessels, cranes, port quaysides. Tidal turbines are expected to scale in the coming years, from around 1-2MW to 3MW.	2025-2050 This will be constant through the 2050 lifecycle slowing % MW scale changes towards 2050. Tidal steam %MW increases will potentially level earlier due to environmental constraints associated with high tidal flow areas.

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Foundation design and optimisation: Automation of fabrication and material optimisation using advanced mass or batch production techniques. An example would be modular construction of steel reinforced concrete foundations. This will be of particular importance to cost effectively scaling floating wind and tidal stream.	FLOW Tidal stream	4- Optimisation for mass manufacture will allow efficient large scale production runs. The economies of scale will reduce the cost per unit.	5- This can assist in supply chain development and increase efficiency. This links strongly with port infrastructure and nearby infrastructure development. Requirements and investment decision for port and surrounding infrastructure that can be used for multiple array deployments will be key.	2017 – 2031: Scale demonstration floating wind foundations and clusters (5-10) turbines 2031– 2050: Full scale commercial arrays floating wind and tidal stream

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Vessel design: New vessels are required to manage the scale of new offshore wind turbine installation and maintenance. Vessel requirements will vary depending on the renewable device. For example, mooring systems for floating renewables will require specific anchor handling vessels. In addition to the decarbonisation of the existing vessel fleet, there is also a need for new low carbon vessels[36], [37]. Examples include: • Dynamically positioned vessels that hold position using sensors and reference systems and thrusters. • Vessels capable of performing deep water mooring systems floating installation in a cost-effective manner.	Fixed-bottom OSW FLOW Tidal stream	3- Efficient vessel design for new larger turbines and floating wind will reduce costs and installation times.	3 – The existing and expected global demand for OSW will mean that new offshore industry supply vessels will be a requirement for achieving this level of deployment. In a lot of cases, this will require an increase in vessel size and design changes. Larger 15MW+ FLOW turbines will require larger anchor handling vessels with specific design characteristics, e.g. larger chain locker capacity and bollard pull. This could apply to some larger tidal turbine designs.	2025 – 2030: Initial expansion of vessel fleets inclusion hybrid and electric vessels. 2030 – 2040: Large scale adoption of next generation vessels, green full adoption. 2040-2050 Full advanced adoption of new technology, autonomous fleets, sustainable vessel design[38]

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Advanced installation and maintenance techniques such as self-hoisting turbines and cranes and autonomous maintenance systems. These could reduce the cost and demand of large heavy lift vessels and allow maintenance and installation in deeper water locations. Specific equipment allowing multiple tidal turbines to be installed on one structure. Assisting with short slack tide weather windows for installation and maintenance. All OSW technologies would benefit from modular design and remotely operated monitoring.	FLOW Tidal stream	4 - Installation and potential large scale maintenance cost reductions are essential with the increased size of turbines or generating equipment. Specialist equipment is required for differing substructure designs.	4 - Installation and O&M cost reductions.	2025-2030 Scale testing of heave lift equipment and robotic autonomous systems 2030-2040 Adoption in commercial scale offshore renewables.

[36] Riviera (2023) Shipping's journey to decarbonisation: Engine Retrofitting of Vessels for Alternative Fuels
[37] Riviera (2023) First Low-Carbon Floating Installation Vessel Receives UK Funding
[38] NREL (2025) A Supply Chain Road Map for Offshore Wind Energy in the United States

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Integrated assembly techniques: Design and manufacturing techniques that enable large-scale modular assembly in combination with designs that reduce material requirement per unit and reduce bottlenecks by reducing lead times through increased efficiency. For example, modular reinforced concrete and steel for floating and fixed foundations, automated welding techniques, and modular cable and synthetic mooring lengths that are consistently manufactured at a high consistent standard.	FLOW Tidal stream Networks Transmission and distribution Energy storage	4 – Large-scale modular assembly and standardisation will reduce costs across the supply chain, and increase efficiency of installation and O&M.	5 – The supply chain capacity will need to increase to meet demand for parts. Standardisation on a large scale will reduce costs and support this scale up.	2025-2030 Adoption of advanced modular construction methods. This will have a dramatic effect for FLOW and tidal stream.

Table 4: Advanced design, modelling, controls and monitoring innovation opportunities

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Automation and remote monitoring: With OSW farms being located further from the shore and in harsher, isolated environments, new O&M strategies and technologies will be required to remotely operate these assets. This may include drones, remote inspection technologies, remote vehicles or other solutions. This will also be applicable to Tidal stream.	Fixed-bottom OSW FLOW Tidal stream Networks Transmission and distribution	3 - Remote monitoring is useful cost reduction by reducing the in-person dependency for inspection. The development of AI tools using machine learning algorithms and real-time data analysis will assist in review and failure detection, predictive maintenance requirements, fault diagnostics and performance/lifetime optimisation.	3 - Automation and remote monitoring will assist with efficient cost-effective monitoring and inspection, reducing the number of skilled workers required.	2025-2030 Rapid AI advancement will assist in data assessment and pilot schemes development. 2030 -2040 Full scale industry update of remote monitoring for offshore renewables.

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Advanced monitoring and inspection techniques: Large scale offshore farms will be costly to monitor due to the large numbers of turbines (~50 plus for commercial arrays). Cost effective methodologies and advanced data analysis techniques will be required to enable effective monitoring. Examples include sampling techniques and advanced modelling such as digital-twin models. AI could be implemented to support data processing.	FLOW Tidal stream Networks Transmission and distribution	4 - Effective monitoring programs will require fewer overall physical inspections, reducing O&M costs. E.g. advance sampling and clustering using that can be assessed using advance AI tools validating digital twin modelling with live data.	5 - Reduction in the number of skilled workforce and inspection vessels required.	As above

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Advanced turbine control systems: Turbine control systems that optimise the individual turbine and across a wind farm will aid efficiency and prolong the life of assets. Further investment in development for control systems specific to offshore renewables technology is need.	Fixed-bottom OSW FLOW Tidal stream	4 – This can lead to an estimated 20% life extension on some components. There is a potential yield increase with turbines working more efficiently together reducing LCOE.	3 - Advanced control systems linked with monitoring will offer real-time understanding and specific cross array/wind farm knowledge. This can increase yield accuracy and help reduce turbine interaction loads, extending the life of the turbine.	2025-2035
Advanced Wind Modelling of how wind moves through a wind farm during its operational life, and being able to predict this in advance allows more accurate forecasting and planning and design. This can increase yield, reduce uncertainty and risk through a great understanding of effects such as shadowing or turbulence from up wind turbines, and therefore reduce costs.	Fixed-bottom OSW FLOW	4 - Current modelling software is being developed that reduces the processing power these models require. Accurate LCOE estimates can be performed at design stages.	3 - Increased yield accuracy through overall turbine array assessment rather than individual turbine assessment. Reduce turbine interaction loads, increasing turbine life, increasing offshore renewables asset lifetime and increasing yields across and array increasing outputs. There is the potential for this technology to be implemented on older arrays.	2025-2035

Table 5: Grid integration innovation opportunities

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Grid integration and network development: Innovation is required for capacity expansion and transport distances for electricity generation through OSW. Direct Current (HVDC) networks and smart grids and holistic network design (HND) Tidal stream integration in remote locations usually require infrastructure network upgrades[39] Sharing infrastructure generation devices could reduce cost and incentives network upgrades.	Fixed-bottom OSW FLOW Tidal stream Networks Energy storage Transmission and distribution	5 – Shared infrastructure and strategic network planning, which could involve multiple wind farms connecting to a single onshore substation, reducing the amount of cable required. Transmission cost will reduce over longer distances due to reduced losses. HVDC becomes cost-optimal for a 1200 MW project is in the range of 135 -180 km in export cable length. HVDC will allow the linking of national and international networks (interconnection)[40], creating larger networks able to better manage volatility of renewable generation. This combined with smart grids providing improved reliability, efficient energy storage and reduced transmission losses reducing dependence on natural gas. Larger capacity HVDC	5 - The UK's existing infrastructure doesn't have the capacity to transport the level of energy that will be generated offshore. Both the onshore and offshore electricity networks require upgrading to enable the anticipated scale of offshore generation required. Existing barriers including planning, routing and consenting will need to be reduced in complexity, coordinated and accelerated where possible.	2025 – 2030 2030 Offshore wind HVDC national network to be established as part of the HND[41] 2030-2035: Full integration of smart grid technologies adopted in offshore renewables[42]

[39] University of Strathclyde (2014) Tidal Methodology - Site Selection
[40] Power (2024) Offshore Wind Growth and HVDC Developments in the North Sea: Key Trends and Future Outlook
[41] NESO (2024) Beyond 2030: A national blueprint for a decarbonised electricity system in Great Britain
[42] Uk Government (2023) Offshore wind net zero investment roadmap

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
		132kV will allow 14MW plus OSW turbines to be integrated into a network over greater distances, reducing LCOE per turbine.		
Improved network monitoring systems integration: Improved system monitoring (accelerometers, GPS sensors measuring motions, optical fibres measuring cable temperatures) will help monitor and address failures by reducing the number of major failures that take renewable device offline and quickly identifying types and locations of failures in the system.	Fixed-bottom OSW FLOW Tidal Stream Networks Energy storage Transmission and distribution	4 - Real-time monitoring and AI assisted data analysis will help with early potential failure identification. Identifying the specific location of failures will result in reduced network downtime and maintenance costs. Monitoring data will help with end of life opportunities, repowering or life extension.	4 - Increased network system reliance will reduce losses and reduce LCOE for offshore renewables. Currently, there are large numbers of failures and losses from OSW due to cable failures.[43]	2025 – 2030 Pilot projects in advanced monitoring systems, data integration and standardisation [44] 2030-2040 Advanced commercial scale adoption of monitoring systems including advanced analytics and regulatory support.

[43] DNV (Accessed 2025) 80% of insurance claims in offshore wind are related to subsea cable failures – How can the industry manage these risks?
[44] UK Government (2022) £60 million boost for floating offshore wind

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
HVDC substation development: As OSW farms are deployed further offshore, HVDC may be more suited to reducing transmission losses over long distances. Development of specific substations for floating wind and switch gear equipment to reduce topside weights of the substations is necessary.	Floating OSW Tidal stream Networks Transmission and distribution Energy storage	5 - Costs will be reduced as losses will reduce over distance. Without HVDC substations, which are required to combine and convert individual turbine output to higher voltages, from alternating current (AC) to direct current (DC), the development of FLOW will be extremely challenging. This is because there are significant electrical losses associated with High Voltage Alternating Current (HVAC), and the increased distance that electricity must be transported to reach high demand areas from floating arrays further offshore. Offshore HVDC equipment is significantly heavier than High HVAC and requires a reduction in weight for use with floating substations.	5 Directly contributes to addressing a key barrier in transmission and grid integration for offshore renewables.	2025-2035 Commissioned Wind farms using HVDC are predicted to jump to 27% by 2030 and 37% by 2035 worldwide[45]

[45] Spinergie (2024) Offshore substations

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
High Voltage (HV) array cable development: HV array cables (both HVAC and HVDC) which have a higher capacity are essential to support the deployment of FLOW and could reduce costs for fixed-bottom OSW.	Fixed-bottom OSW FLOW Tidal stream Networks Transmission and distribution Energy storage	4 - Overall, the development of cable technology will lead to increased reliability over the lifetime of an offshore asset. FLOW requires the development of high voltage dynamic motions associated loads over the lifetime of a turbine. Better quality cables and testing guidelines could reduce losses and failures. Increased capacity etc. 132kV array cables will be necessary for larger wind turbines 14MW+, reducing LCOE and lowering higher voltage transmission losses.	5 - These developments are essential for high voltage 14MW + turbines. Floating assets will require HV dynamic cables to be developed associated with moored technology (FLOW) and will form an essential part of the technology's cost reduction.	2030 – 2035 The first 132kv cable wind farms are expected in 2032.[46] There will be widespread adoption by the mid 2030's.

[46] Electra (2023) Webinar on market readiness for 132 kV offshore wind farms

Table 6: Decommissioning and end of life approaches innovation opportunities

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Decommissioning: Technologies that minimise the costs and risks associated with decommissioning, and which minimise environmental impacts. Decommissioning will be the final end of life stage, after retrofitting and repowering and life extension (mentioned below) are considered. Cost impact assessments will need to be performed in determining end of life approach.	Fixed-bottom OSW FLOW Tidal stream	2 - Optimisation of decommissioning techniques and procedures for multiple array types will reduce operations costs. Specific vessels or equipment may be required for removing anchors and monopolies in reduced timeframes efficiently without major disruption of the seabed.	2 – Novel decommissioning technologies are less relevant to deployment barriers than other technology areas.	Fixed-bottom OSW: 2030 FLOW and tidal stream: 2040-2050
Retrofitting and repowering: When a renewable array is coming to the end of its ~30-year lifecycle, consideration is need for maximising the site for future power generation. Retrofitting or repowering (for example, with large turbines) are the two main options to minimise the costs as they both use existing infrastructure, and the most cost-effective option will be informed by a techno-economic assessment of the site towards end of life.	Fixed-bottom OSW FLOW Tidal stream	3 – Determining a route to retrofitting and repowering will be a cost-effective way of recommissioning sites which already have existing infrastructure, permits and grid connection. This reduces the costs compared to a novel site but may have implications for reliability and maintenance requirements.	3 - Extension of arrays/wind farms areas working life could reduce the amount of rapid expansion into new sites that would be required to reach Net Zero targets.	Fixed-bottom OSW: 2030 FLOW and tidal stream: 2040 - 2050

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Life extension technologies, including leveraging improved data on fatigue and wear through structural health monitoring and associated maintenance approaches and upgrades.	Fixed-bottom OSW FLOW Tidal stream	3 - Extension will offer developers potential to increase profits post-investment payoff if an array produces power safely past expected life. This will also increase the UK capacity cost effectively if sites can produce for longer without large infrastructure upgrades. Implications for reliability and maintenance should be considered.	3 - Extension of the working life of arrays/wind farms could reduce the number of new sites and costly infrastructure upgrades over time and minimise environmental impact.	2025-2050

Table 7: Energy storage innovation opportunities

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Alternative energy storage solutions: Alternatives to network connection or surplus demand, e.g. cost-competitive production of low carbon hydrogen and ammonia onsite to provide fuel for shipping, for instance. This could be used at refuelling points for vessels in remote locations with limited network connection.	Fixed-bottom OSW FLOW Tidal stream Networks Transmission and distribution Energy storage Hydrogen production	5 – Locations with high offshore renewables resources but limited grid connection, e.g. Orkney, surplus offshore renewables could be stored as hydrogen or ammonia as a fuel additive for vessels. This has the potential to reduce costs for hydrogen-related industries due to the high cost of electrolysis. This would also help balance the grid and mitigates renewable energy curtailment by utilising surplus electricity.	4 - This could open up lease areas, by offering additional income streams and scaling offshore renewables in an area which may not have adequate grid connection or in areas where offshore farms being curtailed.	2030-2035

Table 8: Testing and industry guidelines innovation needs

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Floating foundation design testing and funding support. Full-scale testing and consolidation of designs for large-scale floating wind concepts and innovations. Validation of concept, further funding support and test facilitates are required.	FLOW Tidal stream	4 - Consolidation and proof of concept of the multiple leading FLOW concepts (there are currently multiple concepts at the point of scale testing with pathway due to both funding and the lack of UK test facilities) floating wind concepts) would create a track record and create a further investment pathway, reducing risk and cost.	5 - Cost reduction and supply chain development will be possible as fully offshore testing will demonstrate proof of concept and construction.	2025-2035 Accelerated support is needed as offshore tests usually require 5 years at minimum for proof of concept.

Innovation opportunity	Technology	Cost reduction	Barrier reduction	Time frame
Novel component level development qualification. Novel components such as mooring solutions, self-hoisting cranes, and dynamic cables will need to be developed and certified by a certification body for floating structures at large scale.	Fixed-bottom OSW FLOW Tidal stream	4- Successful novel technology solutions focus on cost reduction as current demonstrations use expensive technology that may not be possible to implement at a large commercial scale. Technology similar to previous O&G technology such as, mooring systems, installation and gid integration technologies, can access accelerated qualification as they can be qualified under similar testing frameworks to O&G, which are pre-existing and tested processes.	5 - Cost reduction and supply chain barriers will be removed by novel system technology development.	2025-2030 Discussions between developers and classification societies will be essential as part of this progression.

Components and costs

Offshore wind

This section outlines the primary cost components, and opportunities for cost reduction, for offshore wind. Figures included in this section for fixed-bottom OSW are based on estimates from the Offshore Renewable Energy Catapult. Figures for FLOW are based on guidance developed by BVG Associates, OREC and the Crown Estate.[47]

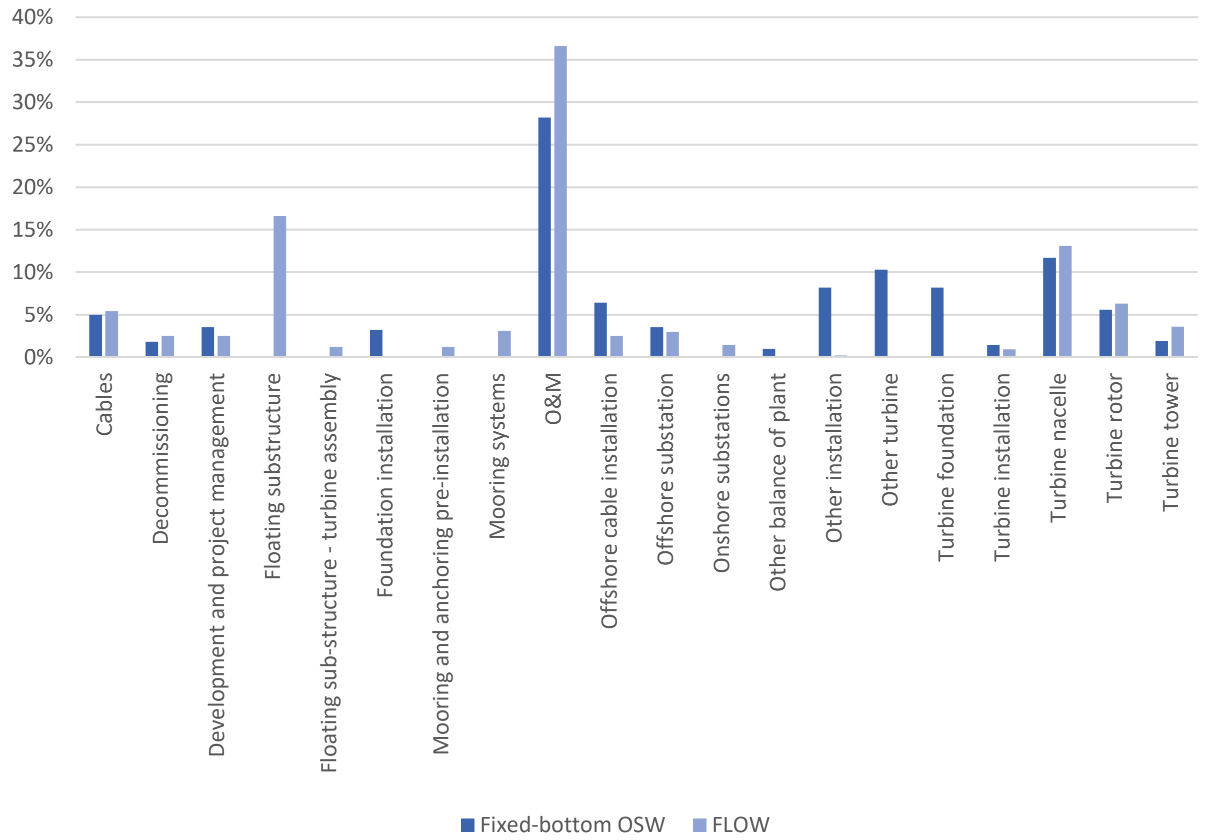

Figure 1: Typical cost associated with a fixed-bottom and floating wind major cost element in terms of levelised cost of energy (LCOE). Source: Guidance to an offshore wind farm fixed/floating

CAPEX: capital expenditure, including development expenditure, and the cost of finance for that CAPEX. This includes finance for the turbine, foundations (plus anchors and moorings for FLOW), and tower and balance of plant, including cost of export and array cables, as well as cable protection, offshore substation, and onshore substation. Installation and commissioning costs are a major part of CAPEX, which will include turbine installation and offshore logistics, including sea-based support, marine coordination, and weather forecasting and metocean data. Reducing FLOW installation cost through innovative solutions will be essential before

[47] BVG Associates (2025) Guide to a Floating Offshore Wind Farm: Wind Farm Costs

large scale commercial arrays are possible. CAPEX is estimated to be 71.8% of LCOE for fixed OSW[48], and 63.4% of LCOE for FLOW[49].

OPEX: The majority of OPEX costs are related to operations will include cost of training, onshore and offshore logistics, health and safety inspections, insurance and maintenance costs (insurance and maintenance are currently very high for FLOW) and will focus on turbine and substructure maintenance and service. Overall OPEX cost is estimated to be 28.2% of LCOE for fixed-bottom OSW, and 36.6% for FLOW. This can be reduced using advanced monitoring techniques and inspection techniques such as automation and remote monitoring.

The key drivers of cost include:

- Site conditions: Typically, FLOW in deeper water require more expensive mooring systems and anchoring solutions and have increased installation cost. Projects further from the shore take longer to access and, due to the stronger metocean conditions, have reduced availability windows for repair, installation and maintenance, which adds cost and increases downtime, reducing energy production.
- Supply chain evolution and development from increased investment, infrastructure upgrades and innovative mass production techniques will reduce production times and reduce costs through economies of scale.
- Technology development has been a major driver in reducing the cost of fixed-bottom OSW. New technology has enabled increasing turbine size at a commercial scale through advanced materials development and manufacture, installation and maintenance innovations.

Alongside technology advancement, the standardisation and industrialisation across the sector, combined with learning by doing, improved risk management and government support, has enabled significant cost reduction and scaled deployment. Learnings and collaboration are a major takeaway from fixed bottom technology development and will continue to assist with cost reduction through collaborative joint industry programs programmes.

Recent advancements in AI technology are also contributing to cost reductions in the offshore wind industry. The incorporation of digital, autonomous, AI, and other applicable technologies will enable cost savings through improved wind farm operation and control.

Development and project management: this includes development and consenting services, such as environmental impact assessments, environmental surveys to assess impacts on marine animals, resource and metocean assessment, geological and hydrological surveys, and engineering and consultancy. For fixed OSW, this is estimated to account for around 3.5% of the LCOE. For FLOW, this is estimated to account for 2.5% of LCOE. Efficient and accelerated consenting can make major differences in the successful development of offshore renewables in lease areas, preventing project failure and accelerating new offshore renewables development to reach Net Zero. More accurate seabed and geophysical surveys of sites will

[48] NREL (2023) 2022 Cost of Wind Energy Review
[49] NREL (2024) Levelized Cost of Energy Comparison of Floating Wind Farms With and Without Shared Anchors

provide accurate detailed mooring requirements for floating wind, preventing delays and costly mistakes in anchor selection.

Decommissioning costs are noted as new lease areas now require decommissioning plans. Costs will include decommissioning of the turbine, foundation, cables and substations. For fixed-bottom OSW this is around 1.8% of LCOE. For FLOW, this is 2.5% of LCOE. Although this is a low LCOE cost, decommissioning has many unknowns as a limited number of large sites have been decommissioned so far. Life extension or repowering of an OSW asset could lead to significant profit gains towards the end of an asset's life and reduce the amount of new renewables required to reach Net Zero.

Tidal Stream

Due to the lower maturity of the tidal stream industry, there is limited data on how the LCOE would break down at commercial scale. Currently, CAPEX is a significantly high percentage of tidal stream LCOE when compared to OSW due to the current small size of the industry, but this will reduce with economies of scale; turbine size increase and increased farm size[50]. Tidal stream's current high cost of £260/MWh could come down to £78/MWh by 2035.[51] There are some reports that estimate a LCOE of £60/MWh could be reached by 2042 and £50/MWh by 2047.[52]

CAPEX: Capital expenditure, including development expenditure, and the cost of finance for the CAPEX. This includes finance for the turbine, foundations plus anchors and moorings depending on the tidal stream device, and tower and balance of plant including the cost of export and array cables, as well as cable protection. CAPEX also includes the turbine foundation, offshore substation, and onshore substation.

OPEX: Operations will include cost of training, onshore and offshore logistics, health and safety inspections, as well as insurance. Maintenance costs will focus on turbine maintenance and service.

Some key drivers of cost for tidal stream include:

- Increased size of turbines to capture more energy from tidal currents. This potential is more limited relative to OSW due to environmental constraints, restrictions in the number of fast-flowing areas suitable for tidal energy, and impact on marine life.[53]
- Advanced control systems to increase the energy capture of turbine blades.

[50] Ocean Energy Europe (2022) Tidal stream energy could dive to record low cost if opportunity is seized
[51] European Marine Energy Centre (2022) Press release: New report highlights promising tidal energy cost reduction pathway
[52] European Marine Energy Centre (2022) Press release: New report highlights promising tidal energy cost reduction pathway
[53] Neil, S. P. et al (2021) A review of tidal energy — Resource, feedbacks, and environmental interaction

- Development of a commercial-scale supply chain and infrastructure. This is of considerably smaller scale in comparison to OSW, requiring large development and investment.
- Grid connection network infrastructure development: Tidal stream sites are often in remote locations with limited grid infrastructure.[54] Efficient and reliable grid connections need to be established and are vital for larger scale commercial tidal energy projects. This includes subsea cables and onshore substations to transmit the generated electricity to the grid, consistent with system resilience and security of supply.
- Maintenance and monitoring facilities: Regular maintenance and monitoring are crucial for the long-term operation of tidal stream generators. Advanced condition monitoring systems help in predicting and preventing failures, thereby reducing downtime and operational cost.
- Initiatives by the European Union (Horizon Europe) and cross-country collaboration between France and the UK TIGER (Tidal Stream Industry Energiser Project) and other bodies have accelerated the development of large-scale tidal projects.

[54] University of Strathclyde (2014) Tidal Methodology - Site Selection

System benefits from innovation in offshore renewables

System modelling to assess the potential impact of innovation in key net zero technologies was conducted using UKTIMES, an energy system model of the UK that was developed by UCL and the UK Department of Business, Energy and Industrial Strategy (now the Department for Energy Security and Net Zero or DESNZ). For each of the selected technologies, three levels of innovation were developed representing a low, medium and high innovation case for the technology. The low innovation level represents a business-as-usual case where innovation follows recent trends or is generally limited, whilst the high innovation case represents significant innovation in the technology to decrease costs and improve efficiencies.

The low, medium and high innovation cases were each run against three different hypothetical scenarios which were developed by DESNZ to represent potential routes to net zero for the UK, namely Minimally Constrained, High Hydrogen and High Diversification. They do not necessarily represent government policy but were selected due to their differing constraints which provide a more diverse set of outputs and insights. A summary of each is presented below, a more in-depth description can be found in the EINAs methodology report.

- **Minimally Constrained:** Designed to show the largest potential impacts from innovation investments by minimising the number of constraints on the energy system. UK Government data assumptions are used across the scenario.
- **High Hydrogen:** Based on the Minimally Constrained scenario, with a range of constraints added to force hydrogen use across the economy. These constraints are based on estimates of H2 demand ranges in the DESNZ Hydrogen transport and storage networks pathway policy paper published in 2023, and provisional figures from DESNZ sector teams that are set to be refined further for CB7. A maximum hydrogen consumption in each sector and a minimum overall level of consumption is applied in each year from 2035 to 2050.
- **High Diversification:** Based on the Minimally Constrained scenario, this scenario aims to be more energy secure through two means, 1) limiting imports of key commodities to reduce UK reliance on overseas resources, and 2) diversifying resource and technology use across the economy to limit the impacts of any supply interruptions, price rises or technology failures.

The results presented below demonstrate the potential impact of innovation for a specific technology on achieving net zero within the confines of the scenario. In each model run for a specific technology, all other technologies are held at their low innovation case so that the impact on the UK energy system of that technology can be isolated. Changing the costs and performance of technologies through innovation can have both direct and indirect consequences:

- Direct consequences are a reduction in cost or an improvement in the quality of the energy service supplied by the technology. Only cost reductions are examined in the UK TIMES energy system model.
- Indirect consequences are changes to the wider system caused by a relative change of cost of a technology relative to other technologies. If the deployment of a technology increases due to a lower cost and the deployment of alternative technologies reduces then a cost reduction will be realised. This cost reduction will be lower than the direct cost reduction that would have occurred if the new technology had already been used at lower innovation levels. More profound changes could also occur across the energy system, for example changes in total electricity consumption or in the relative rate of decarbonisation between sectors of the economy.

We have not considered rebound effects where lower costs of energy due to innovation investments lead to higher energy service consumption. An elastic demand version of UK TIMES could be used to explore potential rebound effects of innovation investments.

The below analysis only refers to offshore wind and tidal stream. It should be noted that, given these results are an output of the system modelling and the three hypothetical scenarios developed for the EINAs, they do not reflect UK government deployment targets and ambitions.

Offshore Wind

High levels of innovation in offshore wind, compared to low innovation runs, can reduce the cumulative cost of achieving net zero by 2050 by £36 billion, in the Minimally Constrained scenario, or £41.1 billion in the High Diversification scenario. Offshore wind is a critical technology to reach net zero in the UK, and innovation could enable significant cost savings. Across all three scenarios, innovation in offshore wind leads to significant reductions in total energy systems costs. It has the highest impact in the High Diversification scenario, which deploys more offshore wind as a result of the constraints applied in this scenario to diversify resource and technology use and to limit energy imports.

In the “Minimally Constrained” scenario offshore wind achieves 540 to 550 TWh of generation in 2050 when innovated in isolation at the medium and high levels, respectively. Offshore wind generation varies significantly as different innovation levels are selected for other technology families in isolation (i.e. across 43 Minimally Constrained runs), between 340 and 550 TWh for 2050 (see Figure 3). Model runs with high levels of innovation in technologies like electrolysis and heat pumps, which rely on low-carbon electricity, increase the value of offshore wind and accelerate its deployment in the energy system. On the other hand, high innovation in technologies like Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS) reduces energy system dependence on offshore wind. These sensitivities suggest offshore wind is a crucial technology for decarbonising the UK energy system as it plays a key role in energy supply even at the lowest innovation levels; it is the cheapest source of electricity in the model in 2050 and is closely interconnected with the innovation of other EINA technologies, scaling up to meet higher electrification demand.

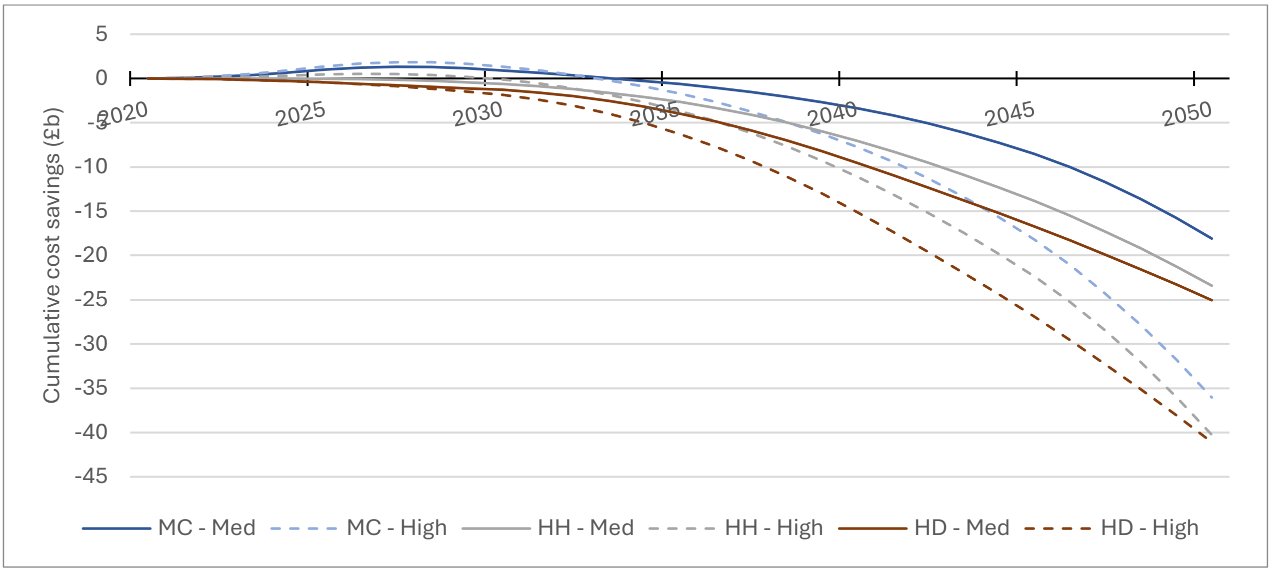

Figure 2: Cumulative cost savings (in real 2022 £) to 2050 for differing levels of innovation in OSW, compared to base all low innovation case

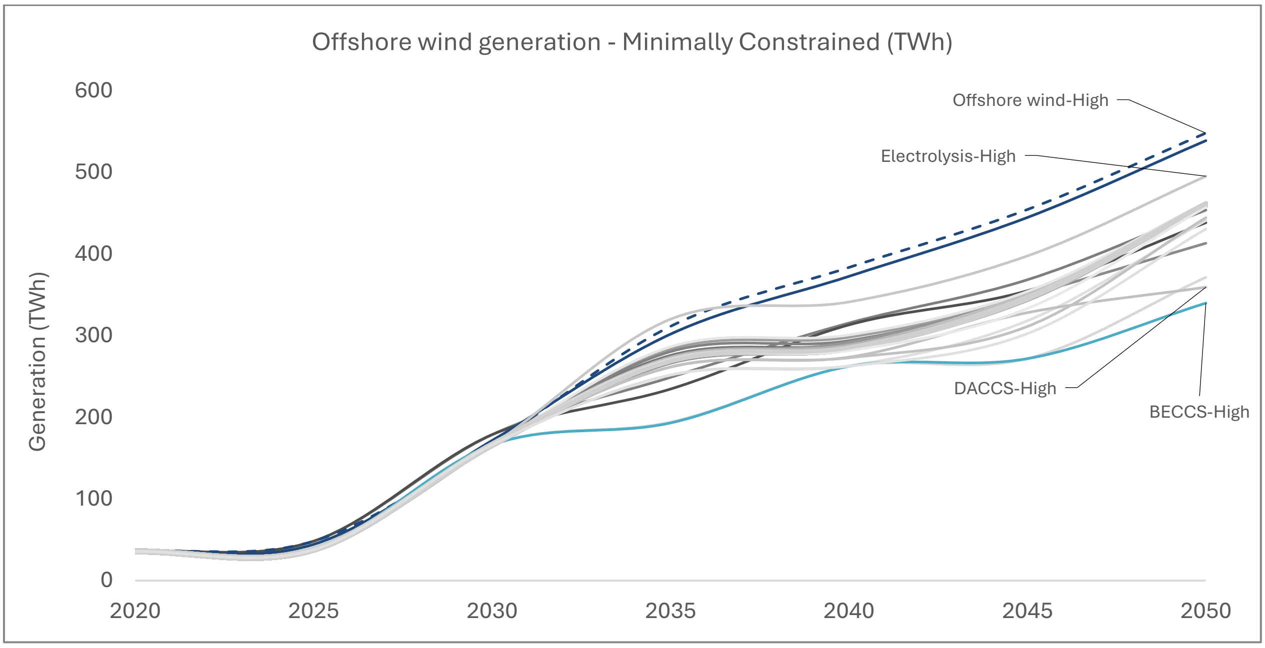

Figure 3: OSW generation (TWh) over time across different innovation runs (low, medium and high levels for each technology) in the Minimally Constrained scenario

Offshore wind generation for "High Hydrogen" and "High Diversification" scenarios follows a similar pattern. Yet the overall offshore wind generation is higher in both scenarios in comparison to "Minimally Constrained" scenario, partly due to the higher deployment of hydrogen electrolysers. Generation in the offshore wind technology family innovation runs reach a maximum of 560 TWh and 530 TWh, respectively, for the "High Hydrogen" and "High Diversification" scenarios. The accelerated penetration of offshore wind between 2035 and 2045 is particularly pronounced in High Diversification compared to the other scenarios.

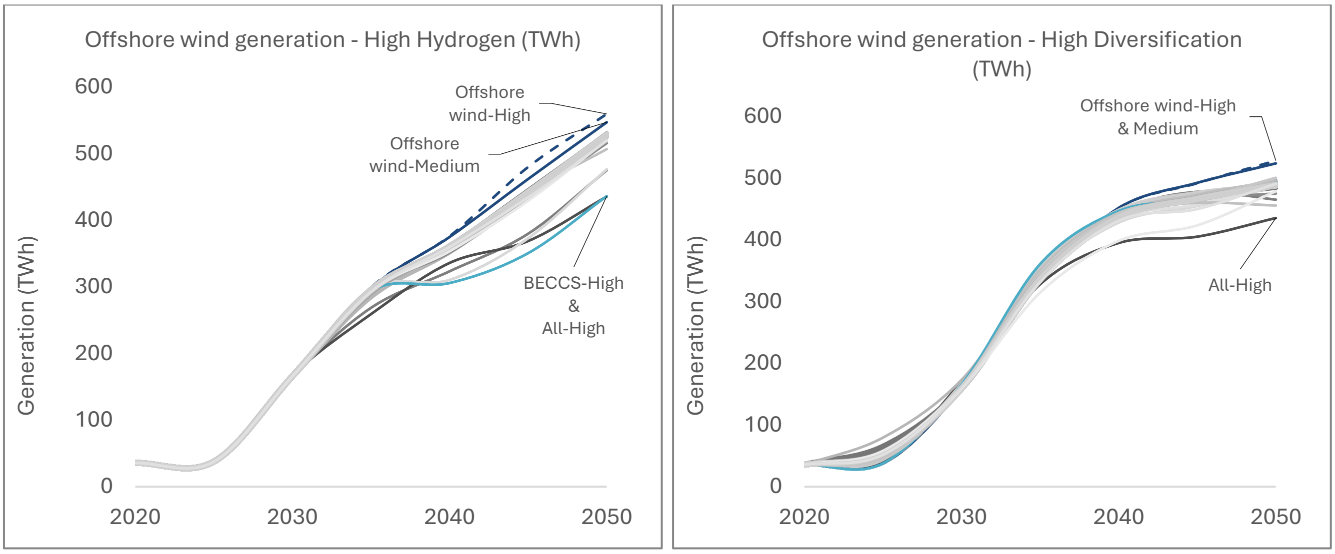

Figure 4: OSW generation (TWh) over time across different innovation runs (low, medium and high levels for each technology) in the High Hydrogen and High Diversification scenarios

The installed capacity of offshore wind does not vary significantly across the model runs, particularly through to the early 2030s to 35-40 GW. Beyond that, High Diversification has a slightly higher rate of deployment before levelling off with Minimally Constrained and High Hydrogen both catching up after 2045, reaching 92-109 GW by 2050.

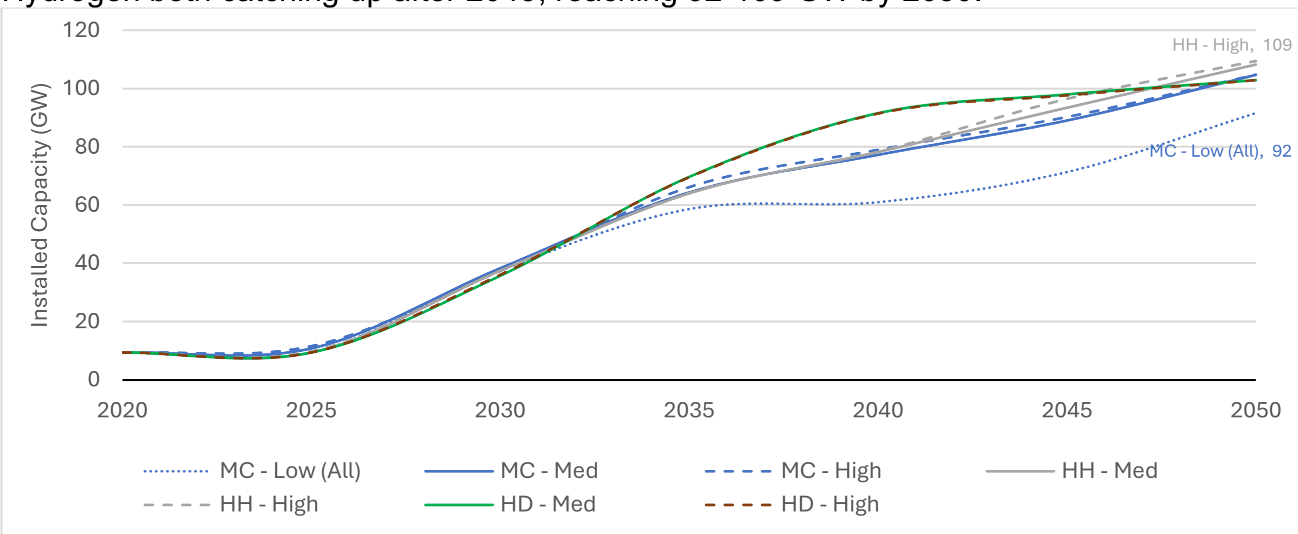

Figure 5: Installed capacity (GW) of OSW by innovation level and scenario

By running the model with innovation levels set at low for all technologies, then increasing the innovation level of offshore wind to medium or high, we can see the effects on the deployment of other technologies. Innovation in offshore wind has relatively minor impact on generation of a range of other EINAs technologies compared to the all low innovation case in the “Minimally Constrained” scenario. Higher levels of generation from offshore wind reduces the system’s need for generation from hydrogen technologies and consequently reduces the need for hydrogen transportation. Similarly, the need for DACCS to lower carbon emissions is also reduced. Conversely, BECCS generation is marginally increased in these model runs through innovation in offshore wind.

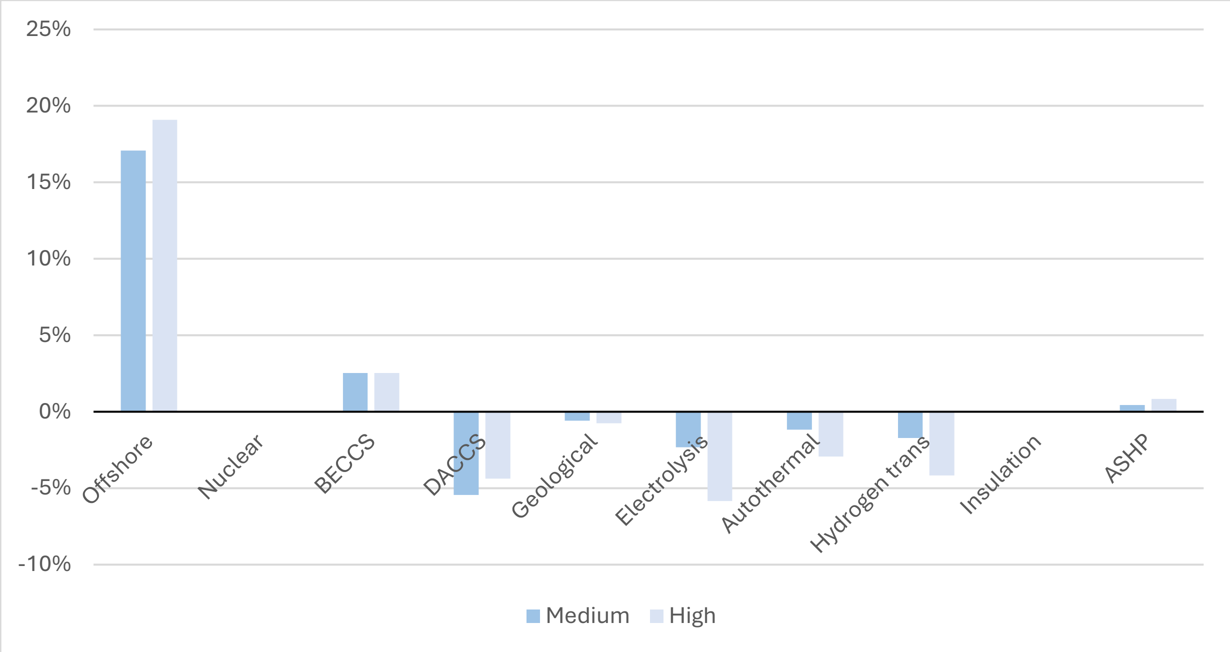

Figure 6: Impact of innovation in OSW on deployment of other technologies in 2050 compared to low innovation level run for the "Minimally Constrained" scenario
Note – tidal, depleted gas field storage, gas-CCS, H2 turbines, and Ground Source Heat Pumps (GSHP) have all been excluded as their deployment is either zero or so minimal as to have no meaningful comparison. Additionally, short and medium storage system modelling is performed using the HighRES model and so are also excluded.

As expected, innovation plays a significant role on the levelised cost of electricity (LCOE) across all scenarios. The levelised cost of electricity for floating offshore wind reduces to a greater extent in the medium and high innovation levels (48% and 56% respectively) compared to the low innovation run (42% reduction).

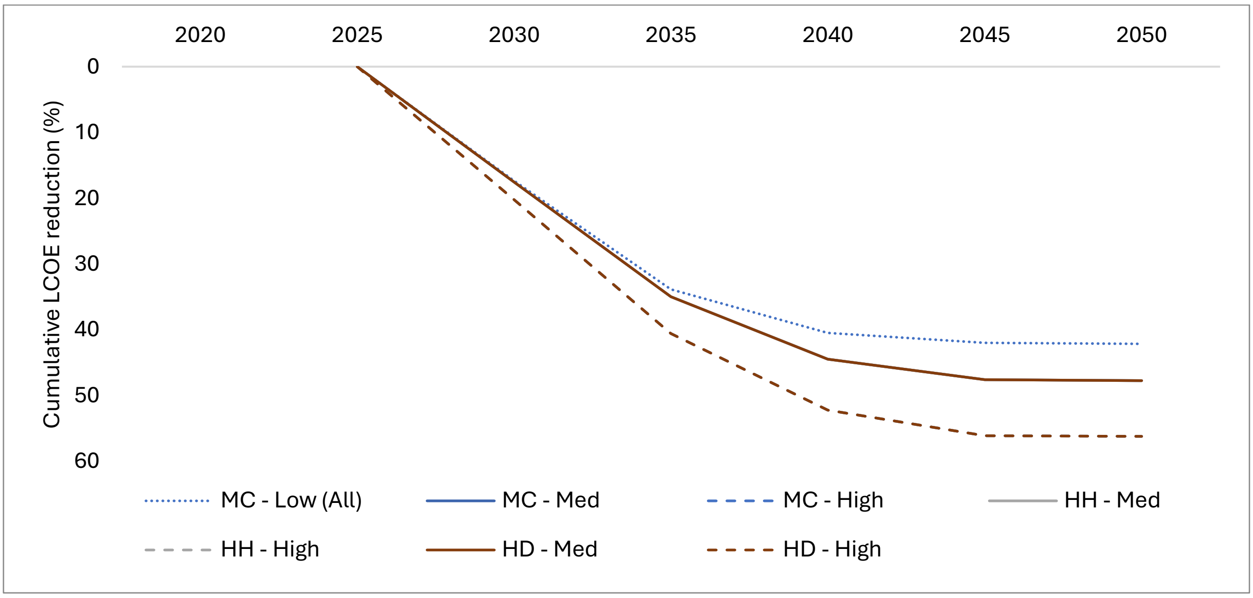

Figure 7: LCOE for OSW by innovation level and scenario over time

Note on 2025 and near-term OSW figures: In UK TIMES, the 2020 offshore wind capacity reflects an average across 2018–2022, only capturing some of the recent growth in deployment in the UK (since the end of 2020 there has already been an approximate 55% increase in UK offshore wind deployed capacity by the end of 2024). The UK TIMES 2025 figure represents an average across 2023–2027. In scenarios such as Minimally Constrained and High Hydrogen, capacity in 2025 appears relatively flat compared to 2020, which does not reflect most recent trends in the sector. In the High Diversification scenario, the 2025 capacity figure reaches 14.3 GW, which is closer but still below the 16-18 GW capacity expected by the end of 2025. Therefore, near term offshore wind projections represent an underestimation of activity compared to the latest available evidence. These outcomes reflect available data at the time of modelling and the model's cost-optimisation to meet energy demands across the economy and the carbon budget for the 2025 period. While near term figures are lower than most up-to-date expectations and do not include recent increased policy ambitions[55], post-2030 modelled figures provide a useful basis for long-term energy systems analysis as the model meets projected energy demand and Carbon Budgets.

Tidal Stream

Tidal has a limited role in the majority of scenarios in UK TIMES. Tidal stream reaches 6 GW of capacity by 2050 in the technology-specific high innovation level run in the "High Diversification" scenario, reaching the cumulative capacity limits in the periods 2040 and 2050. This run is the only instance of tidal energy deployment across all modelled runs.

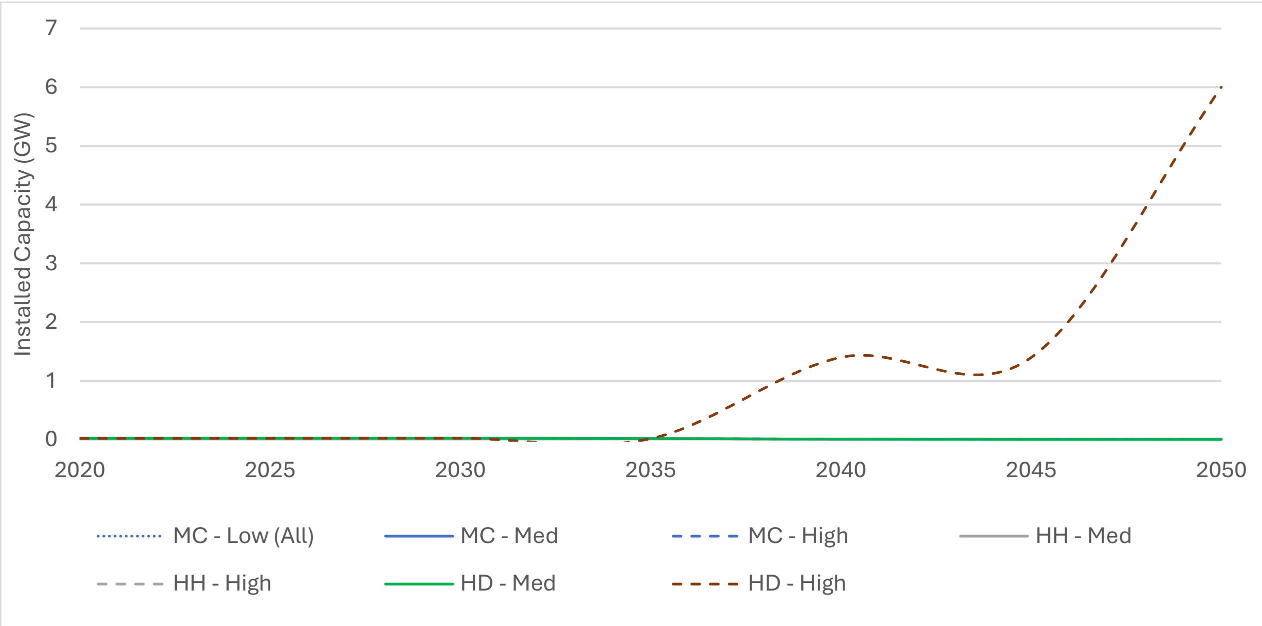

Figure 8: Installed capacity (GW) of tidal stream by innovation level and scenario

[55] Department for Energy Security and Net Zero (2025) [Energy Trends: UK renewables - GOV.UK]

Due to its limited deployment, innovation in tidal stream only creates a cost saving to the overall energy system for the high innovation High Diversification run where it is deployed to meet the diversification constraints. Cumulative cost savings for this run reach £10.5 billion.

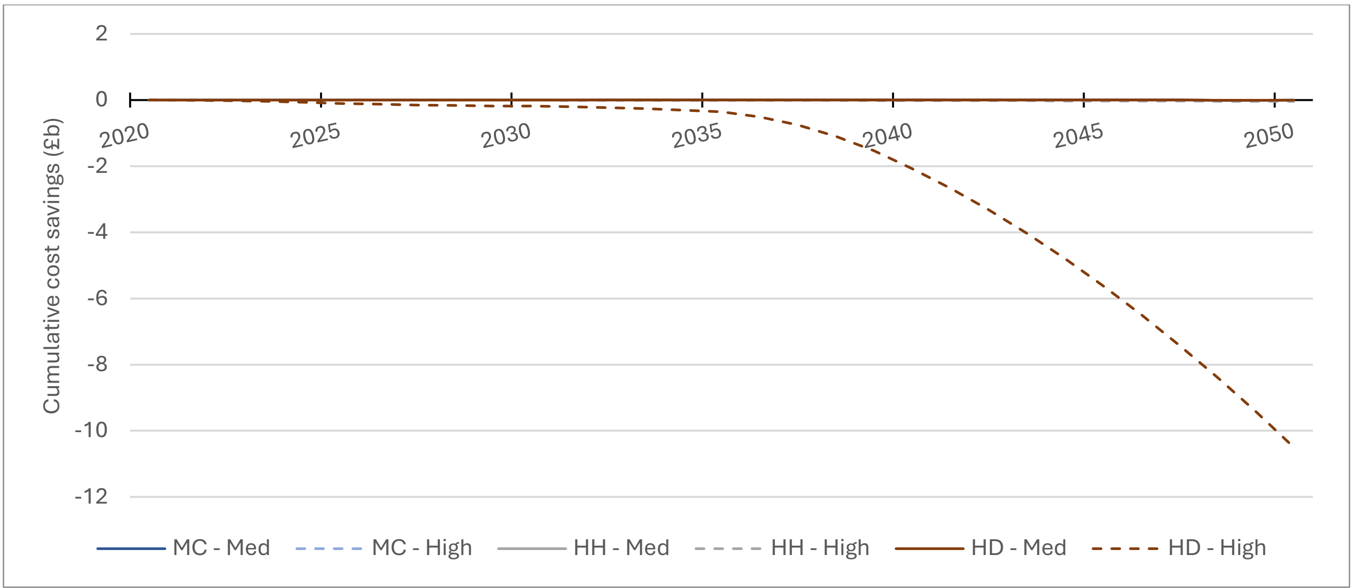

Figure 9: Cumulative cost savings (in real 2022 £) to 2050 for differing levels of innovation in tidal stream, compared to base all low innovation case

Investment in innovation significantly reduces the levelised cost of tidal by 2050. Reduction in LCOE for tidal for the medium and high innovation levels are 57% and 71% respectively, compared to 49% in the low innovation runs. However, the LCOE for tidal is still significantly higher than for offshore wind and many other generation technologies. This is aligned with wider research on tidal stream technologies that indicate that significant investment is required to further bring down costs and make the sector competitive with alternatives.

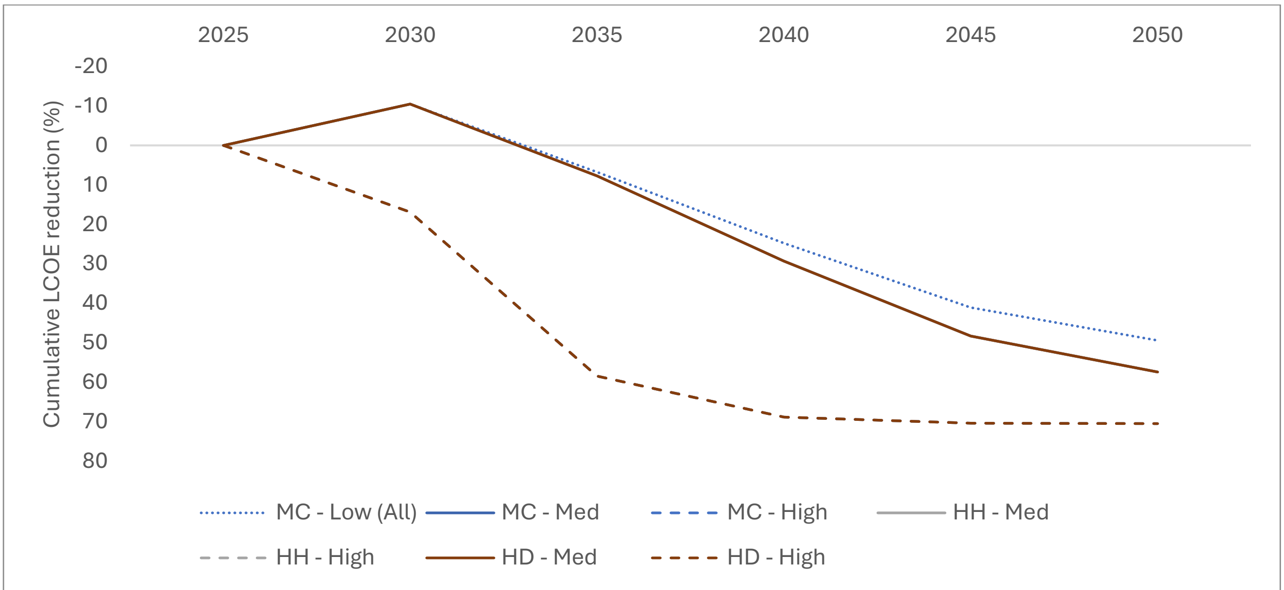

Figure 10: LCOE for tidal stream by innovation level and scenario over time

Market innovation barriers and enablers: deep dives

As part of the EINAs, a barriers and enablers assessment was carried out across the prioritised technologies to understand the factors which should be considered in addition to technology innovation. This included qualitative analysis across eight variables, which included an assessment and rating to indicate the relevance and risk of each barrier to the deployment and scale up of the technology. The eight variables assessed were:

- **Enabling infrastructure**: For fixed-bottom OSW, there is existing infrastructure at a commercial scale. However, for FLOW and tidal stream, there Is limited established infrastructure, and upgrades will be required, for example increased port capacity to facilitate assembly of onshore storage and marshalling for FLOW. To facilitate scale up of OSR, increased grid capacity and connections will be required, particularly where generation is in remote locations.
- **Regulatory environment:** There are existing regulatory bodies for OSW, with clear and well-established industry regulation and guidance. However, complex consenting processes can extend planning timelines and create delays in deployment.
- **Stakeholder acceptance:** Fixed-bottom OSW farms are well established, and key stakeholders have a strong understanding of the risks. There is some resistance from the public in relation to environmental and visual impacts.
- **Availability of funding and investment:** Fixed-bottom OSW has a strong track record and there are significant investments. There is funding available for FLOW, but funding and investment is challenging to obtain for tidal stream, as most investment is targeted at OSW.
- **Business model viability:** Fixed-bottom OSW has a well-proven business model, although increasing costs and interest rates have introduced challenges. FLOW and tidal stream need further technological innovations to reduce cost, increase reliability and reduce LCOE.
- **Resource availability:** Material costs for OSR have increased significantly, and expansion of fabrication facilities will need to increase in speed and scale to enable accelerated deployment.
- **Supply chain:** The UK supply chain is a major barrier to the development of OSR technologies at the scale required to achieve Net Zero targets. Worldwide, the supply chain has been experiencing challenges relating to the high costs of raw materials, reduced profits and high uncertainty.
- **Skills and training:** There is a shortage of skilled workers in the OSR sector. Further training across technical and scientific roles will be needed to facilitate expansion of OSR. Increasingly, this workforce will need to be located or deployed to remote coastal

locations, offering an opportunity to bring high quality employment and economic growth to these areas.

Following assessment across these key factors, the three most highly rated barriers were selected for further analysis. For OSR, the focus areas selected were supply chains, skills and training, and regulatory environment (consenting). This section summarises and expands on the key barriers and enablers for the offshore renewable energy technologies, which can be considered alongside the priorities for technology innovation.

Deep dive 1: Supply chain

The UK supply chain is a major barrier to the development of renewable offshore technologies at the scale required to achieve Net Zero targets. Without addressing these supply chain issues, offshore renewable energy will not be able to achieve its potential contribution to the UK's decarbonisation. While the UK has become a leader in fixed OSW, the country has missed considerable supply chain OSW opportunities. A recent analysis by the Offshore Wind Growth Partnership found that the UK could capture up to £92 billion in economic value from OSW by 2040 if the right actions are taken to strengthen the supply chain.[56] With the development of new technologies such as tidal stream, there is an opportunity to support a strong domestic supply chain from an early stage.[57] If 6GW of tidal stream (and 6GW of wave) are deployed by 2050, the UK could harness economic benefits in terms of gross value added (GVA) of £41 billion. The £41 billion represents a robust domestic supply chain where most needs are met domestically.[58]

Capacity expansion

The UK and global supply chain capacity needs to expand at an accelerated rate to achieve offshore renewable targets. This has been difficult as the current worldwide supply chain has been experiencing challenges relating to the high costs of raw materials, reduced profits and high uncertainty.[59] Currently, the rate of expansion is not fast enough to meet the demand of near-term 2030 global targets.[60] While the UK has established a supply chain network for fixed wind, significant further investment and time is required to grow manufacturing facilities, vessel supply and port infrastructure. Infrastructure specific to the less developed offshore energy technologies, floating wind and tidal stream, will be particularly important as these existing supply chains are not currently scaled up. Areas for focus include the supply and development of high volage and dynamic cables synthetic rope and mooring equipment fabrication, quayside installation facilities, appropriate marshalling (storage of renewable assets in sheltered locations or on land before they are deployed), and storage areas which are suited to individual technology needs. Due to existing ports and harbours used by the Oil & Gas and

[56] Offshore Wind Industry Council (2023) UK Supply Chain Industry Analysis
[57] Serin E, Andres P, Martin R, Shah A, Valero A (2023) Seizing sustainable growth opportunities from tidal stream energy in the UK
[58] Supergen Offshore Renewable Energy (2023) Research and innovation for wave and tidal stream
[59] WTW (2023) Global Renewable Energy Supply Chain Risk Report
[60] Wood Mackenzie (2023) US$ 27 billion investment required to mobilise global offshore wind supply chain

fixed bottom industry and established manufacturing bases for fixed bottom wind and a skilled workforce; there is an opportunity for the UK to be the first mover in supporting commercial scale installations both floating wind and tidal stream if these supply chain challenges are addressed. However, without significant investment in the UK ports and manufacturing facilities, we may lose significant market share to Europe and even Asian markets, or global supply chain constraints due to worldwide expansion and suppliers' local markets saturating demand/capacity may lead to extensive UK OSR project timeline creep or cancellation.

Vessels

Support vessels for installation, maintenance and decommissioning of offshore renewables will be in major demand in the coming years. The International Energy Agency (IEA) estimates that major investment in vessels will be required to reach the global offshore wind capacity of 560 GW by 2024.[61] For example, global demand for offshore wind turbines installation vessels is projected to grow from 11 vessel years in 2021 to nearly 79 vessel years in 2030, outpacing the supply from 2024.[62] This is also driven by the increasing size of turbines. Larger turbines require larger and varied types of cranes and installation vessels which can lift heavier material higher. There are currently a limited number of vessels which can install turbines over 10 MW and there are no vessels able to install 14 MW+ turbines. [63] This may start to change in the near term with new vessel and crane upgrades in development.[64] Many existing vessels have moved from Europe to China, where there is significant demand for lower crane capacity vessels. Unable to install new and larger turbines, first-generation installation fleets have transitioned into maintenance and repair services for installed turbines.

For floating wind, this is an even more significant challenge. Large numbers of specific anchor handling vessels (AHV) for mooring system installation will need to be considered capable of handling larger mooring components such as large chain, scaling with the size of turbines, floating foundation and specific mooring system requirements. Vessels suitably equipped for major component exchange will be required if permanent rings cranes at suitable quayside port facilities to facilitate tow-to-port exchange are not close enough to lease areas.

Tidal stream will require specialistic multifunctional vessels to lower costs and cope with the demands of limited installation and maintenance windows associated with slack tide periods, when the current is low enough to perform interventions as the tide changes direction.

Quality control technology

Advanced technology, for example the innovative manufacture of turbine foundations, high voltage inter-array cables and advanced synthetics for floating platform moored technology

[61] IEA (2025) Wind
[62] Rystad Energy (2022) Bottlenecks Loom Unless Installation Vessels Keep Pace with Super-Sized Wind Turbines
[63] Rystad Energy (2022) Bottlenecks Loom Unless Installation Vessels Keep Pace with Super-Sized Wind Turbines
[64] Rystad Energy (2022) Bottlenecks Loom Unless Installation Vessels Keep Pace with Super-Sized Wind Turbines

(floating wind) will be essential to support supply chain expansion, reduce timescales and potential bottlenecks and offer cross-offshore energy cost-savings. Across all offshore renewables high quality control standards will be required as multiple manufacturing facilities will be needed as the industry scales up. If adequate quality controls are not in place across the supply chain, there is a risk of serial design or material defects, a major risk to offshore wind energy, as remediation across large-scale arrays may not be cost effective.

Deep dive 2: Skills and training

Skills and training will be essential to develop the workforce necessary to scale up offshore renewable energy. Highly skilled occupations required to accelerate deployment include scientists, asset managers, project managers, engineers and technicians. OWIC's 2023 skills report estimates a current UK OSW workforce of 32,257, and forecasts a workforce 104,401 by 2030 if the Clean Power 2030 Action Plan target of 50GW is met (estimates via the EINAs modelling suggest more conservative numbers as presented in the Business Opportunities section of this report).[65] In order to achieve this, the industry therefore needs to attract and retain around 10,000 people every year. Currently, the rate of growth of the workforce is slower than the rate needed to meet this target. The sector will also face competition for skilled workers from other relevant industries in the UK, as there is a shortage of skilled workers across a range of industrial sectors. Interventions to support the scale up of the workforce is therefore required to enable the deployment of offshore renewables.

This skilled workforce will need to be located in coastal and remote locations where offshore renewable energy infrastructure is situated, and so incentives may need to be implemented to support this. The location is of particular consideration for floating offshore wind, as this is in deep water further offshore typically further from larger populations, for example in north Scotland and the Celtic Sea, and for tidal stream in remote locations. However, this challenge also creates a potential opportunity to create economic value, long-term highly skilled jobs, and benefits to previously deprived or disadvantaged areas, particularly where existing jobs in polluting industries such as oil and gas may be at risk.

Key skills gaps and shortages for the UK's offshore renewables sector identified by OWIC include the following.[66]

Immediate skills shortages include:

- High level electrical skills, including Senior Authorised Persons.
- Digital skills, e.g. data analysts, scientists and engineers with an understanding of data analysis and presentation.
- Consenting skills, particularly amongst SNCBs and regulators but increasingly within the industry.

[65] UK Government (2024) Clean Power 2030: Action Plan: A new era of clean electricity
[66] Offshore Wind Industry Council (2022) Offshore Wind Skills Intelligence Report

- Marine and port-oriented skills.

Over the longer-term, anticipated skills shortages include: [67]

- Electrical technical and engineering skills (particularly substations, HV and cables). These will be exacerbated by the upgrading of the power network and the introduction of battery storage sites.
- Project management of large-scale projects with multiple contractors.
- High level digital specialisms including data analytics, artificial intelligence, robotics, digital engineering/science, machine learning, SCADA related skills, software development.
- On and offshore logistics.
- Construction resource for floating wind projects, which are anticipated to require high numbers of people in fabrication and welding.

The development of a skilled workforce for offshore renewables is therefore a potential barrier to realising the UK's offshore renewable energy potential, but also holds significant opportunity to bring economic value to remote and coastal areas which may be facing job losses with the phase out of traditional oil and gas industries.[68] Guidance and novel approaches such as the Energy Skills Passport enable workers to easily identify qualifications needed for specific roles in oil and gas and offshore wind, as well as mapping out potential future career pathways within the energy sector.[69] More details on the breakdown of jobs indirect and direct over time can be found in 4.3 Direct and Indirect Jobs section.

Deep dive 3: Regulatory environment: consenting

Consenting time is one of the major bottlenecks to implementing large-scale offshore renewables worldwide due to the lengthy and complicated permitting processes. Once a seabed lease area is awarded for offshore renewables, and before construction can begin, developers are required to obtain all necessary consents in relation to their projects and lease areas. This includes consenting for any offshore activities and any land-based activity and infrastructure requirements, including ports.[70] There are different consenting requirements for different offshore renewable technologies due to the nature of the physical environments (e.g. increased water depth and sites further offshore, shallow fast flowing near shore locations) and technology (movements of turbines, inter-array cables in water column) which mean that some renewable technologies, for example floating devices, raise specific challenges.[71]

[67] Offshore Wind Industry Council (2022) Offshore Wind Skills Intelligence Report
[68] Serin E, Andres P, Martin R, Shah A, Valero A (2023) Seizing sustainable growth opportunities from tidal stream energy in the UK
[69] Offshore Energies UK (2025) Energy Skills Passport launches, helping workers transition across the energy mix
[70] Offshore Renewable Energy Catapult (2021) Development and Consenting Process Risks and Opportunities Public Summary
[71] Offshore Renewable Energy Catapult (2021) Development and Consenting Process Risks and Opportunities Public Summary

The UK consenting processes vary across the administrations (England, Wales, Scotland and Northern Ireland) and depend on the location and energy generation capacity of the proposal. For commercial wind farms, the process from pre-application to final determination of the necessary consents is estimated to take from between 3-5 years.[72] In general, once the seabed lease is awarded, the consenting process involves:

- Stakeholder engagement through the consenting process across a broad range of stakeholders, environmental agencies, local communities and marine spatial users, such as fisheries and shipping in conjunction with marine traffic surveys.
- Extensive environmental surveys (birds, marine mammals) as part of habitats regulation assessment (HRA) in contingency environmental impact assessments (EIA); assessing the potential environmental impacts of the project and proposing mitigation measures.[73]
- Planning/project and infrastructure development signoff by the Planning Inspectorate of the Development Consent Orders (DCOs) specific to offshore renewables technology, including decommissioning of any assets.[74]

Some key consenting risks to OSW deployment identified by the ORE include:

- Insufficient regulatory resource to process applications or for case work: Under-resourced regulators can increase timescales for consent decisions, particularly with complex applications. A skilled workforce needs to be trained in consenting to ease the process.
- Lack of strategic and spatial planning in all geographic areas: There are varied marine planning processes across UK nations. Competition for sea space has indicated the need for greater spatial planning in offshore areas and potential prioritisation of activities, which would involve a substantial evolution in how marine planning is undertaken in all areas around the UK.
- Consenting complexity due to regional differences and multiple jurisdictions: Varied consenting requirements dependent on jurisdiction. Projects may straddle multiple jurisdictions with lack of understanding about how transboundary consenting and post-consenting will operate.

However, there are some ongoing major efforts to speed up consenting processes:

- The Planning and Infrastructure Bill is expected to address grid connection permitting bottlenecks through a ‘first ready, first connected’ system, alongside fast-tracked consenting process for major projects[75].
- Co-location and co-existence with, for example, fisheries, biodiversity preservation and other marine activity, such as aquaculture, could reduce consenting pressures by minimising spatial conflict.

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[72] The Crown Estate (2019) Information Memorandum Introducing Offshore Wind Leasing Round 4
[73] Society for Underwater Technology (2023) Consenting and Permitting in the UK
[74] UK Government (2021) Consents and planning applications for national energy infrastructure projects
[75] UK Government (2025) Planning revolution to fuel growth and make Britain energy secure - GOV.UK

- Incorporating evidence from ongoing projects or similar designs in local vicinities to make evidence-based decisions.
- R&D programmes such as the ORJIP programme help reduce consenting risks through increasing understanding of consenting activity.
- Increased support for R&D programs which reduce consenting risk, learning from existing successful approaches, as well as the upskilling and increasing numbers of a specific consenting workforce will be key to reducing consenting times and alleviating this bottleneck for offshore renewables.

Business opportunities in offshore renewables

Introduction

The purpose of this section is to explore the potential scale of the business opportunities for UK-based businesses associated with the national and global development of the offshore renewables sector (as elsewhere in this report defined as fixed and floating offshore wind and tidal stream technologies). Innovation will be a key driver in supporting the growth of this sector in the UK and realising these business opportunities, and therefore an important element to capture as part of this innovation assessment.

The section summarises the key findings from the development of a series of ‘business opportunities calculators’. These calculators integrate projections of domestic deployment of the three technologies, derived from scenario-based systems modelling (see Innovation analysis section), with assessments of the UK’s potential market share in overseas markets, informed by global modelling and literature reviews. They combine this understanding of potential deployment with assumptions around the cost structure and employment intensity of the different activities required for the manufacturing, deployment, operation and decommissioning of each technology to generate an understanding of the potential business opportunities in terms of:

- Gross Value Added (GVA) – a measure of the value generated by the production of goods and services. GVA can be thought of as broadly equivalent to the contribution of that sector/activity to Gross Domestic Product.
- Employment – Employment is measured in terms of jobs and includes both direct employment – the jobs associated with the construction, operation and decommissioning of the assets – and indirect employment – the jobs associated with the production of the goods and services needed by the workers with direct jobs i.e. jobs associated with the supply chain needed to construct, operate and decommission the assets.

The methodologies for the calculators, along with key caveats and assumptions, is available in the EINAs Technical Methodology report.

All results are illustrative of the potential business impacts of the particular innovative technologies in question. They are generated using a particular set of modelling outputs, assumptions and data available at the time of commissioning. The UK TIMES model used in this analysis drew on assumptions based on UK wind deployment data up to 2020, given it was commissioned in 2023 and UK TIMES only models 5-year intervals.

However, the offshore wind sector has seen a significant increase in both activity and ambition which has not been captured in this analysis. This includes a 55% increase in UK deployed offshore wind capacity since the end of 2020[76]. The Government has also set out its mission to become a Clean Energy Superpower, and under the Clean Power 2030 Action Plan aims to deliver up to 43-50GW of Offshore Wind by the end of 2030[77]. For this reason, the modelling results should rather be considered in the context of meeting energy system needs in 2050 and overall long-term business opportunities of net zero. Recent government analysis reflecting this increased ambition suggests that the offshore wind sector could support up to 100,000 direct and indirect jobs in Great Britain by 2030.[78]

It is important to stress that the results are specific to the technologies of focus for the report, rather than indicating the GVA and employment opportunities for the wider sector within which these technologies may often be categorised. As such, care should be taken when comparing the figures presented below with estimations which cover the entire sector and use different scenarios and models. An "additional potential" figure is included within graphs to note additional offshore wind opportunities, reflecting the possibility of favourable global market developments which can provide further growth.

Results do not reflect UK government targets or ambitions for either deployment or the business opportunities that might be realised. All monetary values in this section refer to 2022 GBP unless otherwise specified.

Offshore renewables market landscape

UK market position

As discussed earlier in this report, the UK has a strong competitive advantage in offshore renewable technologies and is already reaping significant business benefits as a result. The UK accounted for around 20% of the world's fixed offshore wind capacity as of 2023, developed the world's first floating offshore wind farm and the first commercial-scale tidal turbine, and has the largest floating offshore wind pipeline in the world based on confirmed seabed exclusivity.[79], [80], [81], [82] This domestic deployment, coupled with the UK's strong skillset in marine engineering developed through the oil and gas industry, has given UK-based companies a strong foothold to compete in international markets. For example, in a 2024 report, RenewableUK reports that the UK-based offshore wind sector exported between £1bn and £2bn per year.[83] This is broadly consistent with ONS LCREE data reporting exports from the offshore wind sector of approximately £2bn a year on average between 2021-2023.[84] Reflecting this economic activity, ONS data for 2023 suggests that direct employment in the

[76] Department for Energy Security and Net Zero (2025) Energy Trends: UK renewables - GOV.UK
[77] Department for Energy Security and Net Zero (2024) Clean Power 2030 Action Plan - GOV.UK
[78] Department for Energy Security and Net Zero (2025) Industrial Strategy: Clean Energy Industries Sector Plan
[79] The Crown Estate (2023) UK Offshore Wind Report 2023
[80] Offshore Wind Scotland (Accessed: 2025) Floating Wind in Scotland
[81] UK Parliament (2023) Strangford Lough: Tidal Wave Energy
[82] Renewable UK (2025) Floating Offshore Wind: Anchoring the next generation offshore
[83] Renewable UK (2024) 2024 Offshore Wind Industrial Growth Plan
[84] ONS (2025) Low carbon and renewable energy economy first estimates dataset

UK offshore wind sector, measured in full-time equivalents, was around 16,400, 160% higher than in 2014.[85] Other industry reports suggest higher employment levels.[86] Although much smaller, there is further UK-employment in tidal steam with around 200 people employed by tidal stream (and wave energy) companies in 2020.[87]

Global offshore renewable energy market

This positioning puts the UK in a strong position to capture a material share of what is expected to be a rapidly growing global market for offshore renewable energy technologies. For example, 4C has developed bottom-up, site-by-site assessment of the potential for offshore wind deployment over the period to 2040, taking into account current market conditions. Using this analysis and then extrapolating a similar trend to 2050 suggests that the total capacity of fixed offshore wind outside of the UK could grow at a compound annual growth rate (CAGR) of 11% per year, from around 30GW in 2020 to more than 800GW by 2050. The growth rates are even higher for floating offshore wind, at 28% per year[88], and tidal stream, at 36% per year[89], although in both cases this is from a very low base. The total global capacity associated with floating wind and tidal in 2050 - excluding UK deployment - could be around 200GW and around 115GW, respectively.

Building on this discussion, the quantitative analysis below is based on the assumption that the UK can maintain its current position in the export of offshore wind technologies, and supply around 5% of the total global market in value throughout the period to 2050. This market share is assumed to vary across different activities within the supply chain, based on current export performance. The analysis further assumes that the market share of UK-based firms in relation to the UK's deployment of offshore wind can reach the levels projected by BVG Associates for 2030 and maintain that share thereafter.[90] For tidal energy, analysis by the London School of Economics (LSE) suggests that UK-based firms captured around 2% of the global export market in 2020 but that this share has been declining over time. In this analysis we assume that this trend continues with the 2% share in 2020 declining linearly towards 1% by 2050.[91] As with offshore wind, it is assumed that UK-based firms are able to capture higher or lower percentages than this central value for specific supply chain activities, based on current export performance. UK tidal stream projects are assumed to have 80-95% domestic content, based on previous analysis for DESNZ by Ricardo.

[85] Ibid.
[86] Offshore Wind Industry Council (2022) Offshore Wind Skills Intelligence Report
[87] Serin E, Andres P, Martin R, Shah A, Valero A (2023) Seizing sustainable growth opportunities from tidal stream energy in the UK
[88] These projections have been developed using the same source and method as for fixed offshore wind.
[89] These projections have been derived from a TIMES modelling analysis in which net zero is achieved by 2050 and cost inputs meet the European Commission's Strategic Energy Technology Ocean Energy Implementation Plan targets. For more details see: Ocean Energy: Key trends and statistics 2020
[90] Offshore Renewable Energy Catapult (Accessed: 2025) Guide to an offshore wind farm
[91] Serin E, Andres P, Martin R, Shah A, Valero A (2023) Seizing sustainable growth opportunities from tidal stream energy in the UK

Offshore renewables business opportunity analysis

Gross Value Added (GVA)

The business opportunities calculators suggest that, assuming a 'medium' level of innovation, GVA across the EINAs offshore renewables technologies will grow strongly across all scenarios. Real terms GVA growth over the projected years imply CAGR of approximately 7% in all three scenarios. There is little variation between the different scenarios, with GVA in the High Diversification scenario accelerating faster than in the Minimally Constrained and High Hydrogen scenarios. This matches the slight difference in technology deployment across the different scenarios.

Between 2040 and 2050 export markets are expected to become increasingly important as the rest of the world scales up its deployment of offshore renewables. By 2050, export markets are responsible for approximately 65% of modelled sectoral GVA. Fixed offshore wind accounts for the bulk of this opportunity. Floating offshore wind becomes an increasingly important export market opportunity, growing from a negligible contribution in 2025 to potentially accounting for around 30% of the GVA derived from exports by 2050. GVA associated with tidal exports remain more modest throughout the period.

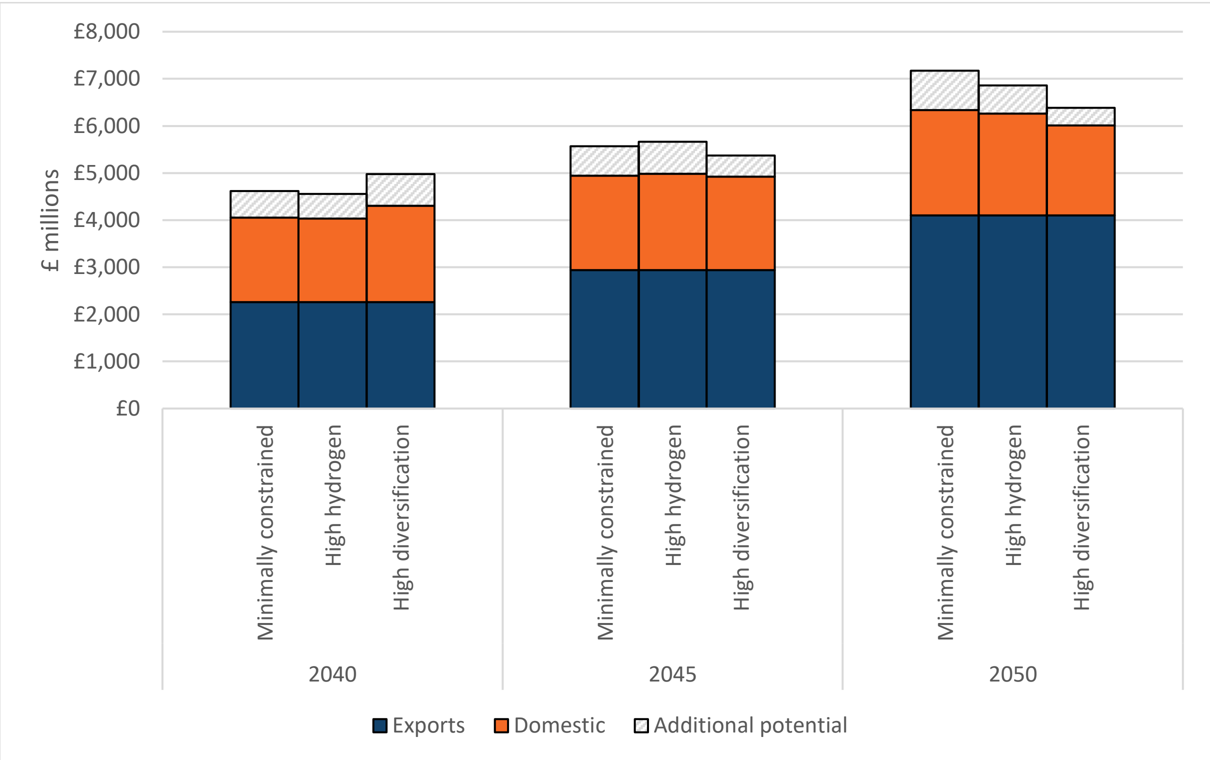

Figure 11: GVA by scenario by market

Note: The figure reports outputs associated with a medium level of innovation.

The modelled Minimally Constrained and High Hydrogen scenarios, there is relatively modest difference in GVA between the different innovation levels, with GVA in 2050 varying by only 3-5% between the innovation level where GVA is highest and that where GVA is lowest. However, in the High Diversification scenario, the differences between the innovation levels by

2050 are more pronounced: in particular, GVA in 2050 is about 20% higher in the high innovation level than in the low and medium innovation levels. This reflects that in this scenario/innovation level combination there is estimated to be an additional 4.5GW of tidal stream capacity added between 2045 and 2050, generating additional GVA. This is the only time period and scenario/innovation level combination where the systems modelling suggests that tidal capacity will increase beyond the 0.12GW of tidal capacity in the known pipeline at the time of modelling.

Focusing specifically on 2040 and 2050, Figure 12 shows that fixed offshore wind makes the largest GVA contribution. Floating offshore wind accounts for an increasing share of GVA over time, rising from an average across scenarios of 3% (2025) to 25% (2050). Tidal energy makes a small contribution to GVA throughout the period, relative to offshore wind. Floating offshore wind makes the greatest contribution to GVA in the Minimally Constrained scenario (31% by 2050), reflecting the relatively higher deployment of these technologies in this scenario.

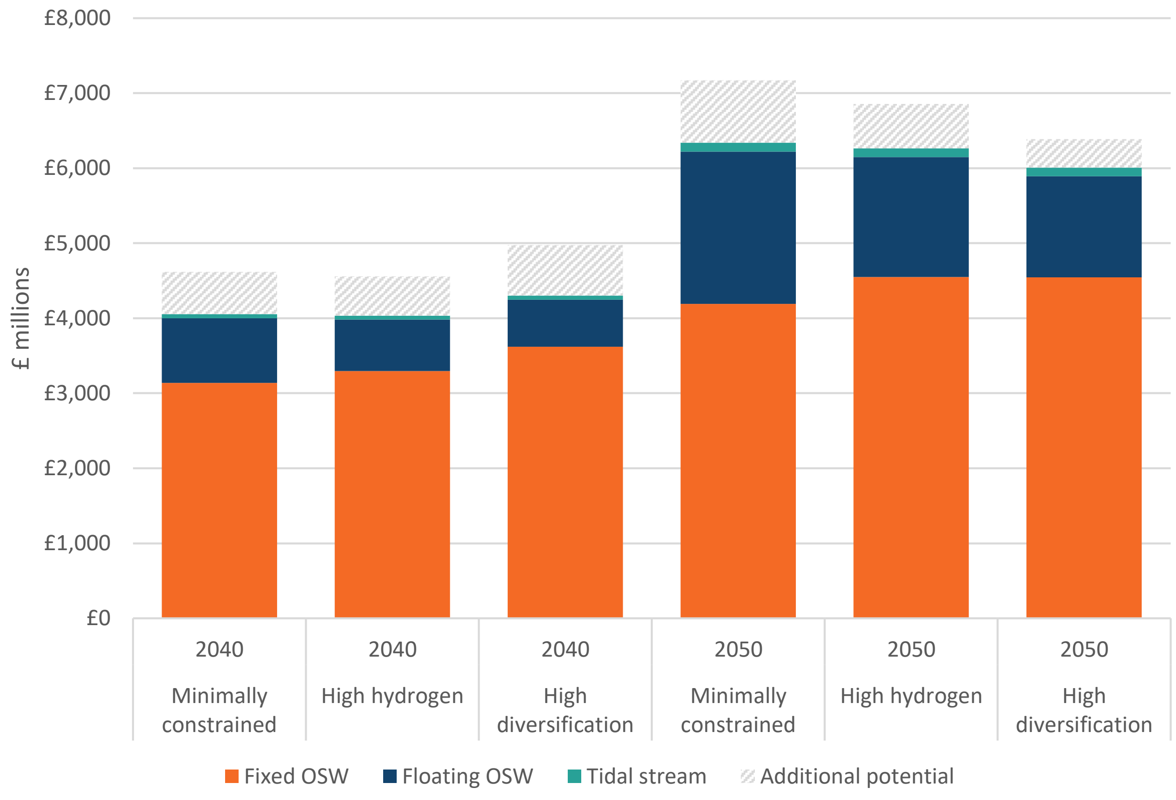

Figure 12: GVA by scenario by technology

Note: The figure reports outputs associated with a medium level of innovation.

Direct and indirect jobs

Recent evidence in offshore wind and impact on business opportunity estimates

Estimates within the EINA analysis are based on specific deployment scenarios and assumptions with significant levels of uncertainty. The offshore wind sector has been growing rapidly in recent years, with a 55% increase in UK deployed capacity since the end of 2020, meaning that lengthy modelling exercises such as those carried out as part of the EINAs (started in 2023) often rely on data that is soon superseded.

Since the development of the EINA analysis, more up-to-date datasets on both domestic and international offshore wind deployment have become available. The government's ambitions for the offshore renewables sector have also evolved, with a significantly increased ambition as part of the Clean Power by 2030 ambition, reaching between 43-50GW of offshore wind compared to approximately 35GW originally modelled in UK TIMES as part of this analysis.

As a result, early year projections by the EINA offshore wind analysis now significantly underestimate the level of GVA and job opportunities that could be achieved by 2030, given the latest evidence and Government's deployment ambition. Therefore, only longer-term offshore wind projections from the EINAs should be considered when examining business opportunities from the sector.

For better near-term estimates of business opportunities, the latest 2030 estimates published as part of the Industrial Strategy should be considered. These rely on the same EINA methodology, but present optimistic 'upper' estimates for 2030, using more up-to-date information and assumptions. A more detailed note on the assumptions and methodological details of these estimates can be found in the published job estimates for wind generation.[92]

Supported employment (direct and indirect jobs[93]) follows the rapid growth in GVA. As part of this research project, on average across the scenarios, supported employment[94] reaches approximately 150,000 jobs in 2050. Around 40% of these jobs are direct jobs in 2025, falling to 35% by 2050, as industry activity shifts from construction to operation and maintenance, the latter having supply chain activities that are more employment intensive. In line with the GVA

[92] Job estimates for wind generation by 2030: methodology note - GOV.UK
[93] A direct job is employment associated with the stated activity. An indirect job is a job that exists to produce the goods and services needed by the workers with direct jobs i.e. those jobs associated with supply chain activities.
[94] The estimate of indirect jobs within the EINAs is based on the application of Type 1 multipliers to the different cost categories (activities) within the sector. However, ONS methodological updates to LCREE in November 2024, suggest a higher ratio between indirect and direct employment for offshore wind than what Type 1 multipliers suggest. Consequently, current Type 1 EINA methodology could potentially underestimate the number of indirect jobs from offshore wind activity. Standard Type 1 multipliers were continued to be used for offshore wind to maintain consistency across all EINA reports.

results, there is relatively little variation in the expected number of supported jobs across the scenarios, with the different scenarios having only slightly different employment profiles over time. The differences across modelled innovation levels are limited, with only the High Diversification scenarios showing significant changes in the 2045-50 period under high innovation level, as tidal capacity expands beyond what is observed in other scenarios.

The projected expansion of offshore wind globally plays a key role in estimating the number of jobs that could be supported in the future. Likewise, the extent to which UK companies capture a share of the domestic offshore wind market is another critical factor influencing these forecasts. Both assumptions are highly sensitive to political and economic fluctuations, making it essential to consider alternative scenarios. For example, more optimistic assumptions on global market growth and domestic market share captured by UK firms could result in job estimates in 2050 increasing from approximately 150,000 to 170,000 (see "additional potential" in below charts).

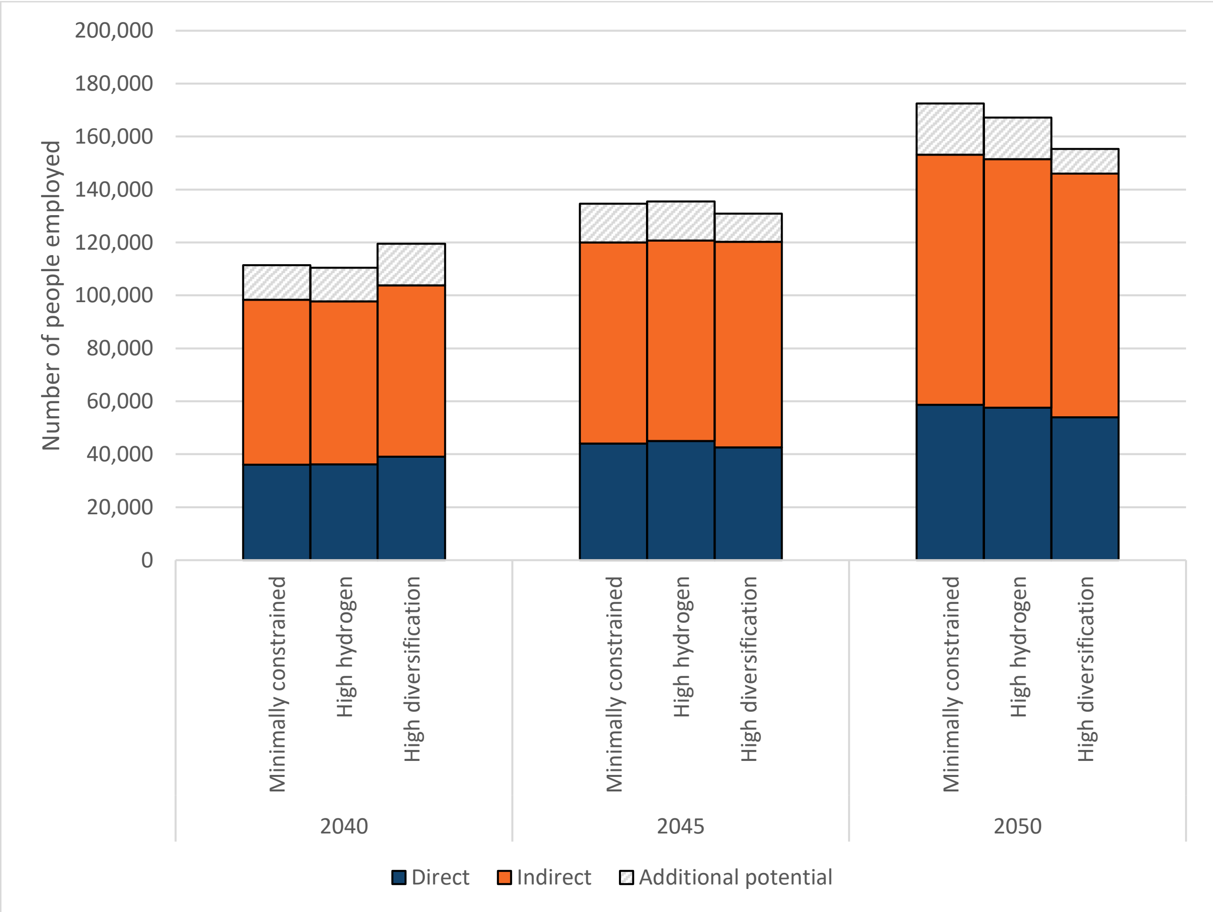

Figure 13: Total jobs supported by scenario by direct vs indirect
Note: The figure reports outputs associated with a medium level of innovation.

Figure 14 shows the distribution in employment across different cost categories i.e. construction, O&M and decommissioning in both 2040 and 2050. Supported jobs by cost category follow the expected trend jobs supported by construction activity being relatively more important in early years but jobs supported by O&M activity becoming more important by 2050 (52% of the total), and decommissioning activity also supporting some jobs by this date (1% of the total). Again, there is only modest variation between the different scenarios. This pattern reflects the growing maturity of the sector and in particular that while construction jobs are determined by the flow of new offshore renewables investment, operating and maintenance jobs are driven by the total stock of installed capacity.

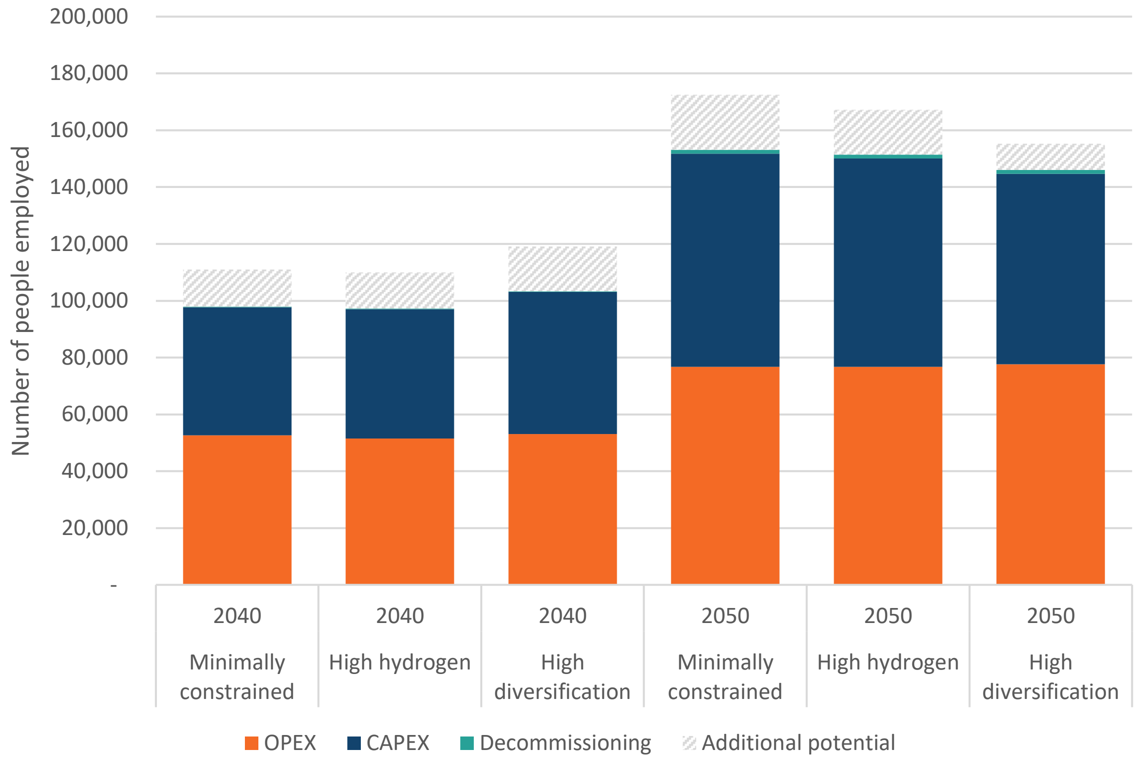

Figure 14: Total jobs supported (direct + indirect) by scenario by cost category
Note: The figure reports outputs associated with a medium level of innovation.

Finally, Figure 15 shows that most of the direct jobs supported by the sector in 2050 are expected to be in high-skilled professional occupations. The occupations that account for the largest number of jobs supported are professionals in science, research, engineering and technology (with an average across scenarios of about 21% of direct jobs), skilled trade jobs (17% of direct jobs), followed by managers, directors and senior officials (16% of direct jobs).[95]

[95] Note that the zero jobs reported for transport and mobile machine drivers and operatives is the result of data gaps in the ONS data on the distribution of jobs by SOC code for each SIC code. The true value is unlikely to be zero but, in cases where the numbers are small, the ONS determines that the value for a particular SOC code by SIC code combination is too small to be reliable and so it is excluded. This is the case for a number of the SIC codes assigned to components of the offshore renewable technologies. To account for this missing data, the calculators assign a zero when it will be a small non-zero figure. More generally, the analysis assumes that the same pattern of occupations associated with the construction, operation and maintenance of offshore renewables persists in the future.

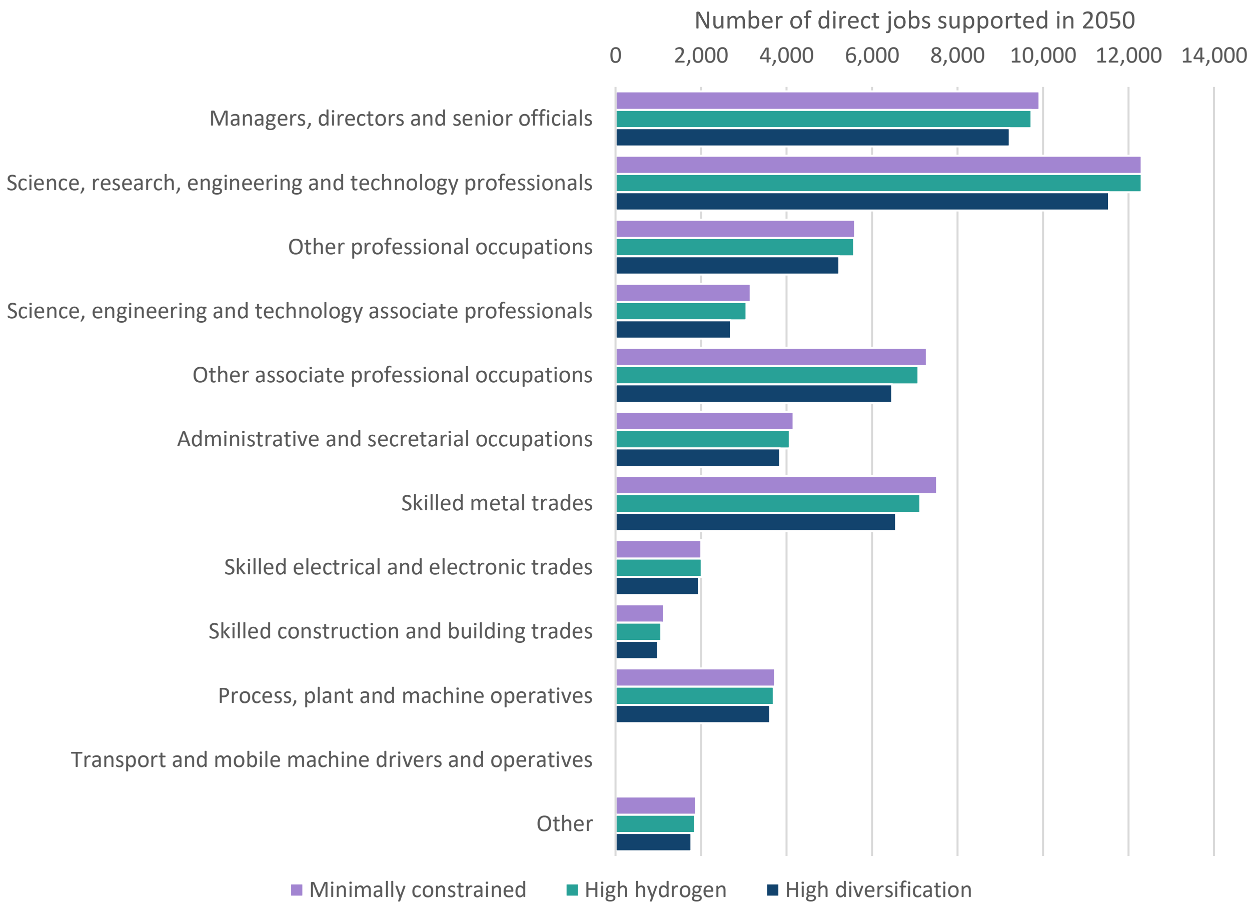

Figure 15: Direct jobs supported by scenario by occupation type in 2050

Notes: The figure reports outputs associated with a medium level of innovation. For the purposes of this analysis, the 412 4-digit SOC codes have been aggregated to 15 SOC groupings. See the EINAs Technical Methodology report for more details on this aggregation. In Figure 15 the heading ‘other’ covers the following four SOC groupings: elementary occupations, other skilled trade occupations, sales and customer service occupations and caring, leisure and other service occupations.

This publication is available from: www.gov.uk/government/publications/energy-innovation-needs-assessments-2025