Department for Transport

Maritime Decarbonisation Strategy

Analytical Annex

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Glossary of terms

AIS - Automatic Identification System

BECCS - Bioenergy with Carbon Capture and Storage

Bio – Biofuel

CapEx – Capital Expenditure

CB4 – Carbon Budget 4 (covering 2023-2027)

CB5 – Carbon Budget 5 (covering 2028-2032)

CB6 – Carbon Budget 6 (covering 2033-2037)

CCC – Climate Change Committee

CCUS - Carbon Capture, Usage, and Storage

CH_4 - Methane

CII - Carbon Intensity Indicator

CO_2 - Carbon Dioxide

CO_2e - Carbon Dioxide Equivalent

DACCS - Direct Air Carbon Capture and Storage

DfT - Department for Transport

EEDI - Energy Efficiency Design Index

EEXI - Energy Efficiency Existing Ship Index

EEZ - Exclusive Economic Zone

ETS - Emissions Trading Scheme

EU - European Union

GT - Gross Tonnage (a measure of vessel size)

GHG - Greenhouse Gas

IMO - International Maritime Organization

IPCC – Intergovernmental Panel on Climate Change

JMSC - Joint Maritime Security Centre

LCF – Low Carbon Fuel

LSFO - Low Sulphur Fuel Oil

LNG - Liquified Natural Gas

MDO - Marine Diesel Oil

Mt - Megatonne (a million tonnes)

NAEI - National Atmospheric Emissions Inventory

OCCS – Onboard Carbon Capture and Storage

OpEx – Operating Expenditure

PM – Particulate Matter

NO_x - Nitrogen Oxides

N_2O - Nitrous Oxide

SO_x - Sulphur Oxides

Syn - Synthetic

TtW - Tank-to-Wake (the emissions that are generated by operating maritime vessels, i.e. operational emissions)

WtT – Well-to-Tank (the emissions from the production and distribution of the fuels and other energy sources that are used by maritime vessels)

WtW - Well-to-Wake (the sum of Tank-to-Wake and Well-to-Tank emissions)

1. Introduction

1.1 The Maritime Decarbonisation Strategy sets out the UK Government's plan for decarbonising maritime, including new decarbonisation goals for the UK domestic maritime sector. These goals outline our ambition to reduce the lifecycle greenhouse gas (GHG) emissions of the fuels and other energy sources (e.g., electricity) used by UK domestic maritime (also known as fuel lifecycle or Well-to-Wake GHG emissions) by 30% by 2030 and 80% by 2040, relative to 2008, aligned with the upper end of International Maritime Organization (IMO) ambitions, ahead of an ambition to reach zero fuel lifecycle GHG emissions by 2050.

1.2 Meeting our goal of zero fuel lifecycle GHG emissions by 2050 requires ending the contribution to climate change made by the fuels and energy sources consumed by UK domestic maritime from when they are produced to when they are used on board vessels.[1] We intend to achieve these goals without recourse to out-of-sector offsets. To achieve zero fuel lifecycle GHG emissions, any residual GHG emissions will therefore need to be balanced by GHG removals from the energy system of the UK domestic maritime sector. Key definitions relating to our goals are provided in Box 1 *(in Section 2),* and a discussion of how these goals relate to achieving UK Carbon Budgets is provided in Box 5 *(in Section 4).*

1.3 This document provides further details on the illustrative decarbonisation scenarios for the UK domestic maritime sector that are presented in the strategy and explains the assumptions and uncertainties behind these in more detail.

1.4 The rest of this document is structured in the following way:

i. ‘Section 2: Maritime emissions modelling’ provides a short introduction to DfT’s new maritime emissions model, and the key decarbonisation measures it includes.

[1] This is different to the approach taken when calculating transport's contribution to meeting carbon budgets, which does not generally consider the upstream emissions emitted during the production of fuels (as this is accounted for in other sectors’ totals).

ii. 'Section 3: Policies to decarbonise the maritime sector' sets out the policy measures included within our modelling.

iii. 'Section 4: ‘Illustrative decarbonisation scenarios for UK domestic maritime’ provides further details on the core range of illustrative decarbonisation scenarios for UK domestic maritime that are presented in the strategy, explains the assumptions underpinning this range, and presents the results of the scenarios, including fuel mixes, costs, and benefits. The results of modelling of the impact of our policies on the UK’s share of international maritime GHG emissions are also included in this section.

iv. 'Section 5: Sensitivity Analysis’ explores a wider potential range of decarbonisation scenarios for UK domestic maritime by 'stress testing' various uncertainties.

v. ‘Section 6: Conclusions’ summarises some of the main conclusions of the document.

2. Maritime emissions modelling

Model overview

2.1 Underpinning the Maritime Decarbonisation Strategy is updated analysis of the greenhouse gas (GHG) emissions from the UK maritime sector, informed by our new maritime emissions model. The strategy is the first use of the model, which represents a significant step change in our ability to estimate the emissions of GHGs and other pollutants from the UK maritime sector, and to model how these emissions may change over time.

2.2 The model uses big data and cloud computing to provide state of the art analysis of maritime emissions in an historical ‘base year’ (2019)[2] and projections out to 2050. The ‘base year’ emissions estimates draw on detailed automatic identification system (AIS) ship tracking data for individual ships in the global fleet in 2019 and follow a similar methodology to the existing modelling for vessels fitted with AIS in the UK’s National Atmospheric Emissions Inventory (NAEI). The AIS data was provided by the Government’s Joint Maritime Security Centre[3] (JMSC), who collect it from multiple sources.

2.3 To provide a robust foundation for our future forecasts, the ‘base year’ estimate for 2019 is then inputted into the model. Assumptions are made within the model on the particular policy levers in place and the cost, effectiveness, and availability of technologies like engines, fuels, and energy efficiency measures.[4] Individual ship operating decisions are then modelled to comply with policy measures on a cost-minimization basis. Key outputs from the model include emissions, fuel use, technology uptake, and costs.

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[2] 2019 was chosen as the base year because it was the most recent year unaffected by Covid-19 for which we had a full set of data, when the model was first developed. We have produced backcasted and forecasted estimates to cover all years from 1990 onwards. We will explore producing AIS based estimates for other years as part of the long-term development of the model.

[3] https://www.gov.uk/government/groups/joint-maritime-security-centre

[4] These assumptions have been informed by research conducted by a consortium of KMPG, Mott MacDonald, and Houlder for DfT on technology costs, availability and effectiveness, engagement with external stakeholders and the Government’s existing evidence base. For further details, see the Maritime Emissions Modelling Framework.

2.4 The model uses two main approaches for measuring the GHG emissions from the UK maritime sector: Well-to-Wake (WtW) emissions and Tank-to-Wake (TtW) emissions. Box 1 *(below)* explains the difference between these two approaches. The model can produce estimates of both the maritime emissions that contribute to UK territorial GHG emissions estimates (i.e. UK domestic maritime emissions) and the UK's share of international maritime emissions (i.e. UK international maritime emissions). Definitions of UK domestic and international maritime emissions used within this document are set out in Box 1.

2.5 Using the model, we estimate that, in 2019, the GHG emissions from UK domestic maritime (excluding inland waterways) were 7.2 $MtCO_2e$ on a WtW basis and 5.9 $MtCO_2e$ on a TtW basis. In addition, we estimate that 2019 GHG emissions from UK international maritime were 9.4 $MtCO_2e$ on a WtW basis and 7.5 $MtCO_2e$ on a TtW basis. Unless stated otherwise, estimates of emissions presented in this document are presented on a WtW (i.e. fuel lifecycle) basis, and do not include emissions from inland waterways and leisure craft. As set out in the strategy, a fuel lifecycle approach encourages the use of cleaner fuels as it means accounting for GHG emissions generated during the maritime fuel production process itself, which can vary depending on the fuel production method. Inland waterways and leisure craft are not included in our new maritime emissions model at this stage due to the limitations of the available evidence. Further details on inland waterways and leisure craft are included in Box 2.

2.6 Whilst the new model is an important addition to the department's analytical capabilities, it has limitations. These limitations include the following:

- We do not currently model all potential solutions for reducing emissions (for example, shore power, hybrid-electric vessels, onboard carbon capture and storage, and nuclear power are not currently modelled), landside infrastructure or the supply of fuels

- There are limitations regarding how we model certain solutions for reducing emissions (such as batteries), due to a lack of evidence.

- While we have the capability to model some emissions of other air pollutants, such as nitrogen oxides (NO_X), sulphur oxides (SO_X) and primary particulate matter, we do not currently model secondary particulate matter. We also do not currently have the evidence to model water quality or biodiversity impacts.

2.7 We plan to address key model limitations through a longer programme of model development and further calls for evidence. We will be continuously refining our estimates and forecasts as we develop the model and the assumptions. Further details on the technical aspects of the model, including how it works, historical emissions estimates and comparisons with other existing estimates, data sources, quality assurance, modelling limitations, and plans for future development, are set out in the Maritime Emissions Modelling Framework, published alongside the strategy. We would welcome any feedback on the methodology, assumptions, and results to help us develop the model in the future. If you have any feedback, please get in touch at MaritimeForecasts@dft.gov.uk.

Box 1 – Key definitions underpinning our new decarbonisation goals for the domestic maritime sector

Our goals cover the lifecycle greenhouse gas (GHG) emissions of the fuels and other energy sources (e.g., electricity) used by UK domestic maritime, which are also known as fuel lifecycle or Well-to-Wake GHG emissions.

The International Maritime Organization (IMO) has developed guidelines on assessing the lifecycle GHG emissions of the fuels and energy sources used by maritime.[5] In line with the IMO's guidelines, for the purposes of our goals, we define fuel lifecycle or Well-to-Wake GHG emissions as the sum of:

- the GHG emissions from the production and distribution of the fuels and other energy sources (e.g., electricity) that are used by maritime vessels, which are also known as Well-to-Tank emissions; and
- the GHG emissions that are generated by operating maritime vessels, which are also known as Tank-to-Wake emissions.

In more detail, our definition of fuel lifecycle or Well-to-Wake GHG emissions specifically takes into account the GHG emissions associated with the following six steps in line with the IMO's guidelines:

- "feedstock extraction/cultivation/acquisition/recovery";
- "feedstock (early) processing/ transformation at source";
- "feedstock transport to conversion site";
- "feedstock conversion to product fuel";
- "product fuel transport/storage/delivery/retail storage/bunkering"; and
- "fuel utilization on board a ship".

In line with the IMO's guidelines, our new goals for the domestic maritime sector therefore do not cover the GHG emissions from the construction of the vessels responsible for UK domestic maritime emissions and the other landside infrastructure used by these vessels (such as port facilities). However, all GHG emissions within the UK's borders are captured by the UK's net zero target and carbon budgets. As such, any GHG emissions from construction activities within the UK's borders will be accounted for within other sectors of the economy in the Net Zero Strategy and Carbon Budget Delivery Plan.

UK domestic maritime emissions are defined as the sum of:

- the emissions from journeys between two UK ports or offshore installations in the UK's Exclusive Economic Zone (EEZ);
- the emissions from journeys from one UK port or offshore installation in the UK's EEZ returning to the same port or installation; and
- all emissions from vessels at berth in a UK port or at an installation in the UK's EEZ (including those from vessels performing international journeys), with a vessel being 'at berth' when it is securely moored or anchored in a UK port or at an offshore installation in the UK's EEZ.

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[5] IMO Marine Environment Protection Committee (2024) 2024 Guidelines on life cycle GHG intensity of marine fuels (2024 LCA guidelines) https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2081/Annex%2010.pdf

In line with the reporting guidelines agreed by the United Nations Framework Convention on Climate Change (UNFCCC), current estimates of UK international maritime estimates produced by the NAEI are based on the volume of maritime fuels refuelled at bunkers[6] in UK ports. The CCC has recommended that the Government “explore options for an activity-based measure of UK shipping emissions” including “exploring the benefits of changing the emissions accounting approach for international shipping, to ensure that a fair share of emissions for voyages to and from the UK are captured within the UK's inventory even if vessels refuel in other jurisdictions.”[7] As our new maritime emissions model uses data on the movement of ships, we can now produce activity-based estimates of the UK’s share of international maritime emissions. There are still different ways that this could be defined (e.g. emissions from all inbound journeys, all outbound journeys, or 50% of all journeys), however, in this document, the UK’s share of international maritime emissions is defined as:

- 50% of emissions from all journeys between a UK port (or an offshore installation in the UK’s EEZ) and a port in another country, excluding any emissions produced at berth. This refers only to the previous and next port of call.

GHG emissions are defined as the sum of Carbon Dioxide (CO_2), Methane (CH_4) and Nitrous Oxide (N_2O) emissions expressed in Carbon Dioxide Equivalent (CO_2e) terms. In line with the approach taken for the UK territorial greenhouse gas emissions national statistics and international reporting protocols, the Global Warming Potential (GWP) figures, as published in the Intergovernmental Panel on Climate Change 5th Assessment Report (IPCC AR5)[8], have been used to convert the CH_4 and N_2O emissions into CO_2e terms.[9]

[6] A large container or compartment that stores fuel for ships or aircraft.

[7] Climate Change Committee (June 2022) June 2022 Progress in reducing emissions 2022 Report to Parliament (theccc.org.uk) page 554

[8] United Nations Intergovernmental Panel on Climate Change (IPCC), 5th Assessment Report https://www.ipcc.ch/assessment-report/ar5/

[9] UK greenhouse gas emissions: other technical reports https://www.gov.uk/government/publications/uk-greenhouse-gas-emissions-explanatory-notes

Box 2. Emissions from inland waterways and leisure craft

Throughout this document, we refer to the '*inland waterway'* and '*inland waterway and leisure'* sectors interchangeably. In the UK's National Atmospheric Emissions Inventory (NAEI)[10], the inland waterways sector covers the following categories of vessels:

- Sailing Boats with auxiliary engines
- Motorboats / Workboats (e.g., dredgers, canal, service, tourist, river boats)
  - recreational craft operating on inland waterways
  - recreational craft operating on coastal waterways
  - workboats
- Personal watercraft i.e., jet ski
- Inland goods-carrying vessels.

For the purposes of the UK NAEI, the inland waterways sector has been defined in a way that is intended to capture those vessels that do not carry automatic identification systems (AIS) transponders. These vessels are therefore not captured in the detailed ship tracking data used in DfT's maritime emissions model and are treated as being out of scope of the initial version of this model.

For the same reason, vessels in the inland waterways sector are treated as being out of scope of the main shipping model used in the UK's NAEI. Instead, these emissions are estimated separately, based on a research project completed in 2011.[11] To produce estimates of the emissions from inland waterways in other years, proxy statistics are used to estimate the change in fuel consumption over time.[12] However, these proxy statistics may not be closely aligned with actual trends in inland waterways activity. Therefore, there is uncertainty regarding the existing estimates of the emissions from inland waterways.

In 2019, the estimated GHG emissions from the inland waterway sector included in the UK NAEI were 1.0MtCO_2e on a TtW basis.[13] As these vessels are not captured within our new maritime emissions model, to calculate the total GHG emissions from UK domestic maritime, we add this estimate to the estimated GHG emissions from vessels included in our new model.

As we continue to further develop our new maritime emissions model, a key area of focus will be developing our capabilities to model the contribution that inland waterways make to UK domestic maritime emissions. To develop our evidence base on this, we

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[10] NAEI (2024) UK Greenhouse Gas Inventory, 1990 to 2022: Annual Report for submission under the Framework Convention on Climate Change https://naei.energysecurity.gov.uk/reports/uk-greenhouse-gas-inventory-1990-2022-annual-report-submission-under-framework-convention

[11] NAEI (2011) Greenhouse Gas Emissions from Inland Waterways and Recreational Craft in the UK https://naei.energysecurity.gov.uk/reports/greenhouse-gas-emissions-inland-waterways-and-recreational-craft-uk

[12] NAEI (2024) UK Greenhouse Gas Inventory, 1990 to 2022: Annual Report for submission under the Framework Convention on Climate Change https://naei.energysecurity.gov.uk/reports/uk-greenhouse-gas-inventory-1990-2022-annual-report-submission-under-framework-convention

[13] Department for Energy Security and Net Zero (2024) Final UK greenhouse gas emissions national statistics: 1990 to 2022 https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-to-2022

plan to undertake a research project to produce a more up-to-date inventory of emissions in the inland waterways sector and to explore options for improving how we monitor changes in these emissions over time.

Model inputs

2.8 As part of the development of the model, we commissioned research to review existing evidence and provide recommendations for a range of assumptions required within the model. This research included a series of stakeholder interviews with a mixture of academics, engine manufacturers, fuel suppliers, vessel classification societies, and technology providers to identify evidence and data that could be used to produce input assumptions.

2.9 We also held industry workshops where stakeholders provided feedback on the methodology, key assumptions, and draft results. We made several updates to the assumptions in response to this feedback. Full details on the assumptions can be found in the Modelling Framework document; however, the following section summarises some of the key inputs.

Low carbon, zero, and near-zero GHG emission fuels and energy sources

2.10 The maritime sector will need to transition away from using fossil fuels to using low carbon and, ultimately, zero and near-zero GHG emission fuels to operate vessels over time.[14] However, the current usage of these fuels in the maritime sector is very low and there is uncertainty about their cost and availability in the future. Given the emergent consensus that a sector as diverse as maritime with important differences in ship and route type will not have a single future fuel, a fuel and technology neutral approach is needed. Therefore, within the maritime emissions model, we model a range of different maritime fuels, and we have tested various future fuel mix scenarios to reflect this uncertainty, as set out in Section 3.

2.11 The following fuels and energy sources are included in the maritime emissions model:

- Fossil fuels: Low Sulphur Fuel Oil (LSFO)[15], Marine Diesel Oil (MDO), Liquified Natural Gas (LNG), Methanol.

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[14] Box 3 of the strategy explains the use of the terms ‘low carbon fuels’ and ‘zero and near zero GHG emission fuels’. The IMO is yet to fully define what will be included in its definition of zero/near zero GHG emission fuels. In our analysis we have included a range of low carbon, zero and near-zero GHG emission fuels that are considered as potential decarbonisation options for the maritime sector. As shown in Figure 1, these might not all be considered ‘near zero GHG emission’ in earlier years, but we assume that, by 2050, they generally produce very little to no GHG emissions on a WtW basis.

[15] Within the modelling, LSFO refers to all fuel oil below the global sulphur cap (maximum 0.5% sulphur content). Further explanation is provided in the Maritime Emissions Modelling Framework.

- Biofuels: Biofuel (Bio) equivalents of the fossil fuels listed above. These are Bio-LSFO, Bio-MDO, Bio-LNG and Bio-Methanol.

- Synthetic fuels: Synthetic (Syn) equivalents of MDO, LNG and Methanol. These synthetic fuels are assumed to be produced by combining low carbon hydrogen[16] with a source of carbon dioxide such as from Direct Air Carbon Capture and Storage (DACCS). This low carbon hydrogen is assumed to be produced from renewable electricity using electrolysis ('green hydrogen') or from natural gas with the use of carbon capture, usage, and storage (CCUS) ('blue hydrogen'). The shares of green and blue hydrogen in the production of synthetic fuels are assumed to change over time, with an increase in green hydrogen.

- Hydrogen: Low carbon hydrogen. As above, the shares of green and blue hydrogen are assumed to change over time.

- Ammonia: Ammonia produced using low carbon hydrogen. As above, the shares of green and blue hydrogen in the production of ammonia are assumed to change over time.

- Renewable electricity.

2.12 Table 1 summarises the available evidence on the advantages and barriers to use of each low carbon, zero, and near-zero GHG emission fuel included in the model from a technical perspective (excluding points relating to costs or emissions factors). This summary draws on research commissioned by DfT to inform the development of our new maritime emissions model. While we have endeavoured to ensure our evidence is the best available, we recognise that, in some areas, the available evidence has limitations, and we will keep our assessments of these fuels under review as the evidence base develops. The following sections briefly explain the assumptions on the costs and emissions savings associated with these fuels that feed into our current modelling. As better evidence becomes available on these fuels, we will update these assumptions in future iterations of this modelling. Further information on how each fuel is currently included in the model is available in the Maritime Emissions Modelling Framework.

[16] The Government has established a UK Low Carbon Hydrogen Standard. To demonstrate compliance with the low carbon hydrogen standard, producers of low carbon hydrogen must be able to report a GHG emissions intensity of 20 $gCO_2e/MJLHV$ of produced hydrogen or less. Further details of the UK Low Carbon Hydrogen Standard are available at https://www.gov.uk/government/publications/uk-low-carbon-hydrogen-standard-emissions-reporting-and-sustainability-criteria.

Biofuels	**Advantages** • Biofuels can be considered a "drop in" fuel as they are compatible with existing maritime infrastructure relating both to vessels and at ports. • Low risk of environmental contamination in the event of a spill relative to other fuels.
	Barriers of fuel use • For biofuels to deliver genuine greenhouse gas savings, they need to be produced from sustainable feedstocks that have not led directly or indirectly to land-use change such as deforestation. • There are concerns about the amount of sustainable feedstock that will be available for producing biofuels, especially if maritime is expected to compete with other sectors of the economy, including other transport modes. • Significant fuel production infrastructure would be required to produce the volume of fuel required. • Risk of methane slip when using biomethane.
Synthetic Fuels	**Advantages** • Synthetic fuels can be considered a "drop in" fuel as they are generally compatible with existing maritime infrastructure.
	Barriers of fuel use • The production of synthetic fuels relies on a sustainable supply of carbon. • Production requires high quantities of electricity which will place pressure on the grid supply. This electricity will also need to be provided by low carbon sources to maximise the GHG emission savings of synthetic fuels. • Significant fuel production infrastructure would be required to produce the volume of fuel required by domestic maritime. Depending on the synthetic fuel, additional bunkering infrastructure may be required.
Hydrogen	**Advantages** • The available evidence indicates that hydrogen produces zero CO_2 emissions on a TtW basis. • Hydrogen also has a high specific energy, meaning that it contains more energy per weight than other fuels.
	Barriers of fuel use • Hydrogen has a very low volumetric energy density and requires significant space for storage, which may be a problem on smaller vessels. • Hydrogen is also highly flammable, meaning it requires careful storage and handling to prevent a leak. • Hydrogen itself is an indirect GHG[17], therefore, any hydrogen leaks will also contribute to climate change. • While hydrogen is expected to burn cleaner than current fossil fuels, the combustion of hydrogen produces NO_x which can impact health and ecosystems, as well as reacting with other pollutants to form $PM_{2.5}$ (although this is not expected to be the case when burnt in a fuel cell). • Very pure hydrogen is required to be used in a fuel cell. • The production of green hydrogen requires high quantities of electricity which will place pressure on the grid supply. As much electricity as possible should be sourced from low carbon sources to maximise the GHG emission savings of hydrogen fuels. • Significant infrastructure would be required for both fuel production and bunkering.

Ammonia	**Advantages** • The available evidence indicates that ammonia is a near-zero GHG emission fuel on a TtW basis, as the only GHG produced is a small amount of N_2O. • Ammonia also requires significantly less cooling than hydrogen to be stored in liquid form.
	Barriers of fuel use • Ammonia is highly toxic, to both human and marine life, meaning that a spill could have serious environmental and safety consequences. • Ammonia may be unsuitable for passenger vessels, due to the dangers of an ammonia leak. • While ammonia is expected to burn cleaner than current fossil fuels, ammonia itself is an air pollutant. Therefore, any ammonia leaks could be damaging to nitrogen-sensitive ecosystems or react with other pollutants to form $PM_{2.5}$ and impact air quality. • It may be physically impossible to store ammonia on a small vessel, given the need for containment and exclusion zones around tanks, pipes and machinery spaces. • The production of ammonia derived from green hydrogen requires high quantities of electricity which will place pressure on the grid supply. This electricity will need to be provided by low carbon sources to maximise the GHG emission savings of ammonia fuels. • Significant infrastructure would be required for both fuel production and bunkering. • A recent study has shown that the public perception of ammonia is as a 'risky' and 'toxic' alternative fuel.[18]
Electricity	**Advantages** • When produced with renewable energy and excluding embodied carbon, electricity produces zero WtW GHG emissions when powering a vessel. • Electricity can provide increased energy efficiency as electric motors are typically more efficient than combustion engines.
	Barriers of fuel use • Batteries have very poor specific energy and energy density, considerably worse than any other potential maritime fuels. This significantly limits the achievable range and creates conflicts with the cargo capacity of a vessel. • Very large batteries may be required for some ships, resulting in those ships sitting lower in the water and impacting the ports that they can access. • There are concerns about the supply of batteries to enable a significant shift of maritime vessels to electric power, due to the availability of the rare metals needed for their construction. • Significant infrastructure would be required, including for recharging batteries, enhancing the electricity grid and any wider requirement for port operations. The cost can significantly vary by port.

Table 1: Advantages and barriers to use of low carbon, zero, and near-zero GHG emission fuels included in the Maritime Emissions Model

[17] For example, see Sand, M., Skeie, R.B., Sandstad, M. et al. A multi-model assessment of the Global Warming Potential of hydrogen. Communications Earth & Environment 4, 203 (2023). https://doi.org/10.1038/s43247-023-00857-8

[18] Carlisle, D.P., Feetham, P.M., Wright, M.J. et al. Public response to decarbonisation through alternative shipping fuels. Environment, Development and Sustainability 26, 20737–20756 (2024). https://doi.org/10.1007/s10668-023-03499-0

2.13 The choice of fuels and energy sources currently incorporated in the model reflects our current evidence base. We recognise that some industry stakeholders are exploring the role of other fuels and energy sources that are not currently captured in the model due to the limitations of our available evidence, including hybrid-electric vessels, nuclear power and onboard carbon capture and storage (OCCS). In addition, shore power is not currently incorporated in this iteration of our model, due to a lack of assumptions about the future availability at ports. We will look to build our evidence base on these fuels and energy sources with the aim of expanding the range of fuels and energy sources we are able to model in the future.

Emissions factors

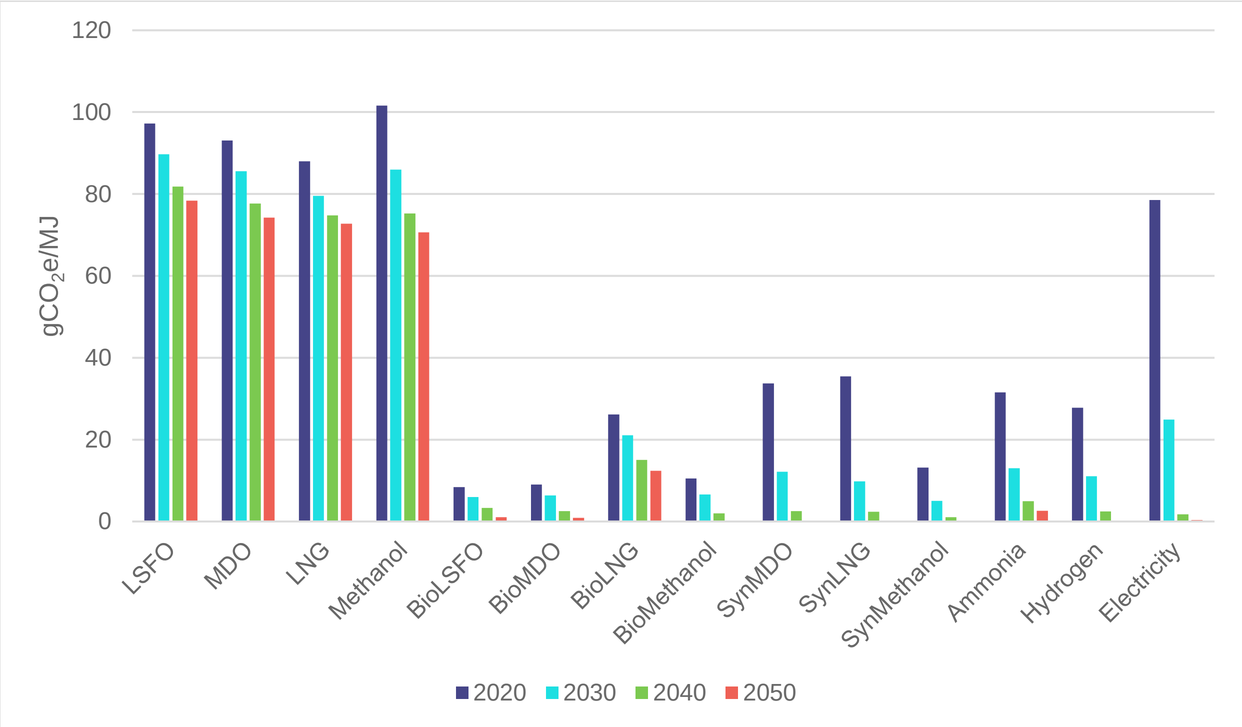
2.14 As the goals proposed in the strategy are on a lifecycle emissions basis, the model includes emission factors for both the production and transportation of the fuel (WtT) as well as the emission factors for the use of the fuel by a maritime vessel (TtW). The WtT emissions factors currently used in the model are based on assumptions developed as part of a (currently unpublished) research project commissioned by the Department for Transport (DfT) and undertaken by a team of experts from UMAS, UCL, and E4tech. The TtW emissions factors are based on a new evidence review conducted by a consortium of KPMG, Mott MacDonald, and Houlder on behalf of DfT specifically to inform the development of our new maritime emissions model.[19]

2.15 Figure 1 shows the lifecycle emissions of each fuel assumed within the modelling and highlights the magnitude of the lifecycle emissions associated with fossil fuels when compared to low carbon, zero, and near-zero GHG emission fuels. This graph also highlights how potential improvements in the production and transportation technology of fuels may be able to decrease total lifecycle emissions to close to zero. In 2020, Bio-LSFO and Bio-MDO are assumed to have the lowest lifecycle emission factors, but by 2050 all alternative fuels are assumed to produce either near-zero or zero lifecycle emissions.

2.16 The WtT emissions associated with synthetic fuels, ammonia, and hydrogen reflect assumptions about the split between the blue and green production of low carbon hydrogen. In line with the approach taken in a research project commissioned by DfT, we assume that that there is a transition from blue to green methods of low carbon hydrogen production, starting with 100% blue sources in 2020, with the green share gradually increasing until it is 100% of the market in 2050. This is a simplifying assumption, and explains the decreasing emissions associated with these fuels. Further information on the WtT emissions associated with these fuels can been found in the Maritime Emissions Modelling Framework.

[19] The global warming potentials (GWPs) used in the calculation of CO_2e were based on the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) over a 100-year period, consistent with current national and international reporting requirements.

Figure 1. Assumed lifecycle (WtW) greenhouse gas emission factors by fuel type



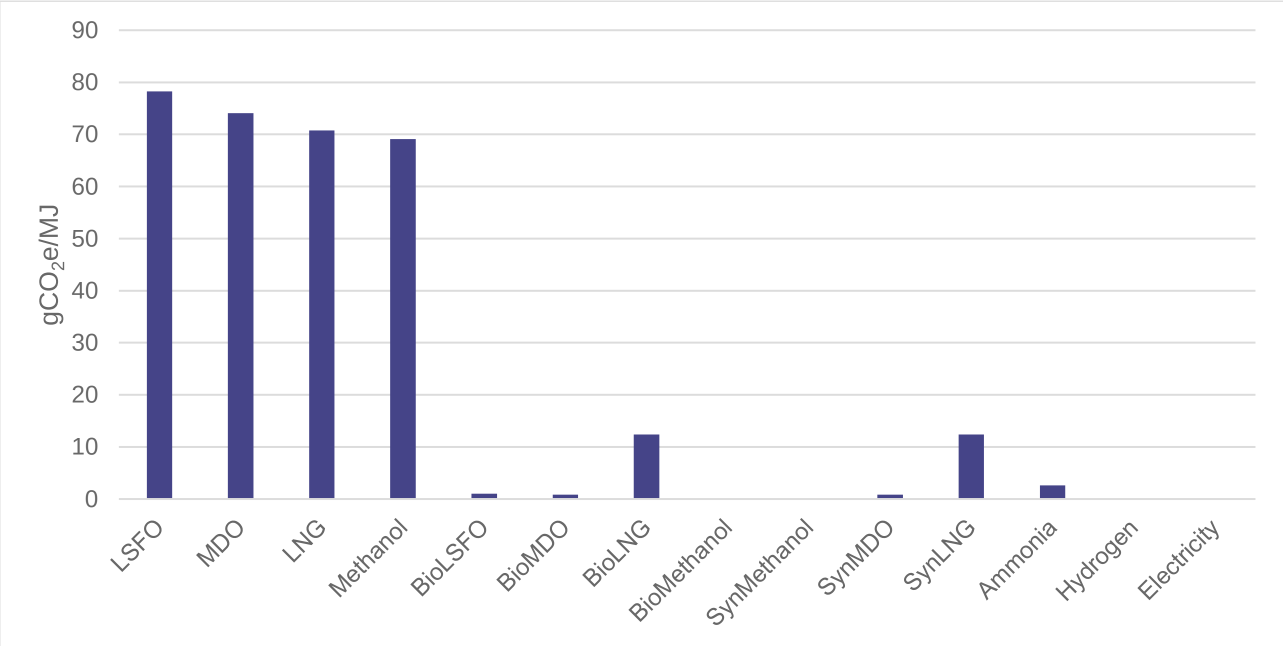
Note: Figure 1 shows the assumed lifecycle (WtW) greenhouse gas emission factors for the fuel types included in the model, expressed in grams of CO_2e per megajoule. The graph includes estimates for each fuel in 2020, 2030, 2040, and 2050.

2.17 Figure 2 presents the assumptions regarding the emissions that are produced by each fuel on a TtW basis only. The figure shows that most fuels included in our modelling are still assumed to produce some residual TtW emissions. For some of these fuels, this may not be the production of CO_2 emissions but instead the emission of methane or nitrous oxide that also have global warming impacts. In line with IPCC guidance, biofuels are treated as zero CO_2 emission on a TtW basis in our modelling (though they may still produce some non-CO_2 greenhouse gases).[20] As synthetic fuels are not yet deployed at scale, international carbon reporting practice for their production and combustion on a TtW basis is as yet undefined. The UK Government is contributing to international discussions on the approach to accounting for production and combustion from these fuels. In line with previously published analysis, the analysis in this document assumes that synthetic fuels are zero emission on a TtW basis, noting this may be subject to change as international accounting protocol evolves. This approach assumes that, whilst synthetic fuels produce CO_2 emissions at the funnel, these are offset during production of the fuel (through the capture of CO_2 that would have been emitted anyway, or by direct

[20] Following IPCC guidance, biogenic CO_2 emissions are treated as zero emission, given an equivalent amount of CO_2 is assumed to be absorbed from the atmosphere during biomass growth with any net changes in carbon stock due to biomass harvesting/use accounted for in the Land Use, Land Use Change and Forestry (LULUCF) sector. IPCC guidance can be found at https://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf (Year of Guidance: 2006; Volume: 2; Chapter: 3. Mobile Combustion; Section: 3.2.1.2 Choice of emission factors; Page: 17)

air carbon capture). This is consistent with the approach taken by others, including the JEC Well-to-Tank report v5[21] and ensures that synthetic fuels are treated equivalently within the model for cost optimisation decisions. (See Box 5 for analysis under TtW accounting in relation to carbon budgets).

Figure 2. Assumed operational (TtW) greenhouse gas emission factors by fuel type



Note: Figure 2 shows the assumed operational (TtW) greenhouse gas emission factors for the fuel types included in the model, expressed in grams of CO_2e per megajoule. These are assumed to not change over time.

2.18 Given the limitations of the available evidence on emissions factors, these emissions factors are subject to significant uncertainty. We will keep the emissions factors included in the model under review and update them as appropriate in future iterations of this modelling. For example, hydrogen is likely to produce N_2O emissions when used in a combustion engine; however, there are currently no studies that estimate the N_2O emissions produced by hydrogen fuel onboard a vessel. Therefore, these emissions have not been included in our main modelling, but we have carried out sensitivity testing on this (see paragraph 5.8) and aim to incorporate them into the model properly as the evidence base improves.

2.19 The fuels included in the model will also have varying impacts on air quality. In the model, we include estimates of the primary emissions of NO_X, SO_X and particulate matter (PM_{10} and $PM_{2.5}$) associated with each of the fuels, which are set out in Figure 3a, 3b, and 3c. There is significant uncertainty relating to these assumptions, particularly for the low carbon, zero, and near-zero GHG emission fuels. For example, hydrogen is likely to produce some NO_X but the scale of this is unknown, therefore it is currently treated as zero and has been excluded from Figure 3b. Further pollutants, such as secondary $PM_{2.5}$ and slippage of

[21] Prussi, M., Yugo, M., De Prada, L., Padella, M., Edwards, R. and Lonza, L., *JEC Well-to-Tank report v5*, EUR 30269 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-19926-7, doi:10.2760/959137, JRC119036

ammonia, alongside impacts on water quality and biodiversity, are also not currently included within our modelling due to a lack of evidence. We will look to address this evidence gap in future.

Figure 3a. Assumed SO_X emissions by fuel type

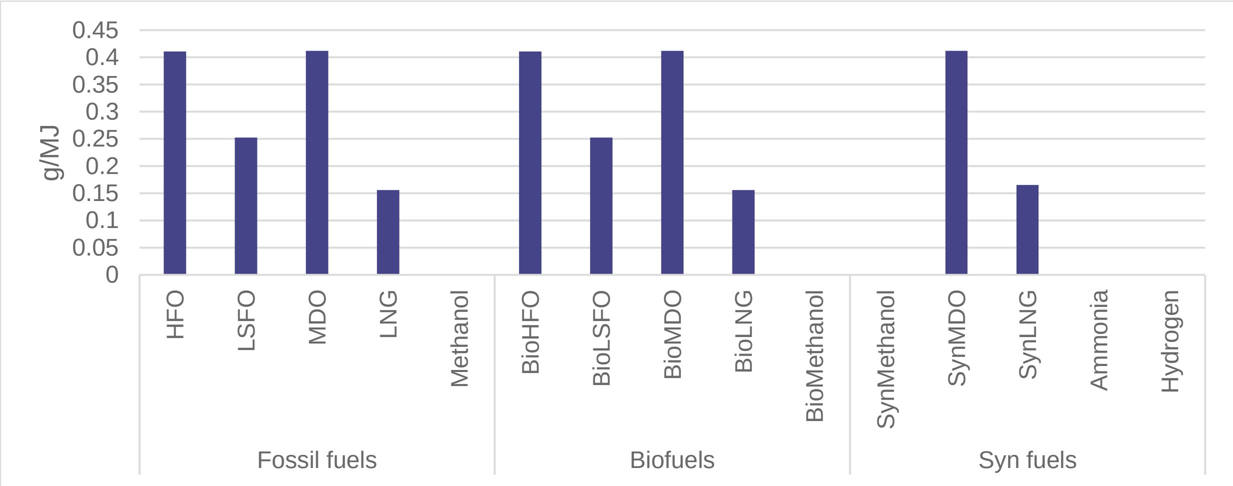


Figure 3b. Assumed NO_X emissions by fuel type

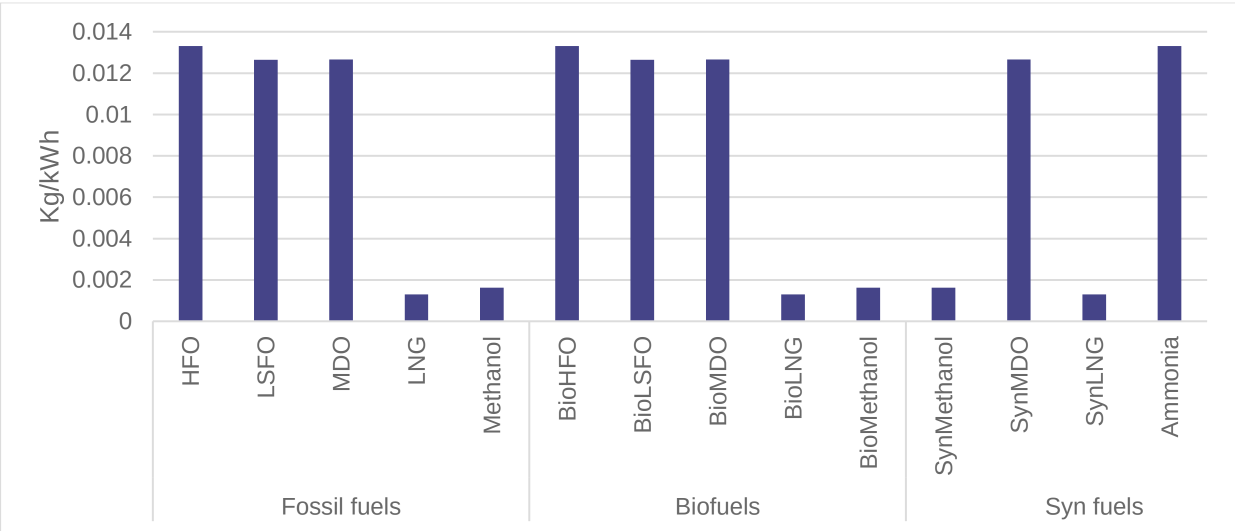
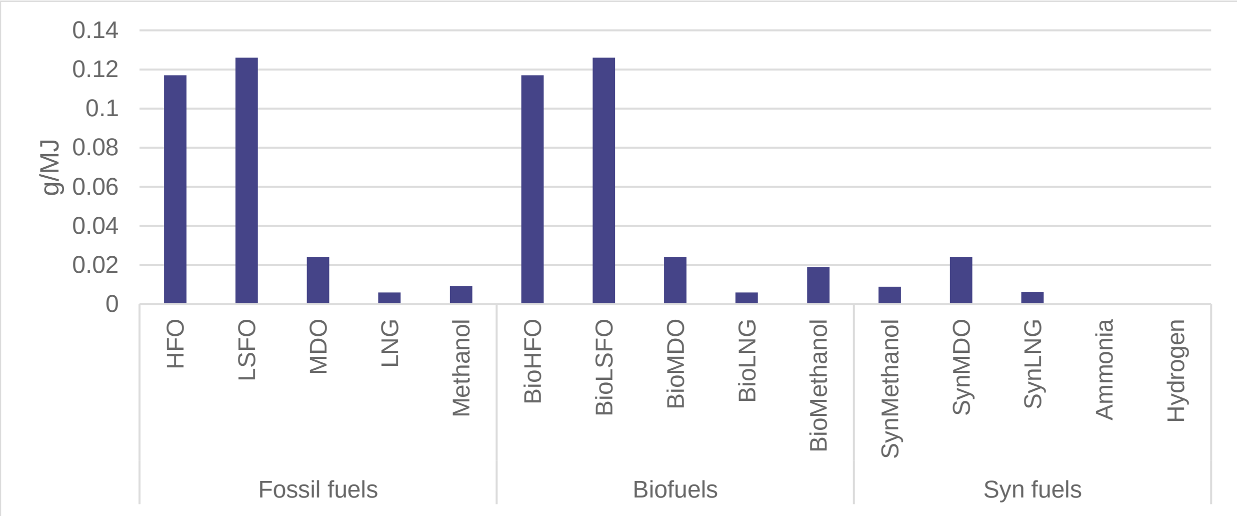


Figure 3c. Assumed PM_{10} emissions by fuel type



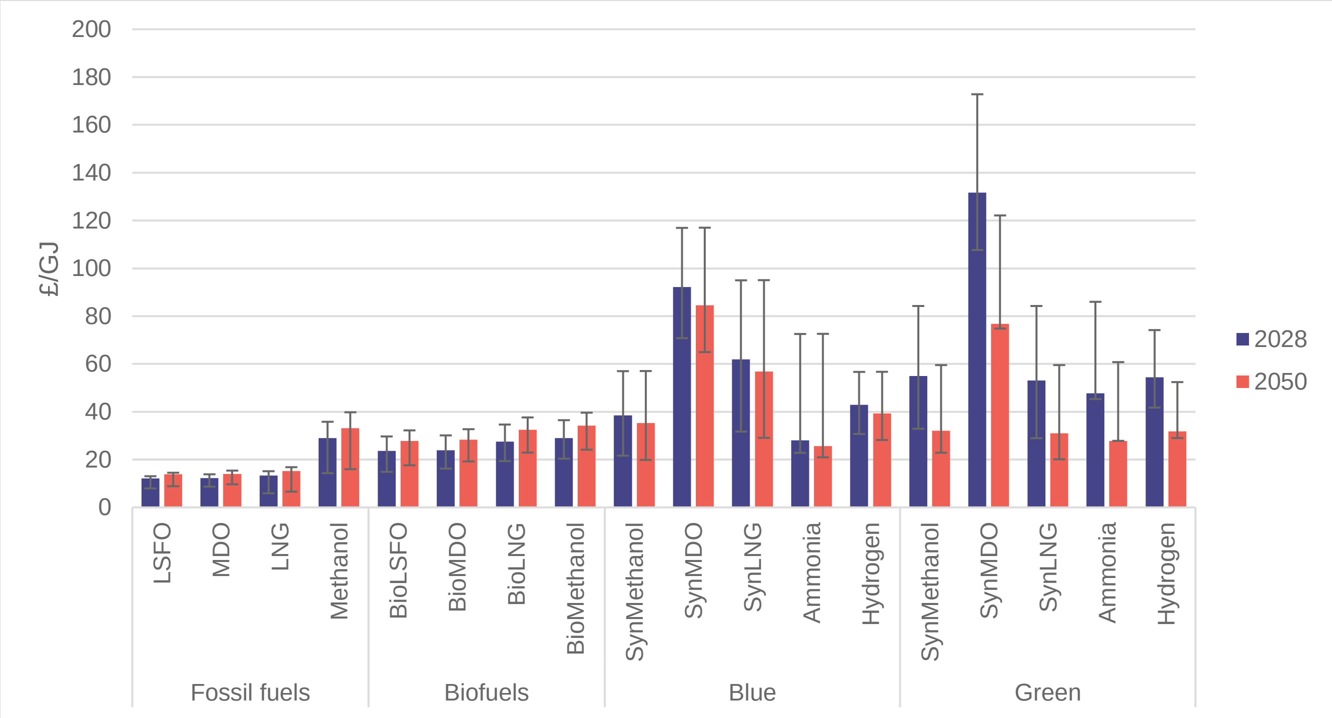
Note: Figure 3 shows the assumed emission factors for NO_X, SO_X and PM_{10} for the fuel types included in the model. SO_X and PM_{10} are expressed in g/MJ, whereas NO_X emissions are expressed in kg/kWh, for consistency with the units used by the IMO for their NO_X limits on engines. These are assumed to not change over time. Hydrogen has been excluded from figure 3b due to an evidence gap explained in 2.19. $PM_{2.5}$ levels are assumed to be 92% of PM_{10} levels, as per the Fourth IMO GHG Study 2020 - Full report and annexes.pdf.

Fuel price estimates

2.20 Figure 4 shows the forecasted prices included in the maritime emissions model for the possible range of fuels in 2028 and 2050. The year 2028 has been selected as this is the year when alternative fuels, those labelled under the blue and green categories, are assumed to become available within the model. The forecasts for prices in future years are produced as indices with a price base of 2023. These indices are applied to the 2023 fuel prices to give a price forecast in real GBP. Prices are presented in terms of energy produced (£/GJ), which takes into consideration the energy density of fuels such as methanol and hydrogen. The bar for each fuel represents the central price scenario within the model, while the error bars represent the low and high forecasts.

2.21 The price forecasts assume that prices of hydrogen, ammonia, and other synthetic fuels will decrease as supply chains develop. Meanwhile, the price of biofuels is expected to rise slightly as demand increases. However, for simplicity, supply constraints are not explicitly modelled within the maritime emissions model.

Figure 4. Assumed cost of maritime fuels in 2028 and 2050



Note: Figure 4 shows the assumed central cost of maritime fuels in 2028 and 2050 in the maritime emissions model, shown in £ per gigajoule. Costs are expressed in 2023 prices. The error bars indicate the high and low-cost assumptions for each fuel. Alternative fuels are split by blue and green production methods, this difference is explained in paragraph 2.10. Forecasts assume that the cost of hydrogen, ammonia and other synthetic fuels will decrease over time as supply increases. However, fuel availability is not explicitly modelled, and there is the potential for supply constraints to drive up costs, which is not considered in these uncertainty ranges.

2.22 As Figure 4 shows, the price of zero and near-zero GHG emission fuels is expected to be significantly higher than fossil fuels in 2028 and expected to remain slightly higher in 2050. However, between 2028 and 2050, it is expected that some low carbon, zero, and near-zero GHG emission fuels will decrease in price as the technologies for producing and using these fuels develop. Green hydrogen and ammonia halve in price between 2028 and 2050 under our central assumptions. Meanwhile, fossil fuels and biofuels are expected to increase slightly in price by 2050.

2.23 There is considerable uncertainty over the price of maritime fuels up to 2050, which makes drawing conclusive trends from these forecasts difficult. This uncertainty is significantly higher for zero and near-zero GHG emission fuels and exists both in the short and long-term forecasts. The relative competitiveness of these fuels in 2050 will be influenced by the policy measures that are introduced between now and 2050.

2.24 As set out in Table 1, there are advantages and disadvantages to each fuel which means that there is no single optimal solution for all cases. The maritime emissions model does not currently include assumptions on the supply of fuels, the onshore storage or the infrastructure costs associated with each of the potential fuels, which contributes further to uncertainty. For further information on the fuel forecasts included in the maritime emissions model, please refer to the Maritime Emissions Modelling Framework.

Engines

2.25 To facilitate a switch to low carbon and, ultimately, zero and near-zero GHG emission fuels, operators may need to change the type of engine onboard their vessel. While several fuel types such as biofuels will be able to directly replace existing fossil fuels as a drop-in fuel, other low carbon, and zero and near-zero GHG emission fuels will require new or retrofitted engines to be installed. The maritime emissions model includes a variety of engine types with different assumptions about their cost, fuel compatibility, efficiency, and when they will become available. For further information on the engine types included in the maritime emissions model, please refer to the Maritime Emissions Modelling Framework.

Energy efficiency measures

2.26 Increasing the energy efficiency of vessel operations will play a key role in the decarbonisation of the maritime sector. These measures can be split into energy efficiency measures and operational changes.

2.27 Energy efficiency measures, such as propeller optimisation and wind assistance, are technologies that operators can install on their vessels with the aim of decreasing their fuel and energy consumption, and therefore decreasing the emissions they produce.

2.28 Operators can also decrease their emissions by adapting their behaviour and management of the vessels. These measures, such as speed optimisation, include very little or no up-front cost but are likely to yield emissions reductions due to the associated decreases in fuel consumption.

2.29 Due to the wide range of vessel operations within the maritime sector, some of these measures and technologies may only be suitable for certain sub-sectors. Therefore, the cost of installation or operation of one of these measures is likely to vary considerably depending on the size and operation of the vessel. Full details of the energy efficiency measures that have been modelled including their applicability to sub-sectors and their costs, are included in the Maritime Emissions Modelling Framework.

Other measures

2.30 There are other potential emissions reduction technologies, fuels and energy sources that are not currently included in our modelling. These include onshore carbon capture and storage (OCCS), nuclear power, and fuels with the potential for negative WtW GHG emissions. While there has been a rapid development of OCCS across the sector and a growing interest in the potential of nuclear power, there was not enough data available at the time of building the model to include these technologies. In addition, fuels with the potential for negative WtW GHG emissions have not been included in the model at this stage as a conservative approach, given the significant uncertainty regarding the extent that these fuels will be available to the maritime sector in the future.[22] Developing the evidence base on these solutions will be a key focus of the further development of the maritime emissions model. Please refer to the Maritime Emissions Modelling Framework for further details on planned model development.

2.31 Other technologies include those that address air pollutant emissions, for example exhaust gas cleaning systems or exhaust gas recirculation systems. However, the primary focus of the model at this stage has been on reducing greenhouse gas emissions, and as a result, emissions treatment technology that focuses on reducing air pollutants has not been modelled at this stage. As part of the further development of the model, we will develop our evidence on the solutions for reducing all maritime emissions, including those solutions not currently included in our model.

2.32 More broadly, there are additional measures that could be used to compensate for any remaining residual GHG emissions within the UK domestic maritime sector in 2050, namely engineered greenhouse gas removal technologies, such as Direct Air Carbon Capture and Storage (DACCS). These options are not included within the maritime emissions model as they are outside of its current scope, and we make no explicit assumptions on their uptake. Whilst our 2050 goal is for the UK domestic maritime sector to reach zero fuel lifecycle GHG emissions, there may be some residual emissions. In this case, any residual emissions must be compensated for by greenhouse gas removals from the energy system of UK domestic maritime. In line with the 2023 IMO Strategy on Reduction of GHG Emissions from Ships[23], our objective is to reduce GHG emissions within the boundaries of the energy system of the UK domestic maritime sector to as near to zero as possible and prevent a shift of emissions to other sectors.

[22] Examples of non-modelled fuels that could have negative WtW GHG emissions include the use of hydrogen produced using bioenergy with carbon capture and storage (BECCS); and methanol produced using renewable electricity and carbon dioxide (CO_2) extracted from the atmosphere using Direct Air Carbon Capture and Storage (DACCS) and used by vessels fitted with Onboard Carbon Capture and Storage (OCCS).

[23] Resolution MEPC.377(80): 2023 IMO Strategy on Reduction of GHG Emissions from Ships https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf

3. Policies to decarbonise the maritime sector

3.1 As set out in the Maritime Decarbonisation Strategy, there are significant market barriers to decarbonising the UK maritime sector. To overcome these barriers and accelerate the decarbonisation of the sector, the strategy has announced the UK's intention to develop several new policies. This includes the expansion of the UK emissions trading scheme (ETS) to include the maritime sector, as set out in the UK ETS scope expansion consultation[24], and new regulation to reduce the greenhouse gas emissions intensity of fuels used by the UK domestic maritime sector. These policies, alongside international policy measures being considered at the IMO, the measures announced by the EU, and potential further measures, have been modelled in the maritime emissions model. The sections below highlight the key considerations in the modelling of each policy, and any important caveats and limitations. Further information on how each policy has been modelled can be found in the Maritime Emissions Modelling Framework. These scenarios modelled in this document are illustrative only and do not pre-empt any future policy decisions. The following descriptions **should not** be interpreted as providing any insight into the UK's negotiating position at the IMO, or to future decisions of the UK ETS Authority on the expansion of the UK ETS to domestic maritime, or to the final designs of any other new policy measures.

Measures to improve energy efficiency (EEDI, EEXI, CII)

3.2 The model includes several mandatory measures that have already been implemented by the IMO which aim to improve energy efficiency on board vessels.

3.3 The first measure is the Energy Efficiency Design Index (EEDI), which aims to improve the technical performance of new-build ships. The index mandates that ships, which are designed and constructed today, must be more energy efficient than the baseline.[25] Over time, the IMO will increase the baseline to further

[24] UK ETS scope expansion: Maritime Sector UK ETS scope expansion: maritime sector - GOV.UK

[25] The EEDI applies to tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers, combination carriers, LNG carriers, ro-ro cargo ships (vehicle carriers), ro-ro cargo ships;

incentivise innovation in ship design. Different ships will have different requirements, recognising the specific nature of different types of ships.

3.4 The second measure is the Energy Efficiency Existing Ships Index (EEXI), which aims to improve the technical performance of existing ships. All ships larger than 400 gross tonnage (GT) are required to calculate their Attained Energy Efficiency, known as their EEXI, and ensure that this meets the requirements for EEXI certification. If a ship's EEXI fails to meet the requirement, they will be required to implement a variety of technical measures to improve their energy efficiency. The IMO has committed to reviewing the effectiveness of the EEXI requirements by January 1st 2026 and develop further amendments, if necessary.

3.5 The third measure is the Carbon Intensity Indicator (CII Rating), which aims to improve the operational performance of existing ships. This measure requires ships that are larger than 5,000 GT to collect and report their fuel consumption data. Using this data, each ship is assigned a carbon intensity rating from A to E, where A is the highest. Ships with a CII rating of E for one year or with a rating of D for three consecutive years will be required to implement a plan of corrective actions to improve their rating to C or above. The IMO has committed to reviewing the effectiveness of the CII by January 1st 2026 and develop further amendments, if necessary.

Emissions pricing

3.6 The strategy also re-stated the UK Government's intention to expand the UK Emissions Trading Scheme (UK ETS) to include domestic maritime emissions from 2026. Under this system, the total amount of certain greenhouse gas emissions across the traded sector (those sectors covered by the UK ETS) are capped, and operators must obtain allowances for each tonne of in-scope emissions produced annually. The overall emissions cap decreases over time, helping to reduce domestic maritime emissions in line with the goals set out in the Maritime Decarbonisation Strategy.

3.7 This expansion will sit alongside other similar international policy developments, including the inclusion of maritime in the EU ETS and the potential implementation of an economic measure for international shipping at the IMO (which, for simplicity, we model as a further emissions pricing mechanism). While the exact details of how these policies interact is still to be worked through, for simplicity, the model assumes that there is no overlap between the various GHG emissions pricing mechanisms. Therefore, at a given time, vessels are only charged by either an IMO pricing mechanism, the UK ETS, or EU ETS.

3.8 There are several variables within the model which can influence the impact of emissions pricing mechanisms. These include: the date when the mechanisms are introduced, the size thresholds for inclusion of vessels within the schemes,

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ro-ro passenger ships and cruise passenger ships having non-conventional propulsion Improving the energy efficiency of ships (imo.org) and which voyages are included within the scheme. These can all be varied within the model to reflect more or less ambitious policy options.

3.9 The range of UK ETS prices used in our modelling are taken from DESNZ published ETS price series.[26] As a simplifying assumption, these price series are also used for modelling the impact of the EU ETS and an IMO emissions pricing mechanism, due to a lack of alternative forecasts. However, this is a limitation of the modelling as this series may not reflect prevailing prices in the EU ETS nor the prices put in place by a future IMO GHG emissions pricing mechanism.

Fuel regulations

3.10 In the strategy, we announced our plan to introduce new regulations to drive the uptake of low carbon and, ultimately, zero and near-zero GHG emission fuels for maritime. Whilst the exact details of such an intervention are subject to consultation, we have modelled the impact of demand-side fuel regulations, specifically a GHG emissions intensity fuel standard. This aligns with how such a policy has been developed by the EU.[27] The IMO is also currently negotiating a "goal-based marine fuel standard".[28] A fuel standard would set a target on vessels that obliges them to decrease the GHG intensity (the GHG emissions per unit of fuel use) of their fuel usage, relative to a baseline. This target would be progressive and would increase in stringency over time. It is likely that this will only apply to vessels over a certain size. As the development of UK regulations in this space is subject to consultation, a fuel standard is modelled as an illustrative policy option, rather than reflecting final policy decisions. Further policy discussion about this is included in the strategy document.

3.11 Within the maritime emissions model, there are several variables that determine the impact that fuel standards have on maritime emissions, including the date they are introduced, the size threshold which determines the vessels covered, which voyages are covered, and the stringency of the standard itself. The UK intends to introduce maritime fuel regulations by the start of CB6, so no later than 2032. However, within the model, the start date can be brought forward to reflect a higher level of ambition. In line with conventional size thresholds considered at the IMO, we have modelled scenarios with regulations applying to all vessels of 5,000GT and above, and a lower threshold of 400GT and above. Lowering the threshold to 400GT significantly expands the number of vessels that would be required to comply with regulations. Finally, the stringency of a fuel standard itself, which indicates how quickly operators will be required to decarbonise, can be altered.

[26] 'Market carbon values' series from *Traded carbon values used for modelling purposes, 2023*. https://www.gov.uk/government/publications/traded-carbon-values-used-for-modelling-purposes-2023/traded-carbon-values-used-for-modelling-purposes-2023

[27] Council of the European Union (2023), FuelEU maritime initiative: Council adopts new law to decarbonise the maritime sector. https://www.consilium.europa.eu/en/press/press-releases/2023/07/25/fueleu-maritime-initiative-council-adopts-new-law-to-decarbonise-the-maritime-sector/

[28] International Maritime Organization (IMO) (2023), Revised GHG strategy for global shipping adopted. https://www.imo.org/en/MediaCentre/PressBriefings/pages/Revised-GHG-reduction-strategy-for-global-shipping-adopted-.aspx

3.12 When modelling fuel standards, as a simplifying assumption, we do not currently assume the existence of flexibility mechanisms such as tradeable allowances or within-fleet pooling. Fuel standards are therefore essentially modelled as maximum GHG intensity thresholds. Finally, as previously mentioned, the maritime emissions model does not explicitly model the supply of fuels, or interactions with other schemes such as the Renewable Transport Fuel Obligation (RTFO) and the Sustainable Aviation Fuels Mandate.

Further measures to address emissions from smaller vessels and emissions at berth

3.13 The modelling includes some indicative further measures to tackle emissions from vessels less than 400GT. These measures are designed as proxies to capture the effects of potential future policies targeting these vessels and are not necessarily representative of current policy thinking. The model includes two measures for less than 400GT ships:

- A phase-in of zero and near-zero GHG emission vessels, where all ships built after a certain date are required to be zero and near-zero GHG emissions capable (including via retrofitting).

- A lowering of the fuel standard size threshold to capture all ships.

3.14 Development of actual policies to target vessels of this size will in part be informed by the call for evidence on measures to reduce emissions from small vessels and targeted subsectors, which was published alongside the strategy. We expect proportionate measures to be introduced at different times, recognising the diversity of the sector and the fact that some sub-sectors have clearer decarbonisation pathways than others.

3.15 Finally, while the strategy has a section discussing the potential for future policies to address emissions at berth (section 4.6), no policies to address these emissions are explicitly included within current modelling. This is because policies are not yet developed and emissions at berth are already captured within the modelling by the other policy measures.

Wider environmental impacts of policies

3.16 As the package of policy measures set out in the strategy encourages the switch to less polluting maritime fuels, there should also be a positive impact on air quality, water quality and biodiversity. However, this impact will vary depending on the fuels used, as some alternative fuels will still produce more pollutants than others, and some could introduce new environmental risks, for example from slippage. As set out above, while we do model some of the main primary air quality impacts associated with our policies, we do not currently have the evidence base to comprehensively model the full impacts of the various low carbon, zero, and near-zero GHG emission fuels on air quality, water quality or biodiversity. We will continue to keep this evidence base under review and aim to develop our modelling capabilities in this space. As the policies themselves are further developed, consideration will be taken to mitigate against adverse wider environmental impacts on air quality, water quality and biodiversity, as far as possible.

4. Illustrative decarbonisation scenarios for UK domestic maritime

4.1 The Maritime Decarbonisation Strategy includes new decarbonisation goals for the UK domestic maritime sector. We have used our maritime emissions model to produce ranges of illustrative decarbonisation scenarios for the UK domestic maritime sector (excluding inland waterways, which are not currently modelled), alongside a baseline projection with no further measures. We have not included a central emissions scenario for the sector, due to the substantial uncertainty surrounding both future technological solutions and policy measures.[29] The ranges are intended to show an illustrative set of futures for how the sector can meet our interim decarbonisation goals and minimise wherever possible residual GHG emissions in 2050.

4.2 The strategy does not set goals for the UK's international maritime emissions, as this is done at the IMO and these emissions are out of scope of our domestic policy measures. We have therefore not included scenarios in the same way for the UK's share of international maritime emissions, although we can also model the impact of international policy assumptions on these emissions, as set out at the end of Section 4.

Scenario assumptions

4.3 The following section sets out the details of, and key policy assumptions underpinning, the baseline and the upper and lower bounds of the core range of UK domestic maritime emissions. These assumptions are summarised in Table 2. As specific policy design details, such as the potential scope of policies and if or when these may change, are not yet finalised for several policies at both the domestic and international levels, we have tested hypothetical higher and lower ambition versions of these assumptions (though it should be noted that the upper and lower bounds are both highly ambitious but vary in the timing and stringency of the policies introduced). These assumptions are illustrative only and do not pre-empt any future policy decisions. They **should not** be interpreted as final policy decisions or be taken to suggest a UK position on any

[29] A single emissions trajectory has been considered for the development of certain policies where a specific trajectory is required, for example the expansion of the UK Emissions Trading Scheme to UK Domestic Maritime and the development of Carbon Budgets. This is further explained in Box 3.

future policy decisions. This core range of decarbonisation scenarios reflects policy uncertainty only. Further sensitivities relating to wider uncertainty, including maritime demand, fuel, and technology prices, and ETS prices are held at central values throughout Section 4. These factors are varied in Section 5 ('Sensitivity Analysis'), where a wider range of potential scenarios are presented.

Baseline

4.4 The baseline pathway represents a 'business as usual' or 'no further policy action' world and provides a counterfactual against which the impact of further policies can be tested. The only policies included in the baseline are existing IMO efficiency measures (CII, EEXI and EEDI), as well as announced EU policies, namely extension of the EU ETS to cover maritime[30] and a fuel standard[31]. No UK policy measures are included in our baseline as these are either still under development or are yet to come into effect.

4.5 We recognise that there is significant uncertainty in the baseline, both in terms of details of policies at the EU level, which are still yet to be confirmed (such as whether the gross tonnage threshold for inclusion in the EU ETS will change and when this might occur), and underlying uncertainty factors, such as fuel prices, and demand for freight and non-freight services. The latter are varied further in Section 5. EU ETS expansion is assumed to have a phased introduction for freight and passenger ships over 5,000GT from 2024-2026, where the share of emissions that must be covered by allowances gradually increases each year. From 2027, 100% of emissions reported must be covered by allowances and offshore ships are included. Additionally, the EU fuel standard is introduced in 2025 for vessels over 5,000GT, requiring an 80% reduction in the GHG intensity of fuels by 2050.

Upper bound (lower policy stringency, higher emissions)

4.6 Our upper and lower bound decarbonisation scenarios both assume that ambitious policy packages are taken forward by the UK, EU, and IMO. Compared to the lower bound decarbonisation scenario, the upper bound of the range reflects a higher emissions world due to slightly less ambitious policy assumptions. The differences between the upper and lower bounds reflect the uncertainty regarding the final design of policy measures, including the level of stringency over time as well as the pace at which these policy measures can be implemented. The specific assumptions adopted for our upper bound decarbonisation scenario are described below. We will keep these assumptions

[30] EU (2023) Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union https://eur-lex.europa.eu/eli/dir/2023/959/oj. The EU ETS will apply to 50% of international journeys between the EU and UK. This will have some impact on domestic UK maritime emissions as many vessels carry out both international and domestic voyages, and our definition of domestic emissions includes emissions from vessels at berth in UK ports whilst on international journeys.

[31] EU (2023) Regulation 2023/1805 on the use of renewable and low-carbon fuels in maritime transport https://eur-lex.europa.eu/eli/reg/2023/1805/oj

under review as policies develop and update them as appropriate in future iterations of the model.

4.7 We assume slightly later UK action than in our lower bound decarbonisation scenario, to reflect an illustrative scenario in which it takes longer to develop domestic policy. The UK ETS is assumed to expand to cover domestic maritime vessels over 5,000GT from 2026, which is the proposed threshold for the scheme. The threshold is then assumed to drop to 400GT in 2037. This is not a confirmed policy position, and the 'UK ETS Scope Expansion: Maritime' consultation included questions on whether to review the threshold in 2028. The inclusion of this assumption is not intended to pre-empt the outcome of that consultation. We assume a UK fuel standard is introduced in 2033 for vessels over 5,000GT, dropping to vessels over 400GT in 2038, reaching a 95% reduction in GHG intensity of the fuel mix by 2050 on a WtW basis. A phase-in for vessels under 400GT is assumed from 2035, which assumes that all new vessels under 400GT built after 2035 must use zero or near-zero GHG emission fuels or technologies.

4.8 EU policies are assumed to be the same as in the baseline, other than relating to size thresholds. The upper bound now assumes that EU ETS expansion and the EU fuel standard drop to a 400GT threshold in 2037 and 2038 respectively.[32] Again, as decisions over potential future threshold changes are yet to be made, these assumptions are intended to be illustrative and do not pre-empt any EU policy decisions.

4.9 Alongside the IMO efficiency measures included in the baseline, we assume the introduction of an IMO GHG emissions pricing mechanism and an IMO fuel standard. In line with the 2023 IMO Strategy on Reduction of GHG Emissions from Ships[33], these measures are assumed to be introduced from 2027. Under the timetable agreed by the IMO, the final designs of any new measure(s) will not be known until later in 2025. Therefore, several additional assumptions have had to be made to model these measures. As a simplifying assumption, given the uncertainty surrounding when the IMO policies may drop to 400GT, we have adopted the same assumptions as for the equivalent UK policies. However, we recognise that the timing of any threshold changes may differ at the UK, EU, and IMO levels in practice. Therefore, we assume that these measures are initially applied to vessels over 5,000GT and then to vessels over 400GT in 2037 for the GHG emissions pricing mechanism and 2038 for the fuel standard. Given the uncertainty regarding how an IMO fuel standard would be implemented, to enable us to understand how the GHG emissions from UK domestic maritime would evolve under a less ambitious scenario for the policy stringency that is agreed by the IMO, the IMO fuel standard is assumed to be set at a level that means that the sector only uses fuels with at least a 90%

[32] The EU has announced that the GT threshold for inclusion in the EU ETS is subject to review. Any changes to the GT threshold are likely to be phased by the various maritime sub-sectors, therefore, the inclusion of this assumption within our scenarios is intended to be a general conservative assumption of that process.

[33] IMO Marine Environment Protection Committee (2023) Annex 15. 2023 IMO strategy on reduction of GHG emissions from ships https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf

reduction in GHG intensity by 2050 on an adjusted TtW basis[34]. Given details of these policies are not yet finalised, these assumptions are purely illustrative and are not intended to pre-empt any final IMO position. These assumptions should not therefore be interpreted as providing any insight into the UK's negotiating position at the IMO.

4.10 The upper bound scenario reflects what will be needed as a minimum to meet our interim domestic decarbonisation goals for seagoing vessels (as discussed in Box 4, emissions from inland waterways will also need to fall to meet our overall goals for the sector). There will therefore still be significant challenges in delivering this scenario, such as the development of new technologies to commercial readiness and ensuring the availability of future fuels at the scale needed. Further uncertainty factors such as fuel prices, demand, and technology costs and effectiveness are held at their central values for the core range of trajectories and are varied in Section 5.

Lower bound (higher policy stringency, lower emissions)

4.11 Compared to our upper bound decarbonisation scenario, the lower bound of the range reflects a lower emissions world due to more ambitious policy assumptions. The specific assumptions adopted for our lower bound decarbonisation scenario are described below. We will keep these assumptions under review and update them as appropriate in future iterations of this modelling.

4.12 At the international stage, an IMO GHG emissions pricing mechanism and a fuel standard for vessels over 5,000GT are both assumed to be introduced, starting in 2027 and dropping to 400GT from 2032. To enable us to understand how the GHG emissions from UK domestic maritime would evolve under a more ambitious scenario for the policy stringency that is agreed by the IMO, the fuel standard is assumed to reach a 95% reduction in the GHG intensity of the fuel mix by 2050, on a WtW basis. Due to the current limitations of the maritime emissions model, we judge that this is the highest stringency that we can feasibly model currently, and it restricts the fuel options in 2050 to only biofuels, green hydrogen and hydrogen-derived fuels with no use of any fossil fuels.[35]

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[34] For the purposes of this modelling, the adjusted tank-to-wake GHG intensity of a fuel in a given year is assumed to be calculated as follows:
$adjusted\ TtW$ GHG intensity = WtW GHG intensity * TtW Reference Value / WtW Reference Value, where
'WtW GHG intensity' is the well-to-wake GHG intensity of the fuel in the given year;
'TtW Reference Value' is the average tank-to-wake GHG intensity for international shipping in 2008;
'WtW Reference Value' is the average well-to-wake GHG intensity for international shipping in 2008.

[35] All of the modelled fuels have some level of N_2O or CH_4 emissions. This means there are no zero GHG emission fuels currently included in the maritime emissions model. Achieving a 100% reduction in fuel GHG intensity across UK domestic maritime would only be possible through additional greenhouse gas removals from the energy system of UK domestic maritime, which we have not modelled at this stage. In particular, if some fuels continue to be used in 2050 that have N_2O or CH_4 emissions, some use of other fuels with negative GHG emissions would be would be required to balance any residual emissions with negative emissions elsewhere in the economy. Examples of non-modelled fuels that could have negative GHG emissions include hydrogen produced using bioenergy with carbon capture and storage (BECCS); and methanol produced using renewable electricity and CO_2 extracted from the atmosphere using DACCS and used by vessels fitted with OCCS.

However, we will keep this under review as part of the further development of the maritime emissions model. The existing CII measure is also assumed to be extended to 2030 with vessels required to decrease their carbon intensity by 30% from 2019 levels. This assumption is consistent with the 2023 IMO GHG Strategy's carbon intensity goal of a 40% reduction which is relative to a different base year (2008, rather than 2019). As with the assumptions for our upper bound decarbonisation scenario, given details of these policies are not yet finalised, these assumptions are purely illustrative and are not intended to pre-empt any final IMO position. As above, these assumptions should not therefore be interpreted as providing any insight into the UK's negotiating position at the IMO.

4.13 EU measures are also assumed to be more ambitious than in our upper bound decarbonisation scenario. For this scenario, expansion of the EU ETS to cover maritime is again assumed for vessels over 5,000GT from 2024-26 but dropping to 400GT in 2032.[36] An EU fuel standard is assumed for vessels over 5,000GT from 2025, also dropping to 400GT in 2032. Again, given that this goes beyond what the EU has agreed to date, these assumptions are illustrative and simply aim to reflect a potential higher ambition world, rather than to pre-empt any final policy decisions.

4.14 UK policy measures are assumed to be introduced earlier than in the upper bound decarbonisation scenario, to reflect an illustrative scenario with faster and more ambitious domestic action. Expansion of the UK ETS to include domestic maritime is assumed for vessels over 5,000GT from 2026, dropping to 400GT from 2032 and covering WtW emissions.[37] This is a modelling assumption only and does not reflect current policy thinking. A UK fuel standard is assumed for vessels over 5,000GT from 2027, dropping to 400GT from 2032, reaching a 95% reduction in GHG intensity of the fuel mix by 2050 on a WtW basis. For vessels under 400GT, a phase-in and further policy measures which drive decarbonisation are included from 2035. Due to a lack of clarity over the exact details of these measures, further policy measures are approximated as an expansion of the fuel standard to vessels under 400GT, which creates a similar effect for the purposes of the model.

4.15 The lower bound reflects an extremely ambitious scenario and will be challenging to meet due to the ambitious policy timelines and the substantial scale up in technology readiness required. As stated previously, these assumptions are illustrative only and should not be interpreted as a preferred UK position on any future policy decisions that need to be made, either domestically or at the international stage. As with the upper bound, further uncertainty factors such as fuel prices, demand, and technology costs and

[36] The EU has announced that the GT threshold for inclusion in the EU ETS is subject to review. Any changes to the GT threshold are likely to be phased by the various Maritime sub-sectors, therefore, the inclusion of this assumption within our scenarios is intended to be a general conservative assumption of that process. Certain sub-sectors may see threshold adjustments as early as 2027.

[37] These are hypothetical assumptions and should not be interpreted as confirmed policy decisions relating to the UK ETS. Questions about the scope of the scheme are included in the consultation on *UK Emissions Trading Scheme Scope Expansion: Maritime* and will be confirmed through the government response to the consultation.

effectiveness are held at their central values for this scenario and are varied in Section 5.

Policy measures	Baseline	Upper bound – Higher emissions	Lower bound – Lower emissions
Increasing energy efficiency	Existing IMO efficiency measures: CII, EEDI, EEXI	Existing IMO efficiency measures: CII, EEDI, EEXI	Existing IMO efficiency measures: CII, EEDI, EEXI. Extension of CII to 2030 with a 30% decrease required (relative to 2019).
Pricing emissions	Inclusion of maritime in EU ETS covering TtW emissions, starting in 2024-26 (phased) at 5,000GT threshold.	IMO GHG emission pricing mechanism covering TtW emissions, starting in 2027 at 5,000GT threshold, dropping to 400GT in 2037	IMO GHG emission pricing mechanism covering WtW emissions, starting in 2027 at 5,000GT threshold, dropping to 400GT in 2032
		Inclusion of maritime in EU ETS covering TtW emissions, starting in 2024-26 (phased) at 5,000GT threshold, dropping to 400GT in 2037	Inclusion of maritime in EU ETS covering TtW emissions, starting in 2024-26 (phased) at 5,000GT threshold, dropping to 400GT in 2032
		Inclusion of domestic maritime in UK ETS covering TtW emissions, starting in 2026 at 5,000GT threshold, dropping to 400GT in 2037	Inclusion of domestic maritime in UK ETS covering WtW emissions, starting in 2026 at 5,000GT threshold, dropping to 400GT in 2032
Uptake of future fuels and energy sources	EU fuel standard starting in 2025 at 5,000GT threshold, requiring 80% reduction in GHG intensity by 2050.	IMO fuel standard starting in 2027 at 5,000GT threshold, dropping to 400GT in 2038	IMO fuel standard starting in 2027 at 5,000GT threshold, dropping to 400GT in 2032
		EU fuel standard starting in 2025 at 5,000GT threshold, dropping to 400GT in 2038	EU fuel standard starting in 2025 at 5,000GT, dropping to 400GT in 2032
		UK fuel standard starting in 2033 at 5,000GT threshold, dropping to 400GT in 2038	UK fuel standard starting in 2027 at 5,000GT threshold, dropping to 400GT in 2032
Targeted further measures	None	All <400GT ships built after start date must use zero and near-zero GHG emission fuels, from 2035 (a proxy for future policy that will apply to vessels below 400GT)	All <400GT ships built after start date must use zero and near-zero GHG emission fuels, from 2035 (a proxy for future policy that will apply to vessels below 400GT)
			UK fuel standard extended to <400GT ships (a proxy for policy measures that would decarbonise all ships by 2050), from 2035

Table 2. Policy assumptions used in range of emissions scenarios.

Box 3. A single scenario for projecting the UK ETS cap adjustment.

Given the uncertainty surrounding future policy, we have presented a range of illustrative decarbonisation scenarios in the Maritime Decarbonisation Strategy, rather than one central trajectory. However, for certain purposes, such as feeding into wider policy development, a single decarbonisation trajectory may be required. When a single decarbonisation scenario is required, we will develop midpoint assumptions that strike an appropriate balance between the upper and lower bounds of the uncertainty surrounding future policy.

A single scenario has been required to calculate the adjustment that the UK ETS Authority intends to make to the UK ETS cap from 2026 to 2030 in response to the expansion of the UK ETS to domestic maritime, pending the Authority Response to the consultation, which is expected later this year. For this purpose, the scenario we have modelled includes the following assumptions: all policy measures for vessels over 5,000GT are introduced in the same year as in the upper bound scenario. However, the UK and IMO fuel standards are more stringent. All threshold changes still occur after 2030 and therefore do not affect the projection for the UK ETS cap adjustment, which also currently only includes emissions from vessels over 5,000 GT. These assumptions result in a trajectory that is in line with the midpoint between the upper and lower bounds of our emissions range. As with the assumptions for our upper and lower bound decarbonisation scenarios, given details of these policies are not yet finalised, these assumptions are purely illustrative and are not intended to pre-empt any final IMO position, or the final UK ETS policy position, which will be set out in the Authority Response. As above, these assumptions should not therefore be interpreted as providing any insight into the UK's negotiating position at the IMO.

To calculate the proposed adjustment to the UK ETS cap, we have taken this emissions scenario for vessels over 5,000GT only (i.e. those within scope of the UK ETS from 2026). The proposed cap adjustment figures for maritime are included in the table below. These updated figures supersede those included in the UK ETS Maritime consultation published in November 2024 and will inform the UK ETS Authority's intended cap adjustment. The UK ETS Authority intends therefore to seek views on this new trajectory prior to publication of the Authority Response to that consultation.

	2026	**2027**	**2028**	**2029**	**2030**
Indicative cap adjustment (millions of UK ETS allowances (UKAs))	2.7	2.6	2.5	2.5	2.4

The trajectory used to produce this cap adjustment is on a TtW basis, though the UK ETS scope expansion consultation included a question on whether to extend the ETS to include WtW emissions from maritime. This cap adjustment trajectory also does not account for potential exemptions to the scheme, such as for Scottish island ferries. We intend therefore to amend this trajectory following final decisions on any such exemptions or emissions scope in the Authority Response to the UK ETS consultation. Please refer to the analytical annex to the UK ETS scope expansion consultation for more information.

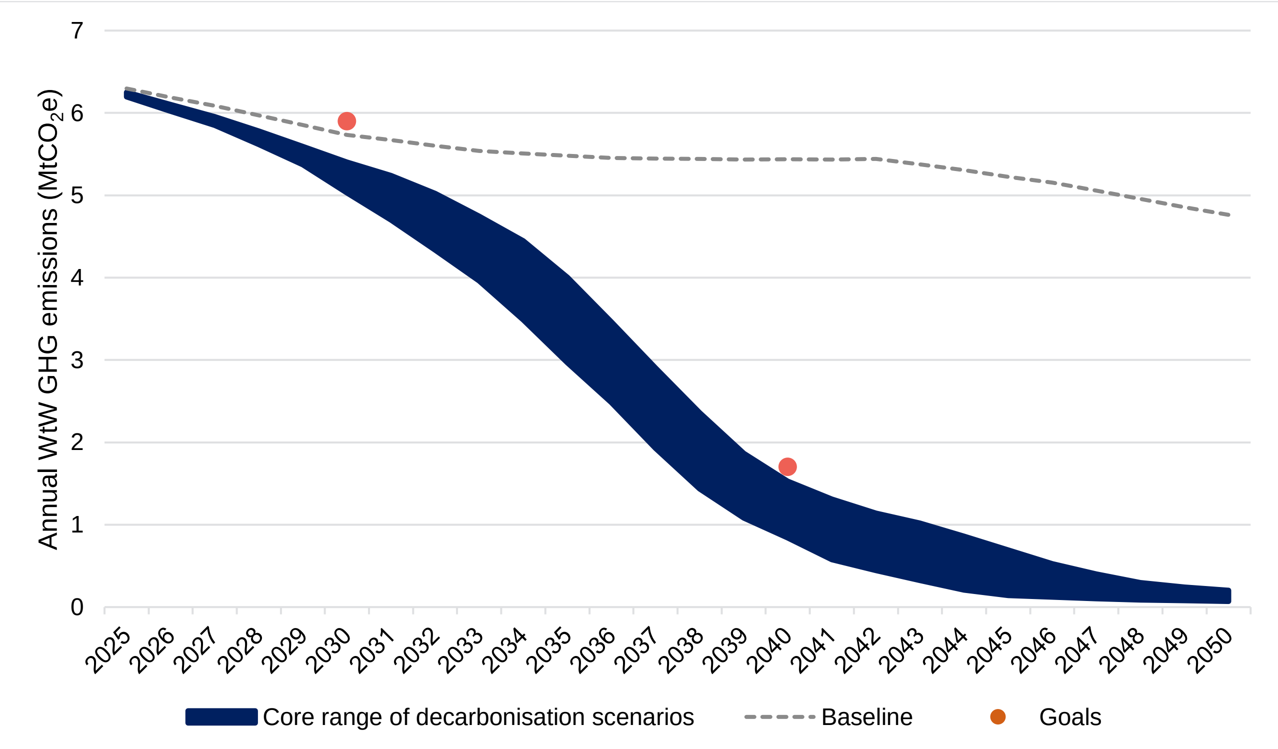
The uncertainty surrounding future policy will decline as policy decisions are taken both domestically and internationally. We will therefore keep all policy assumptions under review and update our midpoint assumptions as appropriate in other situations when a single decarbonisation scenario is required in the future.

Scenario results

4.16 The range of decarbonisation scenarios modelled using the assumptions set out above are illustrated in Figure 5. Note that all charts presented here represent WtW emissions, in line with our decarbonisation goals set out in the strategy, and do not include emissions from inland waterways, unless stated. Box 4 presents our emissions range and goals on a TtW basis, including estimates for inland waterways.

4.17 As illustrated in the chart below, our core range of decarbonisation scenarios (excluding inland waterways) meets our 2030 and 2040 decarbonisation goals as set out in the strategy. In 2050, residual emissions from UK domestic maritime (excluding inland waterways) are around 0.2 $MtCO_2e$ under the upper bound of the modelled range of scenarios, and 0.07 $MtCO_2e$ in the lower bound. While our 2050 goal for the UK domestic maritime sector is to reduce fuel lifecycle GHG emissions to zero, we recognise that some residual emissions may remain. Any residual emissions, including those from the inland waterways sector, will need to be compensated for by greenhouse gas removals from the energy system of domestic maritime to meet this goal. In line with the 2023 IMO Strategy on Reduction of GHG Emissions from Ships, our objective is to reduce GHG emissions within the boundaries of the energy system of the UK domestic maritime sector and prevent a shift of emissions to other sectors.

Figure 5. Core range of WtW greenhouse gas emissions from UK domestic maritime vessels under our illustrative decarbonisation scenarios and baseline, compared to goals (excluding inland waterways).



Note: Figure 5 shows the core range of estimated annual lifecycle (WtW) greenhouse gas emissions from UK domestic maritime under our baseline and our illustrative decarbonisation scenarios, compared to the decarbonisation goals published in the strategy. Emissions are measured in Mt CO_2e. The trajectories and goals presented here do not include emissions from inland waterways. Results are presented for the Balanced Mix fuel scenario (see Table 3 for more details).

Box 4. Tank to Wake emissions and trajectories for inland waterways

Emissions from inland waterways are not currently included in the maritime emissions model, nor our new illustrative decarbonisation scenarios for the domestic maritime sector. Therefore, we have had to make some simplistic assumptions about how these could change over time to meet our goals.

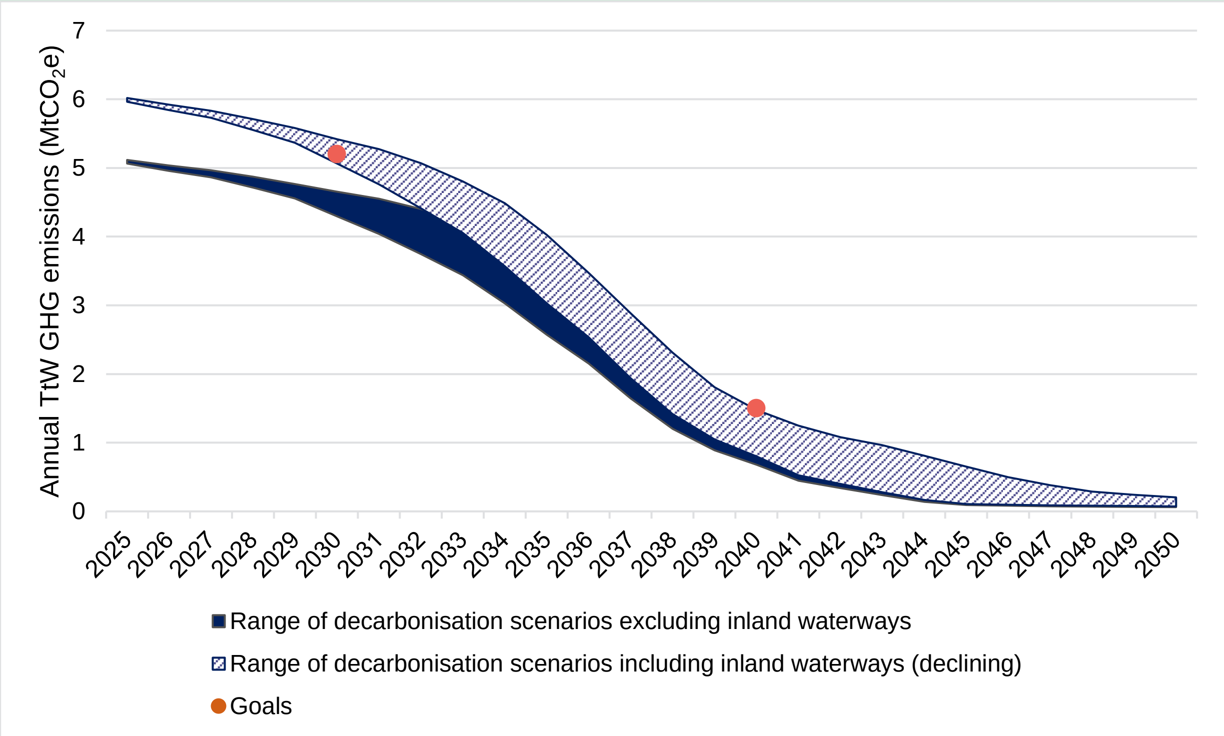
Our decarbonisation goals and scenarios for the domestic maritime sector have been modelled on a WtW basis, in line with the 2023 IMO GHG Strategy. However, the existing estimates we have for emissions from inland waterways are on a TtW basis only. To illustrate how inland waterways can fit into our goals, we can convert both our goals and illustrative decarbonisation scenarios to a TtW basis, as shown in Figure 6.

The goals presented in Figure 6 include emissions from inland waterways. For the trajectories themselves, the GHG emissions from inland waterways are presented, and are assumed to decline from their 2019 level (1.0MtCO_2e on a TtW basis, based on the UK's National Atmospheric Emissions Inventory) at the same rate as emissions from the rest of the domestic maritime sector.[38] As set out in Box 2, there is significant uncertainty surrounding these emissions estimates and the decarbonisation options available to inland waterway vessels, which we will aim to address through the Call for Evidence on emissions from smaller vessels, which was published alongside the strategy, and our planned programme of model development in this space.

Figure 6 illustrates that, assuming emissions from inland waterway vessels fall in line with the rest of the maritime sector, we should be able to meet our 2030 goals (under the lower bound of the range) and 2040 goals (under the full range). The 2030 goal is at risk under the upper bound of the range, highlighting that further policy work will be needed in this space for the inland waterway sector to mitigate this risk and ensure that the inland waterway sector is on track to decarbonise. To the extent that the GHG emissions from the inland waterway sector do not decline sufficiently, more stringent policy measures will need to be introduced for seagoing vessels to meet the 2030 goal in line with our 'lower bound' scenario.

[38] This simplifying assumption is in line with the approach for taking account of non-modelled ships that was adopted in modelling undertaken as part of an external research project previously commissioned by the Department for Transport, which is explained in Section 3.3 of UMAS, Frontier Economics and CE Delft (2019) Reducing the UK maritime sector's contribution to climate change and air pollution. Scenario Analysis: Take-up of Emissions Reduction Options and their Impacts on Emissions and Costs - Technical Annex. A Report for the Department for Transport. https://assets.publishing.service.gov.uk/media/5d25f1ceed915d699a89a253/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs-technical-annexes.pdf.

Figure 6. Estimates of annual operational (TtW) greenhouse gas emissions from UK domestic maritime under our illustrative decarbonisation scenarios, including inland waterways (declining in line with the rest of the sector) and decarbonisation goals.



Note: Figure 6 shows the estimated annual operational (TtW) greenhouse gas emissions from UK domestic maritime under our illustrative decarbonisation scenarios both with and without emissions from inland waterways included, compared to the decarbonisation goals set out in the strategy. The upper range of trajectories includes emissions produced by the inland waterways' subsector, held constant at $1MtCO_2e$ per year. Emissions are measured on an operational (TtW) basis in $MtCO_2e$, and the strategy goals include emissions produced by the inland waterways subsector within their scope. Note that this uses the TtW emissions factors as set out in Figure 2.

Box 5. Consistency with previously published maritime decarbonisation scenarios

For UK carbon budget purposes, the term "transport emissions" broadly refers only to the emissions from fuel combusted during operation, with defined accounting rules for low carbon fuels. Emissions from the wider transport system (e.g. electricity generation and infrastructure) are captured under other sectors. This section demonstrates how the proposed package of policies set out in the strategy compares to the analysis that informed the March 2023 Carbon Budget Delivery Plan (CBDP).

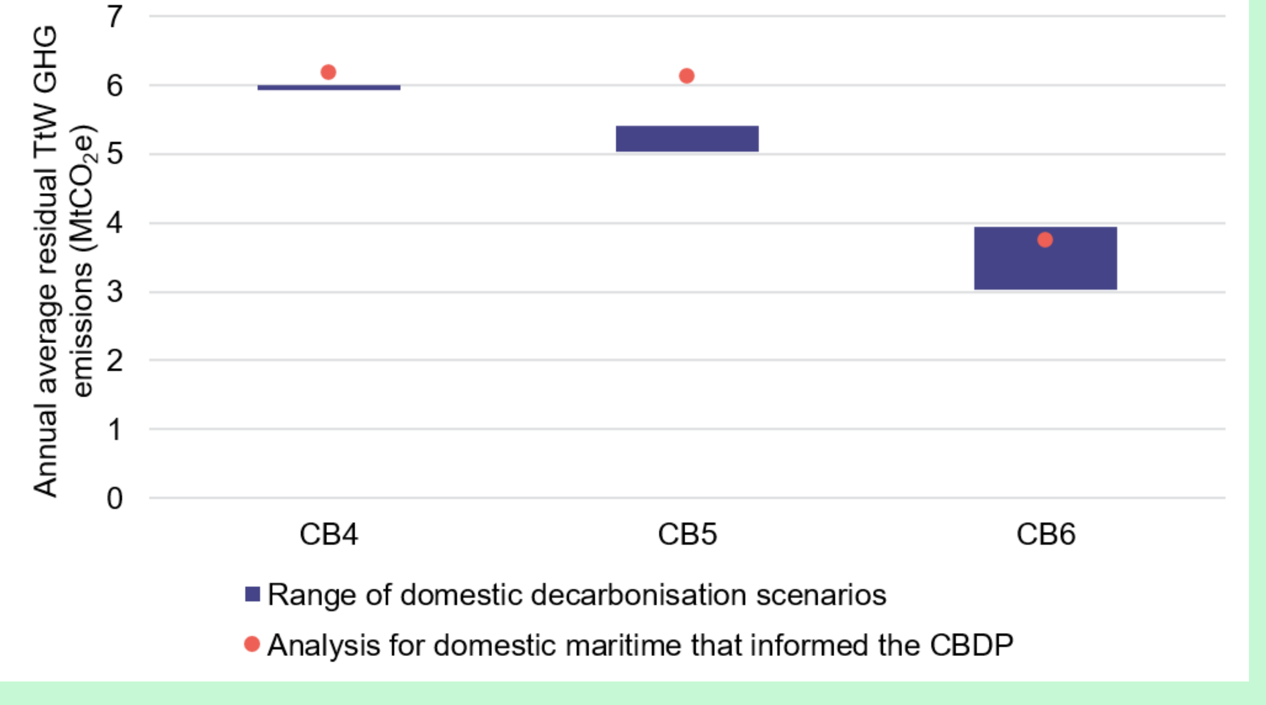
Previous maritime decarbonisation scenarios, which informed the 2021 Net Zero Strategy and the CBDP, were based on modelling undertaken as part of an external research project commissioned by the Department for Transport and completed in

2019.[39] Since then, we have developed new and improved maritime emissions modelling capability internally, as set out in Section 2.

Figures 7a and 7b compare the residual emissions under the range of illustrative decarbonisation trajectories produced for the strategy to the residual emissions for the sector that were included in the Carbon Budget Delivery Plan analysis, for both the domestic and international UK maritime sectors. These figures are provided on an average annual basis over the 5-year carbon budget periods. As set out in section 2.17, this analysis assumes that synthetic fuels are zero emission on a TtW basis, in line with previous published analysis, noting this may be subject to change as international accounting protocol evolves.

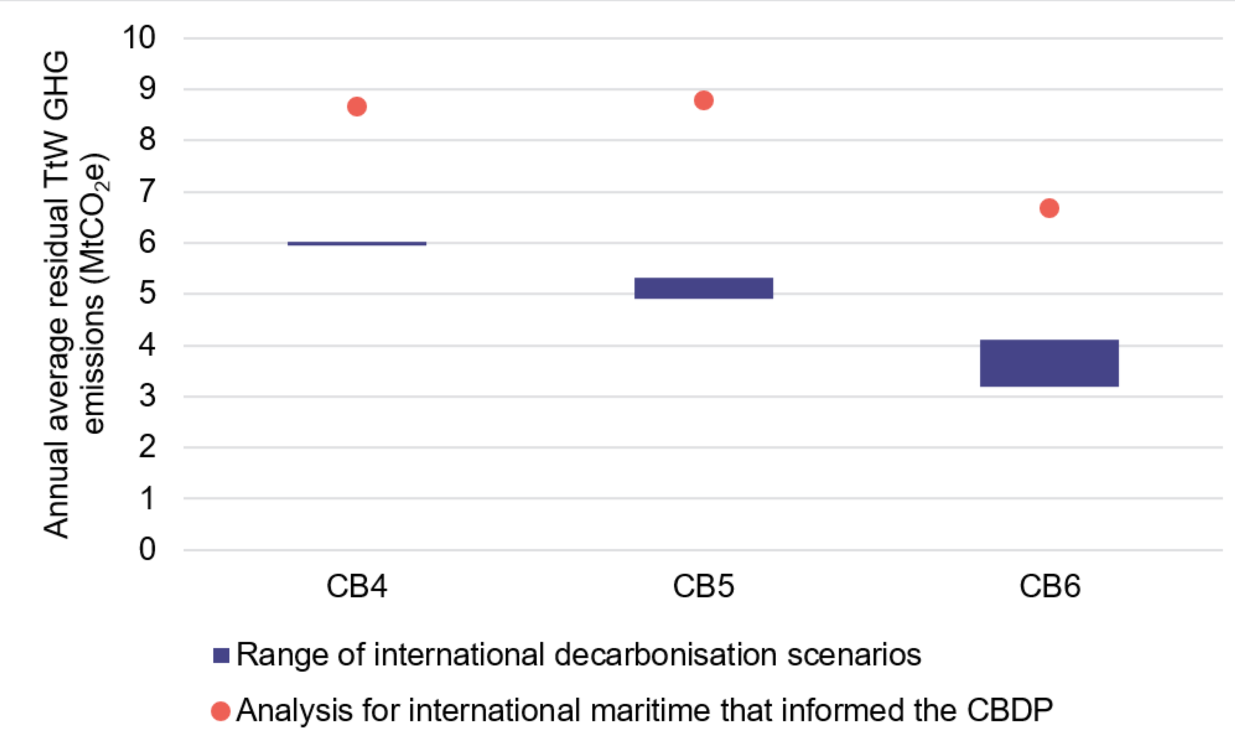
The first chart shows that, for domestic maritime, our new lower bound emissions scenario delivers greater savings than were assumed for domestic maritime in the CBDP, assuming inland waterway emissions decline at the same rate as the rest of the sector. The upper bound emissions scenario still delivers greater savings than were assumed in the CBDP for carbon budgets 4 and 5, however carbon budget 6 emissions are slightly higher than in the CBDP analysis (0.18 $MtCO_2e$ per year, on average). For international maritime, our full range of scenarios delivers greater emission savings than were assumed in the CBDP, as shown in Figure 7b.

Figure 7a. Estimates of annual average residual operational (TtW) greenhouse gas emissions from UK *domestic* maritime under the range of illustrative decarbonisation scenarios, compared to analysis for the Carbon Budget Delivery Plan, over the Carbon Budget time periods



[39] UMAS, E4Tech, Frontier Economics (2019) Reducing the maritime sector's contribution to climate change and air pollution https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816018/scenario-analysis-take-up-of-emissions-reduction-options-impacts-on-emissions-costs.pdf

Figure 7b. Estimates of annual average residual operational (TtW) greenhouse gas emissions from UK *international* maritime under the range of illustrative decarbonisation scenarios, compared to analysis for the Carbon Budget Delivery Plan, over the Carbon Budget time periods



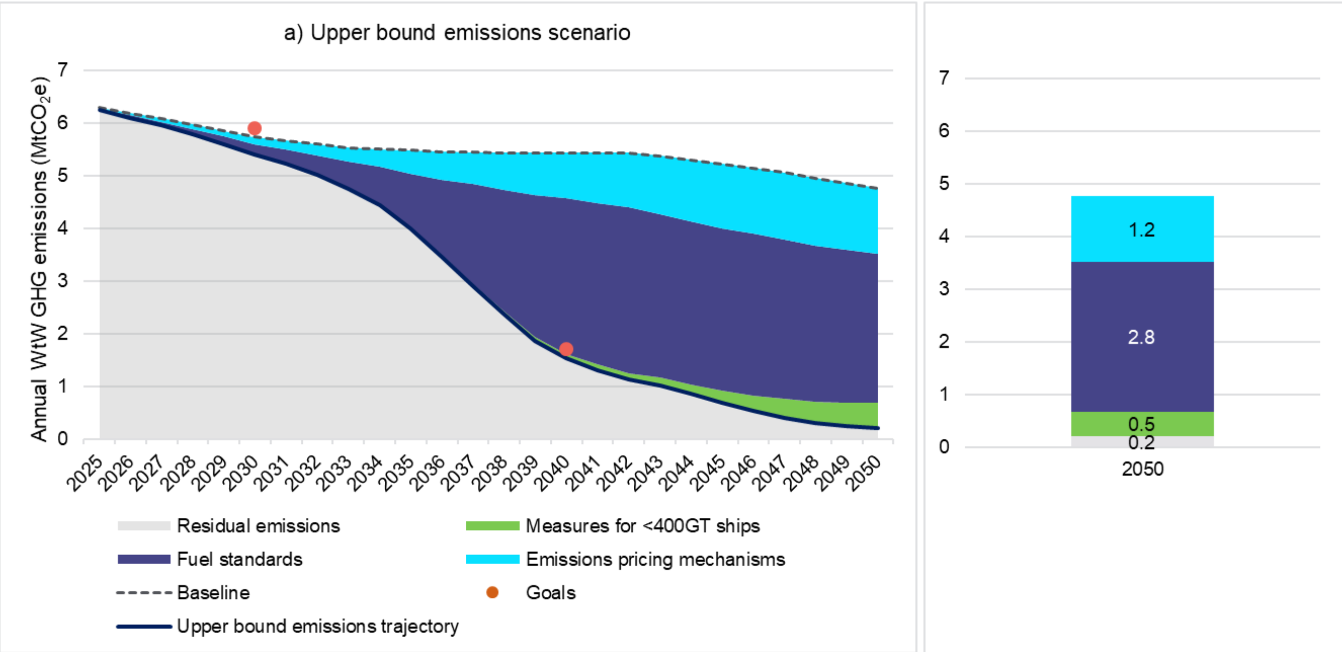
Note: Figure 7a shows the range of annual average estimated residual operational (TtW) greenhouse gas emissions from UK domestic maritime under our illustrative decarbonisation scenarios, calculated over the 5-year Carbon Budget periods. Emissions from inland waterways assumed to fall in line with the trajectory for the rest of the sector. Alongside this we present the residual emissions from the domestic maritime sector from the previous analysis that fed into the Carbon Budget Delivery Plan. Results are presented for the Balanced Mix fuel scenario (see Table 3 for more details). Figure 7b presents the same numbers for the UK international maritime sector. Note that International Shipping is only formally included in the 6th Carbon Budget.

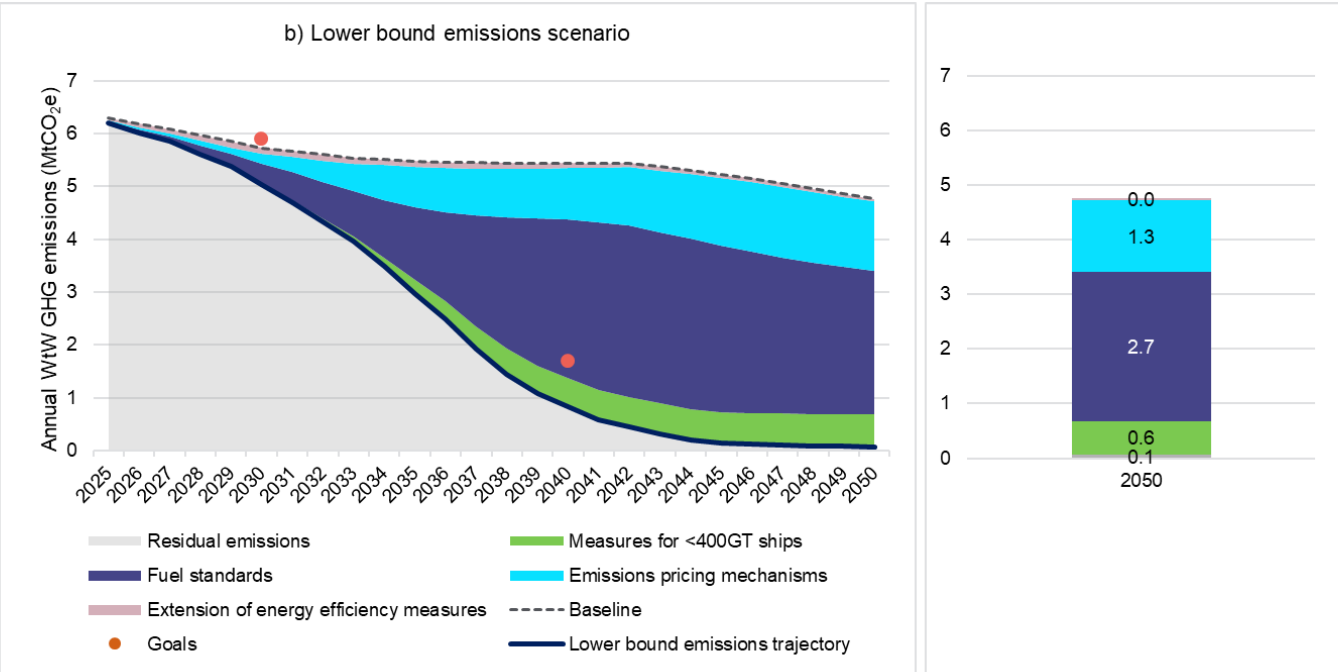
4.18 Figures 8a and 8b show the estimated contribution of individual policy measures to reducing the total annual lifecycle (WtW) GHG emissions from UK domestic maritime (excluding inland waterways) under the upper and lower bounds of the range of decarbonisation scenarios.[40] When split by policy measure, we see that the biggest contribution to overall GHG emission reductions is from fuel standards. However, this is not the case for all vessel types. The modelled decarbonisation of individual vessel types does not strictly follow the pathways set out in Figure 5. Rather, different vessel types will decarbonise at different rates, incentivised by different policy measures. This is partly because of differences in costs, operating profiles, and demand forecasts,

[40] The allocation of emissions reductions to policies is dependent on the order policies are implemented in the model, due to the overlapping impacts of policies. This analysis allocates emissions reductions to policies in the following order: extension of energy efficiency measures, emissions pricing mechanisms, fuel standards, measures for <400GT ships. As an example, there are ships that decarbonise due to the emissions pricing mechanisms that would also decarbonise in response to fuel standards, so if the fuel standards were implemented first, these savings would be allocated to the fuel standards and not emissions pricing.

but a significant factor is the size of vessels and whether they fall within scope of the 5,000GT or 400GT threshold of various policies. The GHG emission reductions from each policy measure in 2040 for different vessel types under the upper and lower bound of the range is set out in Figures 9a and 9b. However, in general, we present results at the aggregated fleet level to ensure a greater level of accuracy than is possible when looking at detailed breakdowns.

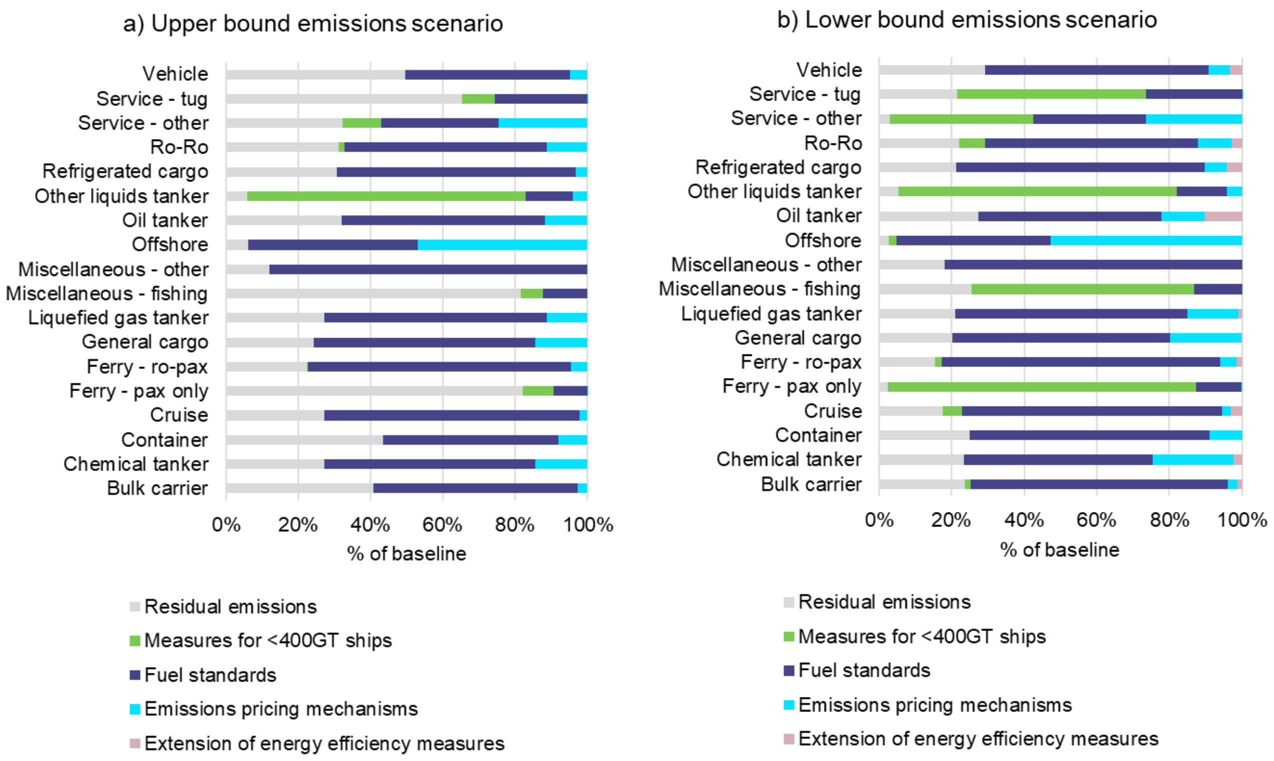
Figures 8a and 8b. Estimated contribution of different measures to reducing annual WtW greenhouse gas emissions from UK domestic maritime (excluding inland waterways)





Note: Figures 8a and 8b show the estimated contribution of different policy measures to reducing the annual lifecycle (WtW) greenhouse gas emissions from UK domestic maritime, associated with our core range of illustrative decarbonisation scenarios, alongside the breakdown in 2050. Emissions are measured in Mt CO_2e, and do not include emissions from inland waterways. The first chart (8a) shows our illustrative upper bound emissions scenario, whereas second chart (8b) shows our illustrative lower bound emissions scenario. Both scenarios hold wider uncertainty factors at their central values.

Figures 9a and 9b. Estimated contribution of different measures to reducing WtW greenhouse gas emissions from UK domestic maritime in 2040, by vessel type (excluding inland waterways)



Note: Figures 9a and 9b show the estimated contribution of different policy measures to reducing the annual lifecycle (WtW) greenhouse gas emissions from UK domestic maritime associated with our core range of illustrative decarbonisation scenarios in 2040, split by the vessel types included in the maritime emissions model. Values are presented as a percentage of baseline emissions, and do not include emissions from inland waterways. The chart on the left (9a) shows the contribution of each policy under our illustrative upper bound emissions scenario, whereas the chart on the right (9b) shows the contributions under our illustrative lower bound emissions scenario. Both scenarios hold wider uncertainty factors at their central values.

Fuel mixes

4.19 There is currently substantial uncertainty about which fuel types might emerge as the main fuels of the future for different vessels due to the early stage of development of the fuels, concerns around safety and certification, and lack of information on the availability of feedstocks and capacity for producing fuels. The Department remains fuel and technology neutral and expects this choice to be largely driven by markets and the needs of vessels. However, policies will be designed to align with wider UK government priorities such as relating to air quality and energy provision, and to reflect cross-economy considerations on fuel sustainability criteria and availability of supply.

4.20 Therefore, alongside the range of emissions scenarios for domestic maritime, we have produced five illustrative scenarios which reflect different states of the world in which different market conditions or constraints arise on certain fuel types or technologies, though we make no assessment here as to which of these are more likely outcomes. We expect that a mix of fuels will be needed. We recognise that not all options have been included here (such as nuclear, hybrid-electric vessels, shore power, or onboard CCS), and that the final fuel mix of the future may not align with any particular scenario. We have also not explicitly modelled the potential future availability of and access for the maritime sector to each of the potential fuel options, especially in the context of competing demand for these fuels across the economy, though we recognise that this will be a crucial factor in the uptake of fuels.

4.21 Table 3 summarises the assumptions used across the fuel mix scenarios. The 'no ammonia' scenario reflects a potential outcome where safety and certification barriers for ammonia have not been overcome, and ammonia is not an option for any vessel types. In this scenario, the model suggests that methanol and hydrogen will be the dominant fuels. Conversely, the 'more ammonia' scenario reflects a situation in which these barriers of safety and certification have been overcome, and where both freight ships and large passenger vessels have the option of using ammonia, although it is assumed to remain unfeasible for smaller vessels, due to the requirements for sophisticated containment mechanisms and highly trained crews. In this scenario, ammonia achieves the largest market share, given it performs well on a cost basis under our current assumptions. The ‘balanced mix’ scenario is somewhere in between these two extremes and reflects a world where safety concerns and public perceptions mean that ammonia is only allowed for freight ships but is not an option for smaller vessels and passenger vessels. We use the balanced mix scenario when presenting results of emissions, costs, and benefits for our core range, as a conservative central assumption based on current expert opinion.

4.22 The 'more Battery Electric Propulsion' (BEP) scenario reflects an outcome where battery costs fall further than currently expected under our central assumptions, allowing them to emerge as a cost-effective option for several smaller vessel types, including passenger ferries and offshore and service vessels. The 'more biofuel' scenario reflects a world where there are no constraints on the use of biofuels by the maritime sector, and these are allowed in up to 100% blends. This is something which we expect to be unlikely given the current evidence on biofuel availability, as suggested by the Climate Change Committee (CCC) in their 6th Carbon Budget report.[41] In a scenario where the maritime sector has a very high demand for biofuels, it is also likely that the costs of biofuels would be higher than assumed in our current modelling, given the expected competition for these resources across the economy. Therefore, in all other scenarios, biofuel use is limited to a maximum of a 30% blend[42], and for use as pilot fuels only.

[41] CCC (2020) The Sixth Carbon Budget: The UK’s path to Net Zero (https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf). Section 3d of the Shipping chapter explains that the CCC sees a limited role for biofuels in shipping.

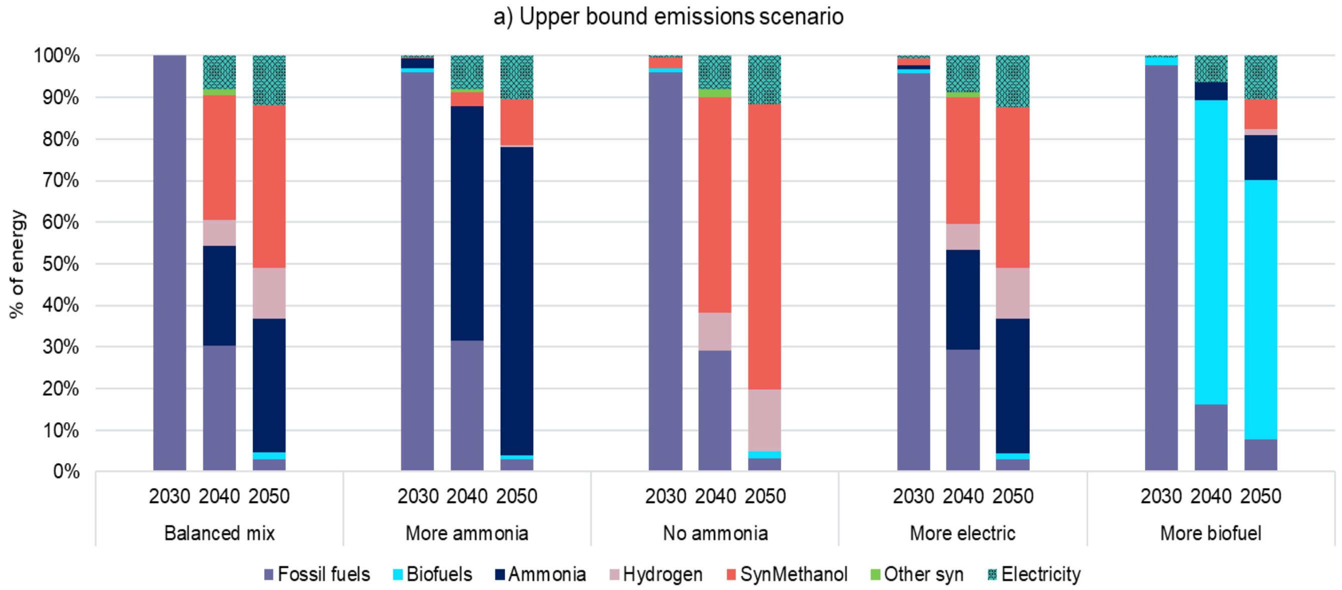
[42] 30% was chosen as this is the level of biofuel blend that is currently available at some ports.

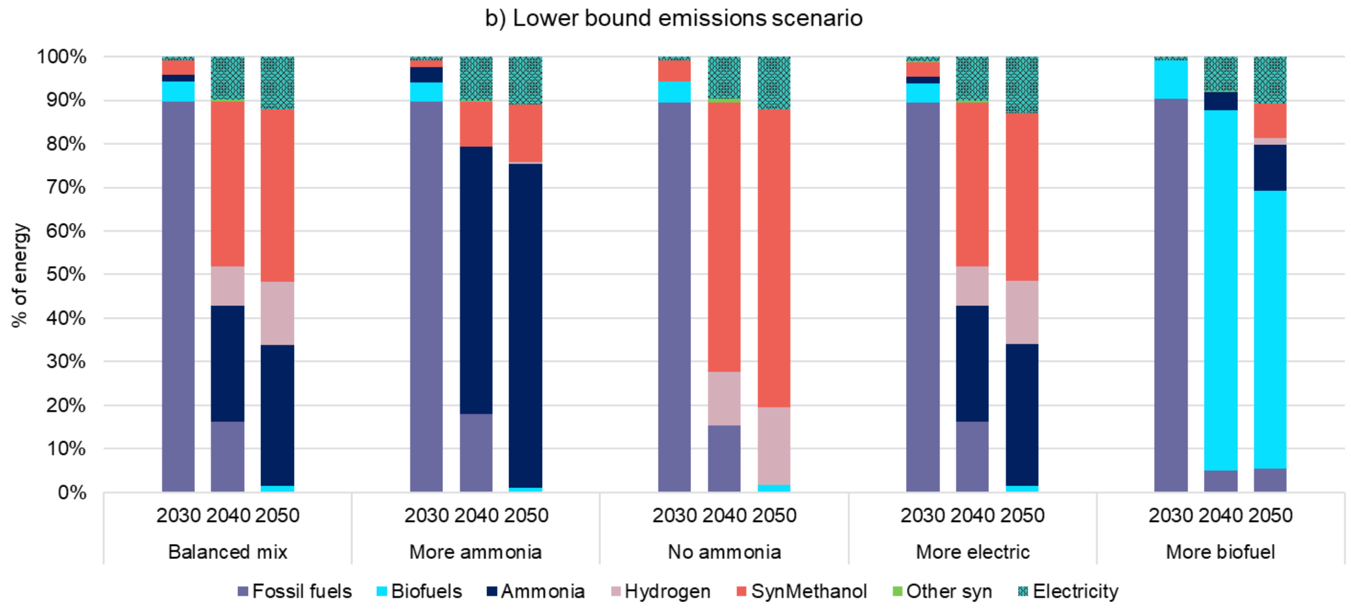
Scenario	Ammonia assumption	Battery assumption	Biofuel assumption	Expected result
Balanced mix	Only allowed for freight ships	Allowed for passenger ferries, offshore and service vessels, central battery costs	Max 30% blend allowed, other than for pilot fuels	Mix of ammonia, methanol and hydrogen
More ammonia	Only allowed for freight ships and large passenger ships	Allowed for passenger ferries, offshore and service vessels, central battery costs	Max 30% blend allowed, other than for pilot fuels	Ammonia dominant, with methanol and hydrogen
No ammonia	Not allowed for any ships	Allowed for passenger ferries, offshore and service vessels, central battery costs	Max 30% blend allowed, other than for pilot fuels	Methanol and hydrogen dominant
More BEP (battery electric propulsion)	Only allowed for freight ships	Allowed for passenger ferries, offshore and service vessels, low battery costs	Max 30% blend allowed, other than for pilot fuels	Mix of fuels with more electric
More biofuel	Only allowed for freight ships	Allowed for passenger ferries, offshore and service vessels, central battery costs	100% biofuel use allowed	Mix of fuels with more biofuels

Table 3. Fuel mix scenarios and associated assumptions

4.23 The estimates of the percentage of the energy demand from UK domestic maritime (excluding inland waterways) that is met by different fuels and energy sources in 2030, 2040 and 2050 under our five fuel mix scenarios are presented in Figures 10a and 10b for our upper and lower bound illustrative decarbonisation scenarios respectively. All scenarios see a diverse mix of fuel use reflecting the various needs across the sector and the assumptions included in Table 3. We also recognise that there are additional uncertainties that it has not been feasible to capture in our current modelling. For example, we recognise that the use of electricity as a fuel may have more of a role in meeting our decarbonisation goals than our current modelling suggests. Again, the fuel mix will also vary significantly by vessel type, as illustrated by Figures 11a and 11b, which break down the results for the balanced mix scenario by vessel type. While several larger vessel types, such as tankers and container ships, do mostly use ammonia because it provides relatively low-cost GHG emission reductions in our modelling, other vessel types such as smaller vessels and passenger vessels use a combination of other fuels in these scenarios.

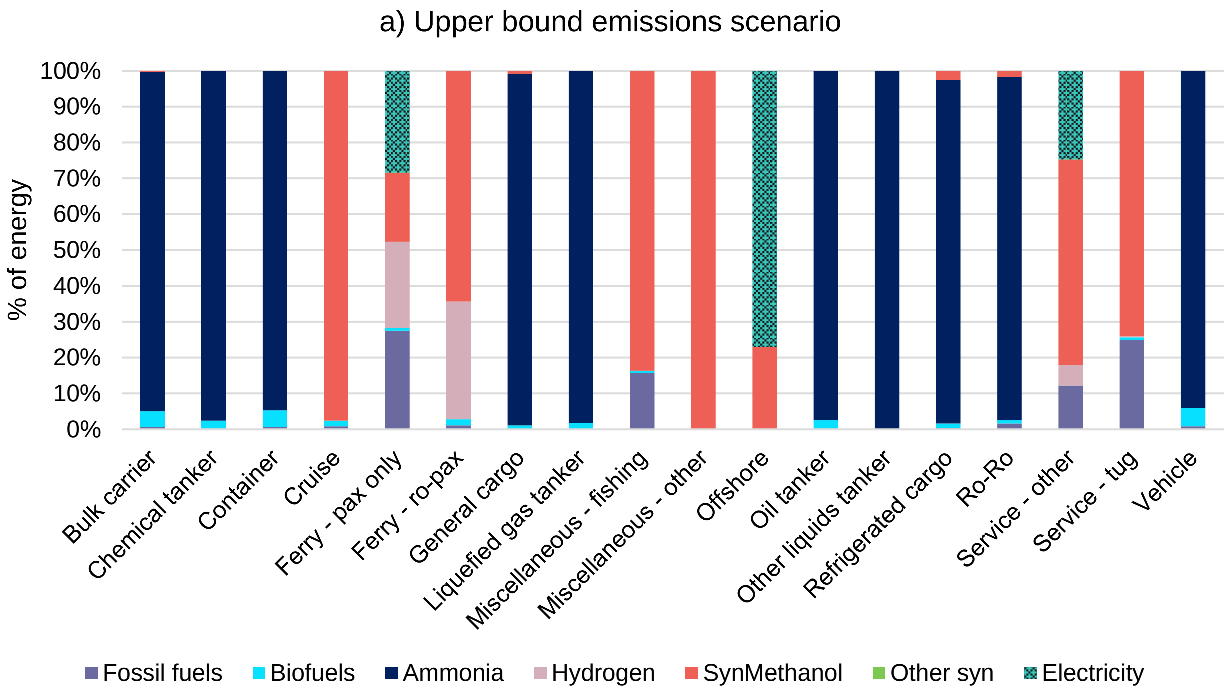
Figures 10a and 10b. Estimated future fuel demand under our five fuel mix scenarios, as a percentage of total UK domestic maritime energy use (excluding inland waterways)

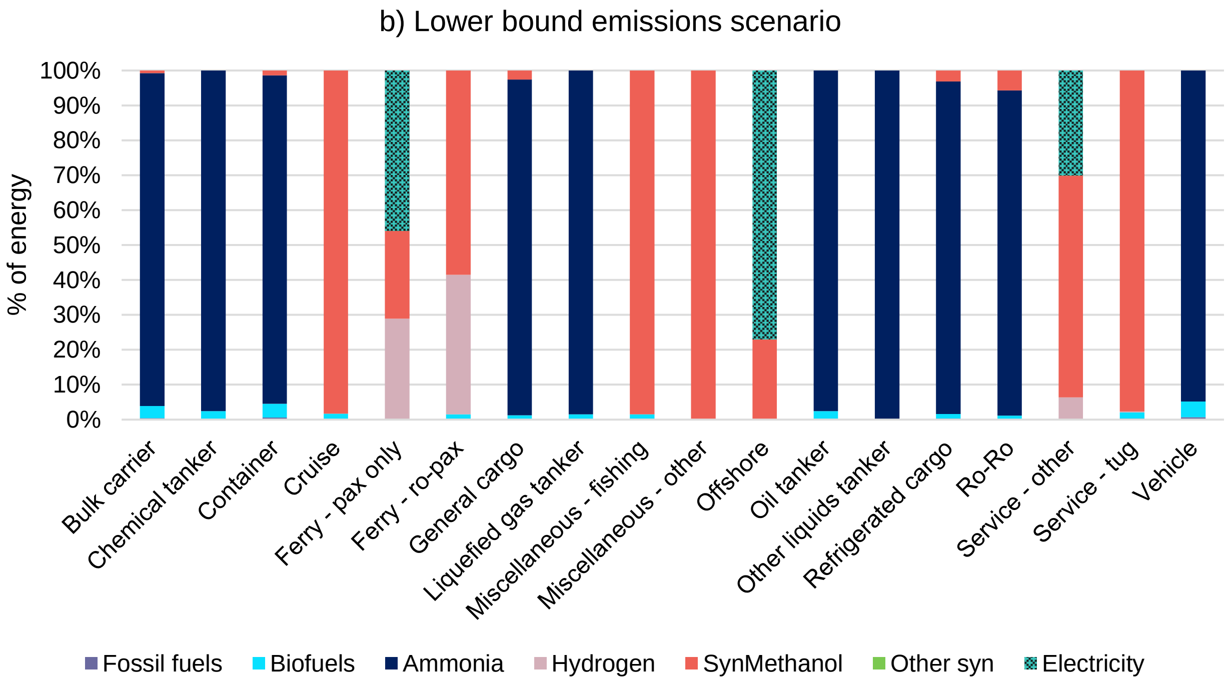




Note: Figures 10a and 10b show the estimated percentage of total energy supplied to UK domestic maritime by different fuel types in 2030, 2040 and 2050 under our five fuel mix scenarios, associated with our core range of illustrative decarbonisation scenarios. Values are presented as a percentage of total UK domestic maritime energy use and do not include inland waterways. The top chart (10a) shows the fuel mix scenarios associated with the illustrative upper bound emissions scenario, whereas the bottom chart (10b) shows the fuel mix scenarios applied to our illustrative lower bound emissions scenario. Both scenarios hold wider uncertainty factors at their central values.

Figures 11a and 11b. Estimated 2050 fuel demand from UK domestic maritime under our ‘balanced mix’ fuel scenario, by vessel type (excluding inland waterways)





Note: Figures 11a and 11b show the estimated share of energy supplied by different fuel types in 2050 within our balanced mix fuel scenario associated with our core range of illustrative decarbonisation scenarios, split by the vessel types included within the maritime emissions model. Values are presented as a percentage of total UK domestic maritime energy use in 2050 and do not include inland waterways. The top chart (11a) shows the balanced mix scenario when applied to the illustrative upper bound emissions scenario, whereas the bottom chart (11b) applies the balanced mix scenario to our illustrative lower bound emissions scenario. Both scenarios hold wider uncertainty factors at their central values.

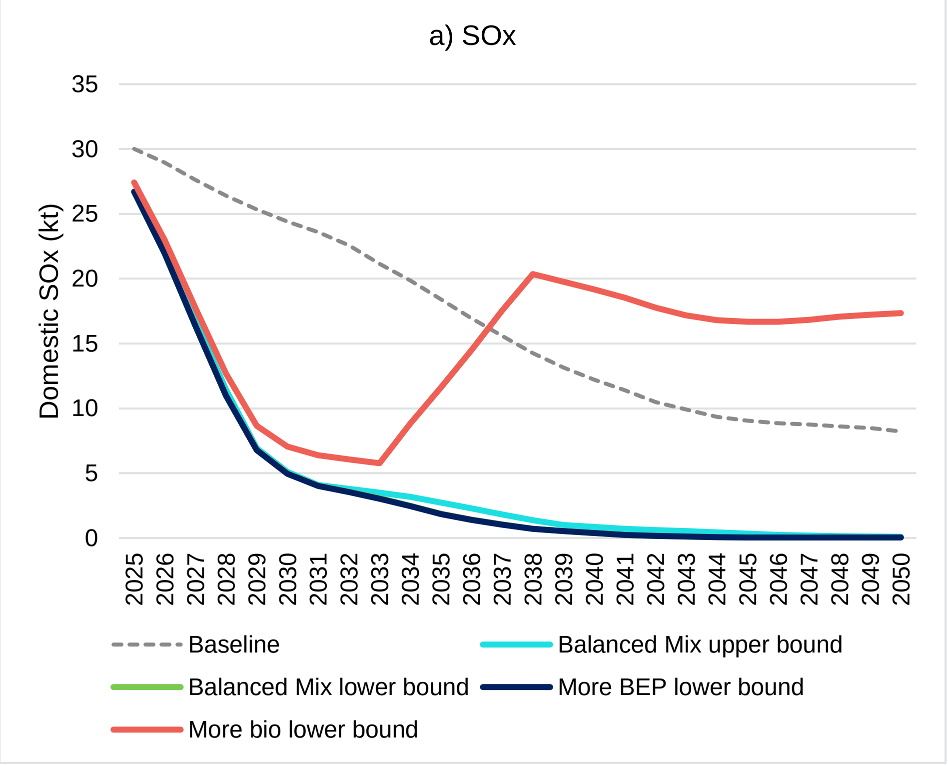
4.24 To provide a sensitivity test for the potential impact of N_2O emissions from hydrogen (as discussed in paragraph 2.17), we have separately estimated the emissions that would be produced under a worst-case scenario for hydrogen, where hydrogen produces the same N_2O emissions as LSFO. Under our "no ammonia" fuel mix lower bound emissions scenario (i.e. the scenario with the highest hydrogen use), using this emission factor for N_2O emissions would lead to an additional 11ktCO_2e in 2050. This is equivalent to 0.2% of total tank-to-wake GHG emissions in 2019.

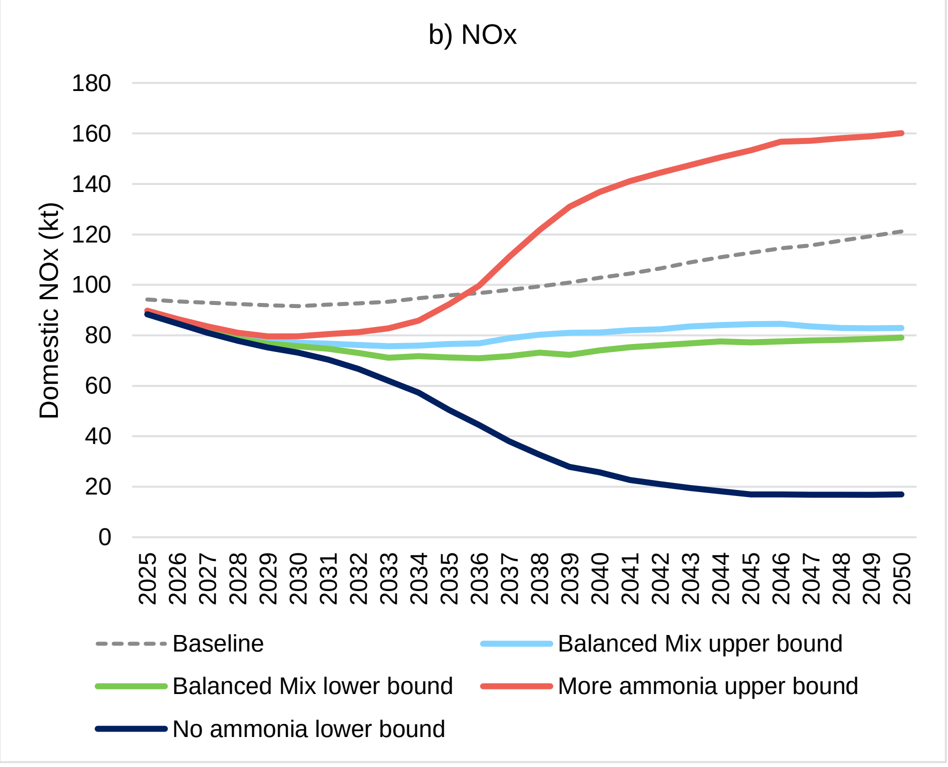
Air quality impacts

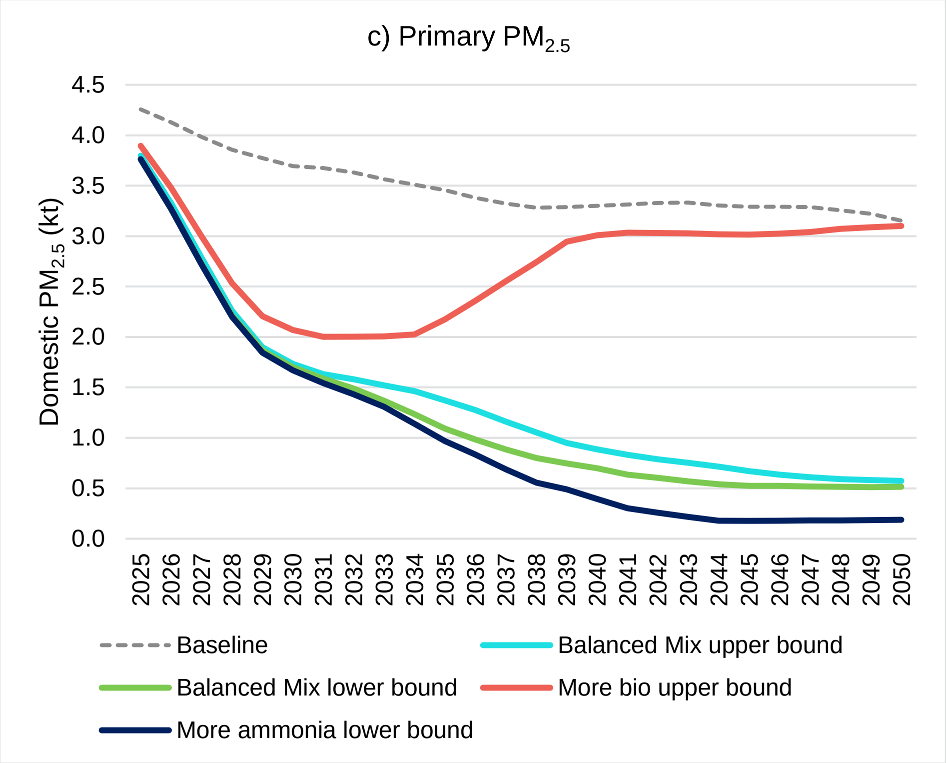
4.25 The modelled impact of our range of decarbonisation scenarios and fuel mixes for UK domestic maritime on domestic emissions of air pollutants are shown in figures 12a – 12c. The fuel mixes with the highest and lowest emissions have been included for each pollutant, alongside the Balanced Mix fuel mix, to illustrate the full range of potential outcomes. The results show that, while our policies can enable a reduction in air pollutant emissions relative to baseline expectations under certain fuel mix scenarios, under other fuel mixes there may be an increase in certain pollutants (e.g. an increase in NO_X emissions under the 'More ammonia scenario', and higher levels of SO_X and particulate matter emissions under the 'More Biofuel' scenario.) It should be noted that air pollution abatement technologies (such as exhaust treatment systems) are not included in our modelling at this stage, though these could also be applied in practise to further reduce emissions of air pollutants.

4.26 The upper estimate for NO_X should be seen as a worst-case outcome, as the model currently includes a pessimistic assumption about NO_X emission rates for ammonia, for which there is currently some uncertainty. The figures also include primary emissions of $PM_{2.5}$ only, and the inclusion of secondary pollutants may change which scenario results in the lowest concentrations of particulate matter in the UK (e.g. higher uptake of ammonia could see high levels of secondary $PM_{2.5}$). Therefore, these results do not predict the concentration of pollutants, which is an important factor in their health impacts. Overall, these results illustrate the uncertainty surrounding the air quality impacts of decarbonising the maritime sector, and therefore we will look to improve our evidence base on this aspect in future, while making sure to design future policy carefully to minimise adverse impacts on emissions of other air pollutants.

Figures 12a - 12c. Modelled impact of range of domestic maritime decarbonisation scenarios on UK domestic maritime emissions of a) SO_X, b) NO_X, and c) primary $PM_{2.5}$ (excluding inland waterways)







Note: Figure 12 shows the range of modelled emissions from UK domestic maritime of primary a) SO_X, b) NO_X, and c) $PM_{2.5}$ under our modelled decarbonisation scenarios and fuel mixes. The fuel mixes with the highest and lowest air pollutant emissions are included, to illustrate the full range of potential outcomes, alongside the Balanced Mix fuel mix. The figures include primary emissions only, and do not include concentration or location data. The estimates also do not include the emissions from inland waterways.

4.27 As the impacts of air pollutants can be highly localised, monetising the impact on air pollution using the recommended Impact Pathways Approach requires specific location and concentration data.[43] We cannot produce air pollution forecasts at this level of granularity using this iteration of the model, therefore we have been unable to undertake an Impact Pathways Approach monetisation of the air quality impacts associated with our illustrative scenarios. We have conducted some initial monetisation using the damage costs approach, which reveals a range of air quality benefits of £2.2bn to £9.7bn between 2025 and 2050, depending on the policy scenario, fuel mix, and wider uncertainty factors applied. However, as these impacts exceed £50m and the damage costs approach is recommended for impacts below £50m, we have not included these benefits in our total costs and benefits calculated below. We will look to develop the model to undertake a more detailed valuation in the future.

Costs and benefits

4.28 The additional costs and benefits to the UK of our illustrative decarbonisation scenarios compared to the baseline can be estimated using our new maritime emissions model. The total estimated additional costs, including capital expenditure (CapEx) associated with engines and abatement options, operating expenditure (OpEx) associated with engines and abatement options, and fuel costs, are shown alongside the estimated monetised benefits in Figure 13 (other costs, such as crew costs are not included in the model). These

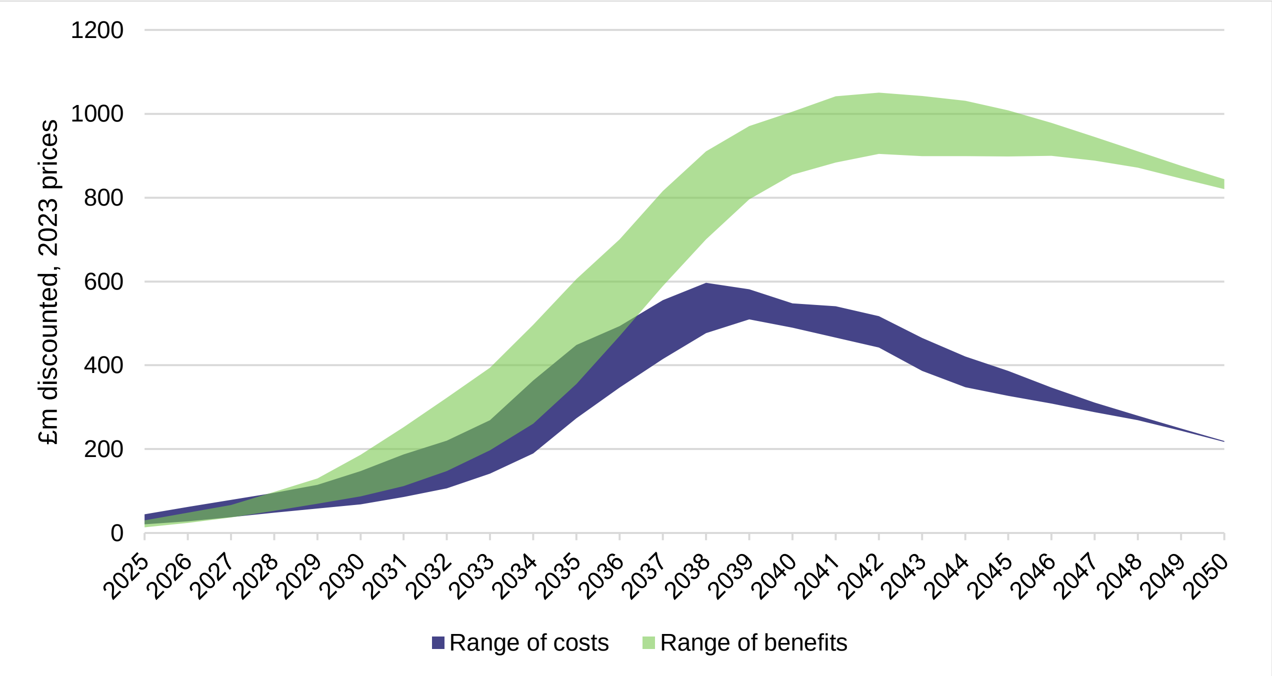
[43] Assess the impact of air quality - GOV.UK

additional costs peak just before 2040, reflecting the fact that operators will have to make decisions regarding vessels and fuels, and therefore face most upfront costs, before 2040 to comply with the assumed regulations.

4.29 Our estimates indicate that the overall cumulative costs of decarbonising the domestic maritime sector between now and 2050 are significantly outweighed by the benefits, from the late 2020s onwards. However, as shown in Figure 13, there is uncertainty about the extent of the costs depending on the level of policy ambition.

4.30 The GHG emissions savings associated with the decarbonisation scenarios are currently the only monetised benefits shown in Figure 13. However, there are likely to be substantial other benefits associated with decarbonising the sector that we have not yet attempted to monetise. These include wider environmental benefits such as reduced emissions of air pollutants (in some fuel mix scenarios), along with job and Gross Value Added (GVA) benefits from encouraging the development of new clean maritime technologies. There are also potential costs that have not been quantified, for example, any potential impacts on water quality, air quality or biodiversity. There may also be a risk of internal carbon displacement to other transport modes, but this has not been assessed at this stage.

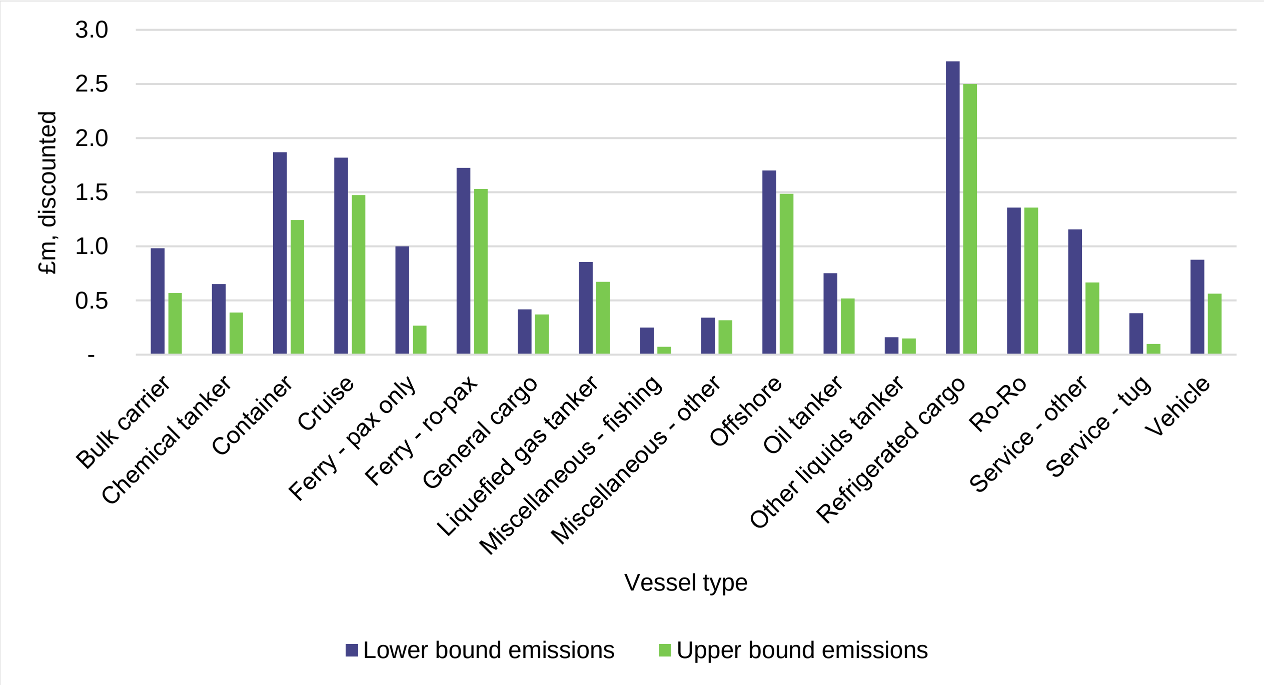
Figure 13. Estimated total additional costs and benefits to UK domestic maritime associated with our illustrative decarbonisation scenarios (excluding inland waterways)



Note: Figure 13 shows the range of estimated total additional annual costs and benefits associated with our core range of illustrative decarbonisation scenarios compared to our baseline scenario. Values are presented in discounted £millions, in 2023 prices with a 2025 present value base year. Costs and benefits have been smoothed. Estimates do not include inland waterways. Both scenarios hold wider uncertainty factors at their central values.

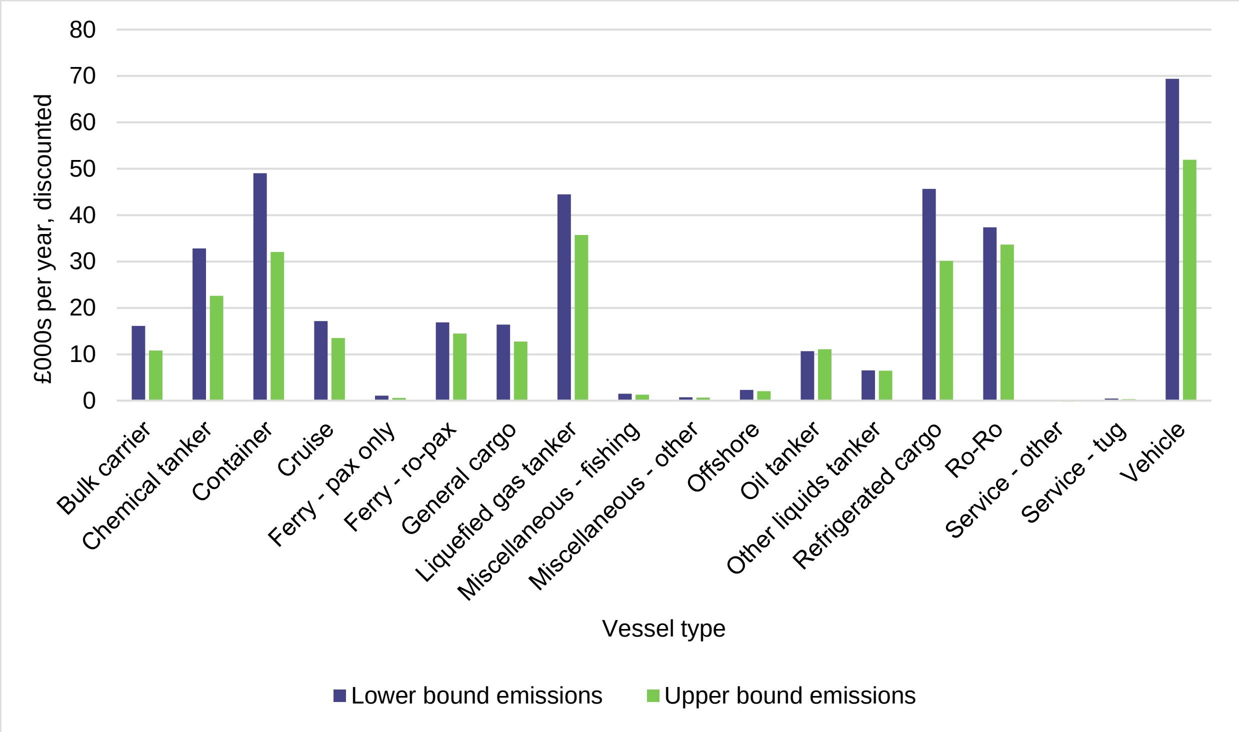
4.31 The estimated annual costs reflected in Figure 13 represent the sum of costs to all vessels operating domestically, including those at berth in UK ports. We disaggregate these estimated costs by the type of cost and vessel in Figures 14 - 16. CapEx is presented as a total additional cost over the period from 2020-2050, given the upfront nature of these costs, while OpEx and fuel costs are presented as an annual average additional cost.

Figure 14. Estimated average total additional CapEx to UK domestic maritime associated with our illustrative decarbonisation scenarios, per vessel between 2025 and 2050 (£m)



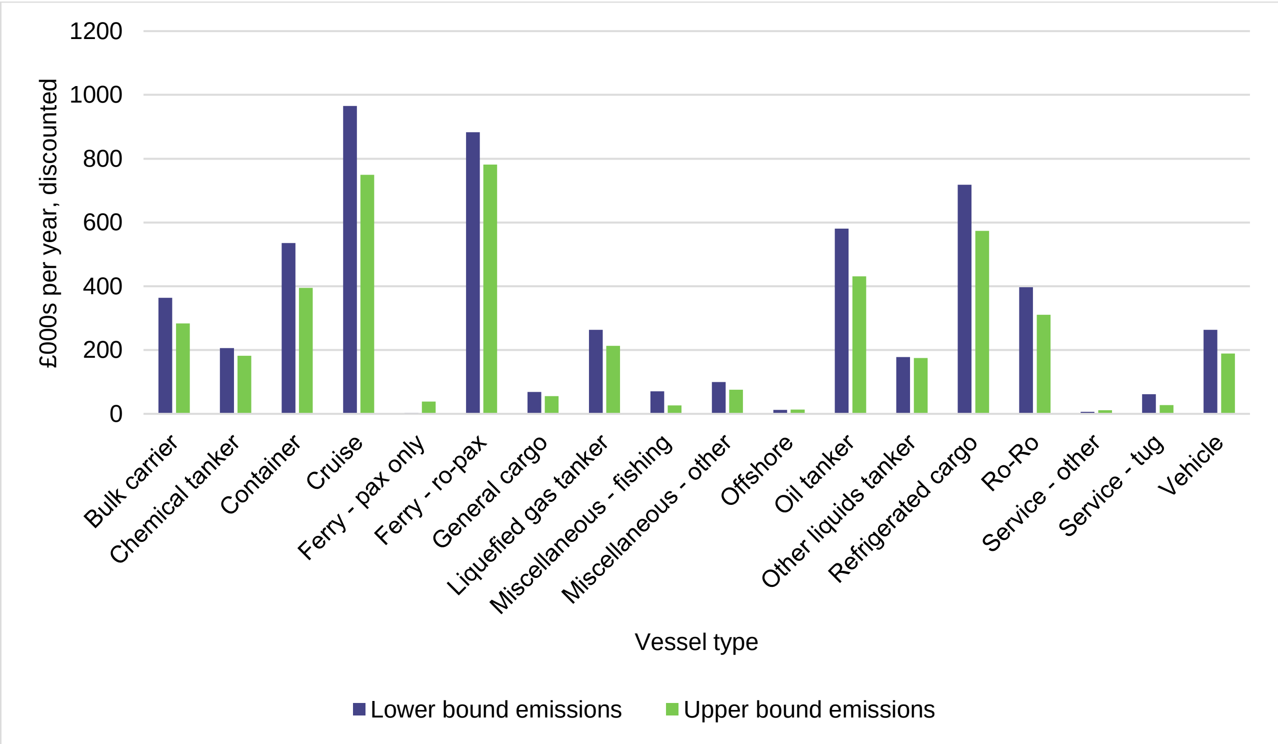
Note: Figure 14 shows the estimated average total additional capital expenditure (CapEx) costs to UK domestic maritime vessels under our core range of illustrative decarbonisation scenarios compared to our baseline scenario, per vessel, summed over the period from 2025 to 2050, and split by vessel type. Values are presented in discounted £millions, in 2023 prices with a 2025 present value base year. Estimates do not include inland waterways. Both scenarios hold wider uncertainty factors at their central values.

Figure 15. Estimated average annual additional OpEx to UK domestic maritime associated with our illustrative decarbonisation scenarios, per vessel (£000s)



Note: Figure 15 shows the estimated average annual additional operational expenditure (OpEx) costs to UK domestic maritime vessels under our core range of illustrative decarbonisation scenarios compared to our baseline scenario, per vessel and split by vessel type. Values are presented in discounted £ thousands, in 2023 prices with a 2025 present value base year. Estimates do not include inland waterways. Both scenarios hold wider uncertainty factors at their central values.

Figure 16. Estimated average annual additional fuel costs to UK domestic maritime associated with our illustrative decarbonisation scenarios, per vessel (£000s)



Note: Figure 16 shows the estimated average annual additional fuel costs to UK domestic maritime vessels under our core range of illustrative decarbonisation scenarios compared to our baseline scenario, per vessel and split by vessel type. Values are presented in discounted £ thousands, in 2023 prices with a 2025 present value base year. Estimates do not include inland waterways. Both scenarios hold wider uncertainty factors at their central values.

4.32 The modelled costs presented in Figures 14 – 16 are determined by the different fuel choices and emission reduction options chosen by operators under the different regulations, compared to the baseline scenario. These should not be interpreted as predictions of the actual costs for specific vessels but reflect the outputs of the modelled scenarios.

4.33 As a comparison to the above estimates, data from Clarksons' Shipping Intelligence Network (SIN) (based on the dry bulk, tanker, container, and gas carrier sectors) suggest that average shipping operating costs (including crew costs) were in the region of $7,000 per day in 2023, or approximately £2 million a year. Meanwhile, the average earnings in 2023 (for spot voyages, those are net of brokerage commission and fuel and port costs; for time charter contracts, fuel and port costs are not borne by the ship owner), as represented by the ClarkSea index, were around $23,500 per day (or nearly £7 million a year), demonstrating the high operating profit margins of shipping globally. Alongside this, shipping operators are typically exposed to substantial fluctuations in fuel prices, as evidenced by the high volatility of fossil fuel prices in recent years. For example, data from Clarksons' SIN suggest that, from 2019 to 2023, the price of Marine Gas Oil (MGO) in Rotterdam (a major European bunkering location) ranged from a low of $253/tonne in May 2020 to a high of $1,308/tonne in June 2022. While this adds to the uncertainty in calculating additional costs, it highlights that the shipping sector in general is familiar with volatile fuel prices, and (larger companies, at least) can respond to and absorb increased fuel costs over time.

4.34 However, different vessel types within the UK domestic maritime sector will vary in their cost and operating models and will have differing ability to absorb additional costs. We recognise that the above earnings are not applicable to all sub-sectors of the UK domestic maritime sector, for example to ferries, fishing, service and offshore. We will therefore be exploring the impact of individual policies on specific sub-sectors as part of the further development of these policies, including the ability to pass through additional costs to end consumers. Given the barriers faced by small businesses, we will work closely with the sector to introduce targeted policies for smaller vessels that are proportionate, workable, and introduced at the right time.

4.35 Estimates of the cost effectiveness (i.e. the average cost of reducing one tonne of carbon dioxide equivalent emissions) of our core illustrative decarbonisation scenarios are presented in Table 4. This has been estimated in line with DESNZ valuation of energy use and greenhouse gas emissions appraisal guidance.[44] For comparison purposes, weighted average cost comparators are

[44] DESNZ (2023) Valuation of energy use and greenhouse gas (GHG emissions): Supplementary guidance to the HM Treasury Green Book on Appraisal and Evaluation in Central Government. https://assets.publishing.service.gov.uk/media/656798482ee693001360cae8/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal.pdf

also calculated. The weighted average cost comparator is a benchmark that represents the estimated maximum level of social costs that should be incurred to decarbonise an equivalent amount of emissions. This comparator is calculated by weighting the share of emissions savings associated with our decarbonisation scenarios in each year against the DESNZ carbon values.[45] Given the cost effectiveness indicators of our decarbonisation scenarios are substantially lower than the cost comparators, our analysis suggests that the scenarios deliver cost effective emissions reductions.

	Unit	Upper bound emissions scenario	Lower bound emissions scenario
Cost-effectiveness indicator	£/tCO_2e	101	108
Weighted average cost comparator (based on DESNZ carbon values)	£/tCO_2e	208	211

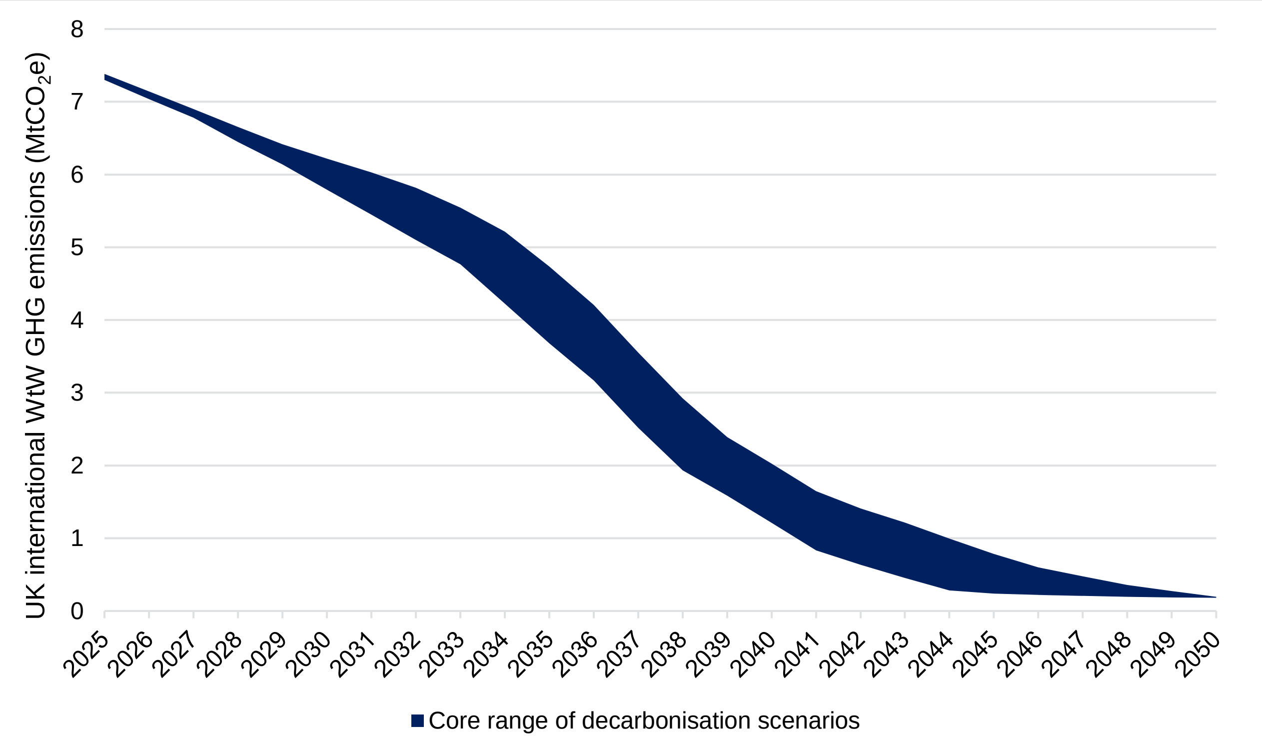
Table 4. Estimated cost effectiveness of our illustrative decarbonisation scenarios versus weighted average cost comparator (£/tCO_2e, 2023 prices) (core range) (excludes inland waterways)

[45] See Boxes 5.1 and 5.2 of DESNZ Valuation of energy use greenhouse gas emissions appraisal guidance for more details.

Impact of policies on UK international maritime GHG emissions

4.36 We can also use the maritime emissions model to assess the impact of the policies assumed above on the UK's share of international maritime GHG emissions. The results, shown in Figure 17, make the same assumptions as set out in Table 2.

Figure 17. Range of illustrative decarbonisation scenarios for the UK's share of international maritime GHG emissions



Note: Figure 17 shows the range of estimated annual lifecycle (WtW) greenhouse gas emissions from UK international maritime under our core range of illustrative decarbonisation scenarios, the assumptions for which are set out in Table 2. International maritime emissions are measured in Mt CO_2e and are defined as 50% of the emissions produced on journeys between UK ports and ports in another country.

5. Sensitivity analysis

5.1 As mentioned throughout this document, decarbonisation of the maritime sector is subject to vast uncertainties. To account for this in our modelling, we have carried out further sensitivity testing relating to maritime demand, fuel costs, and technology effectiveness, the results of which are presented in the following section.

Assumptions

5.2 The core range of illustrative decarbonisation scenarios for UK domestic maritime presented in Section 4 accounts for variation in policy assumptions, such as the timing and ambition level of key policy measures. However, there are various other inputs which are also subject to significant uncertainty. These include fuel prices, technology costs and effectiveness, and demand for freight and non-freight services. These were all held at central values for the core range of illustrative decarbonisation scenarios in the previous section. However, we have also developed an upper and lower set of assumptions relating to each of these variables (see the Maritime Emissions Modelling Framework for further explanation and sources of these assumptions).

5.3 We have combined these low and high assumptions to produce two illustrative 'best case' and 'worst case' scenarios for emissions (set out in Table 5). The terms 'best case’ and 'worst case’ are used only to refer to the outcome for decarbonisation and are not a judgement on the value of these conditions in general.

Wider uncertainty factors	Best case for emissions	Worst case for emissions
Freight demand	Low	High
Non-freight demand	Flat	Growing
Technology costs	Low	High
Technology effectiveness	High	Low
Emissions prices	High	Low
Fuel prices	Low synthetic fuel prices, high fossil fuel prices	Low fossil fuel prices, high synthetic fuel prices

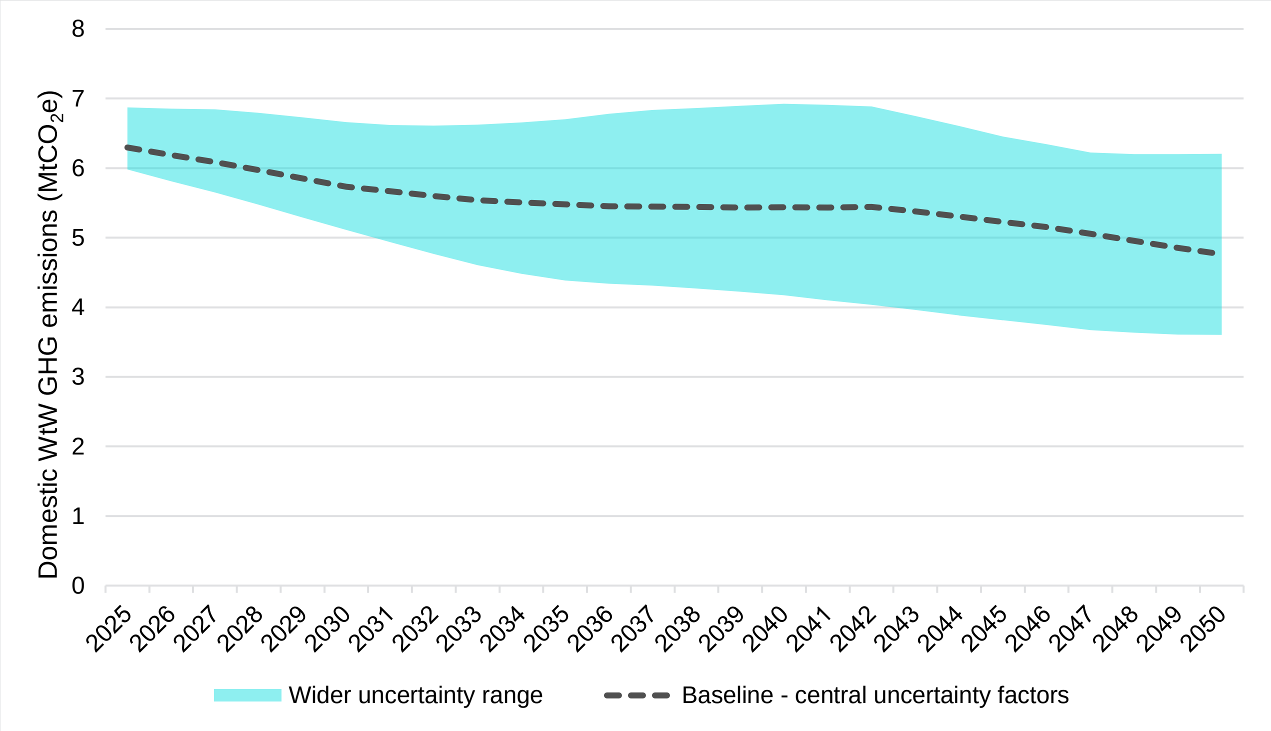
Table 5. Uncertainty assumptions applied under 'best' and 'worst case for emissions' ranges

5.4 Under the 'best case for emissions' assumptions, all underlying conditions are conducive to rapid decarbonisation. For example, technology effectiveness is high and synthetic fuel prices are low. The corresponding 'worst case for emissions' assumptions reflect a world in which all conditions are working in the opposite direction, with the result being that decarbonisation is more difficult. These assumptions have been used to produce two more emissions ranges for UK domestic maritime by applying the 'best' and 'worst case' uncertainty factors to the upper and lower bounds of the core illustrative decarbonisation scenarios presented in Section 4. These ranges are intended to show that we can still make substantial progress towards meeting our goals for the maritime sector, even under the 'worst case' set of uncertainty factors, if policies are sufficiently ambitious.

Results

5.5 Uncertainty exists in relation to our baseline projections, as well as to our illustrative decarbonisation scenarios. To reflect this, the best and worst case for emissions assumptions set out in Table 5 have also been applied to produce an uncertainty range around our baseline for UK domestic maritime. The results of this sensitivity testing are presented in Figure 18, with the light blue band representing the range of uncertainty around the baseline.

Figure 18. Uncertainty range associated with baseline UK domestic maritime WtW GHG emissions under wider 'best' and 'worst case for emissions' assumptions (excluding inland waterways)

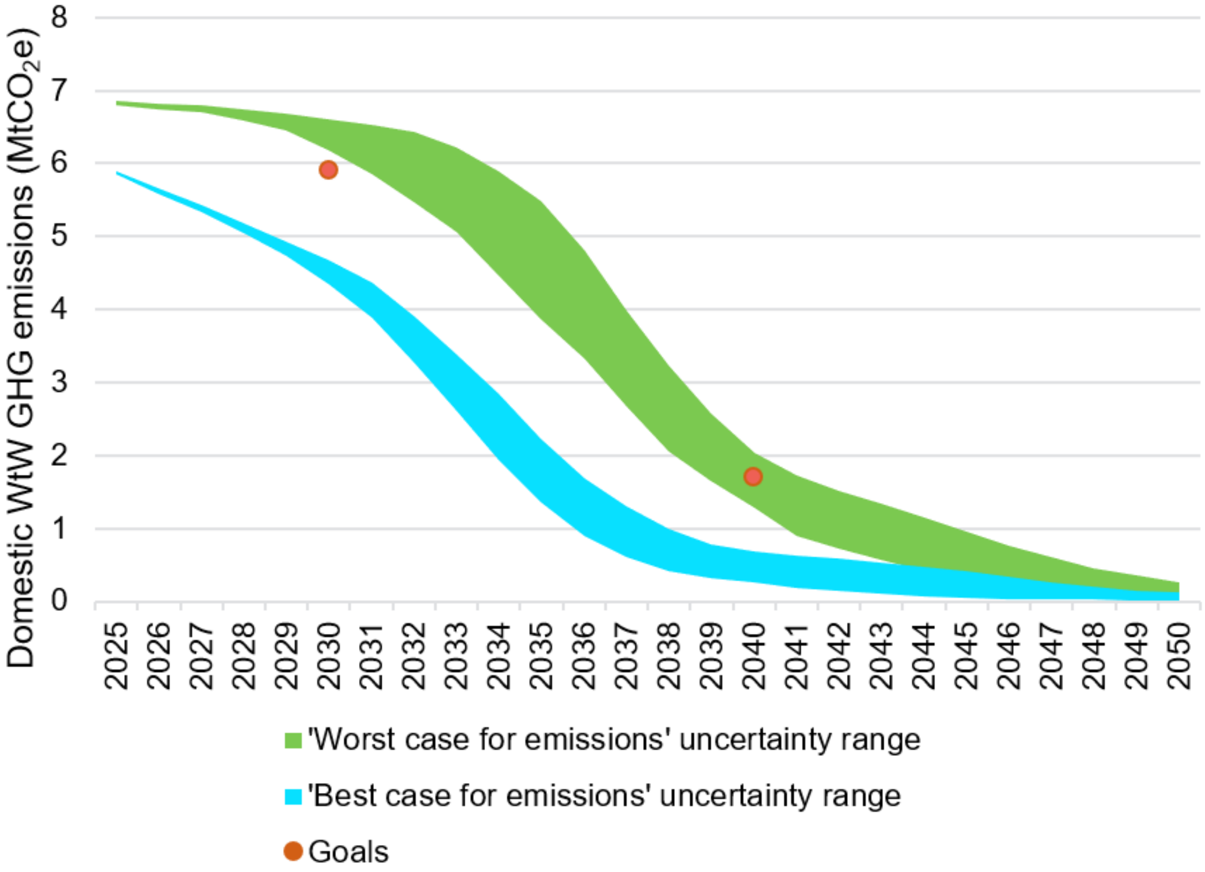


Note: Figure 18 shows the uncertainty range around our estimated annual lifecycle (WtW) greenhouse gas emissions produced by seagoing UK domestic maritime vessels under our baseline scenario. Emissions are measured in Mt CO_2e, and do not include emissions from inland waterways.

5.6 Figure 19 presents our estimates of the WtW GHG emissions from seagoing UK domestic maritime vessels (i.e. excluding inland waterways) under our illustrative decarbonisation scenarios with the 'best' and 'worst case for emissions' assumptions applied. The upper and lower bounds of each range reflect the same policy assumptions as used in the upper and lower bounds of our core illustrative decarbonisation scenarios (see Table 2 for full details).

5.7 Under the 'best case for emissions' assumptions, we are confident of meeting our decarbonisation goals, exceeding them by some margin in both 2030 and 2040. Under the 'worst case for emissions' assumptions, where wider conditions are working against decarbonisation, the results suggest that our decarbonisation goals for the maritime sector could be at risk if policy is not sufficiently ambitious in response.

Figure 19. Ranges of illustrative decarbonisation scenarios for UK domestic maritime under 'best case for emissions' and 'worst case for emissions sensitivity testing (excluding inland waterways)



Note: Figure 19 shows the range of estimated annual lifecycle (WtW) greenhouse gas emissions produced by seagoing UK domestic maritime vessels under our illustrative decarbonisation scenarios with the wider 'best case for emissions' and 'worst case for emissions' assumptions applied, as set out in Table 5. The upper band reflects the range of emissions under the 'worst case for emissions' uncertainty factors, and the lower band reflects the range of emissions under the 'best case for emissions' uncertainty factors. Emissions are measured in Mt CO_2e, and trajectories and goals do not include emissions from inland waterways.

5.8 The results of the uncertainty testing in this section demonstrate that there are risks to meeting our decarbonisation goals due to wider uncertainties. However, if policy making is responsive to wider conditions and can increase ambition in response, then our analysis suggests that it is still possible to meet our interim goals for the maritime sector. The combined results from all modelling are presented together in Section 6.

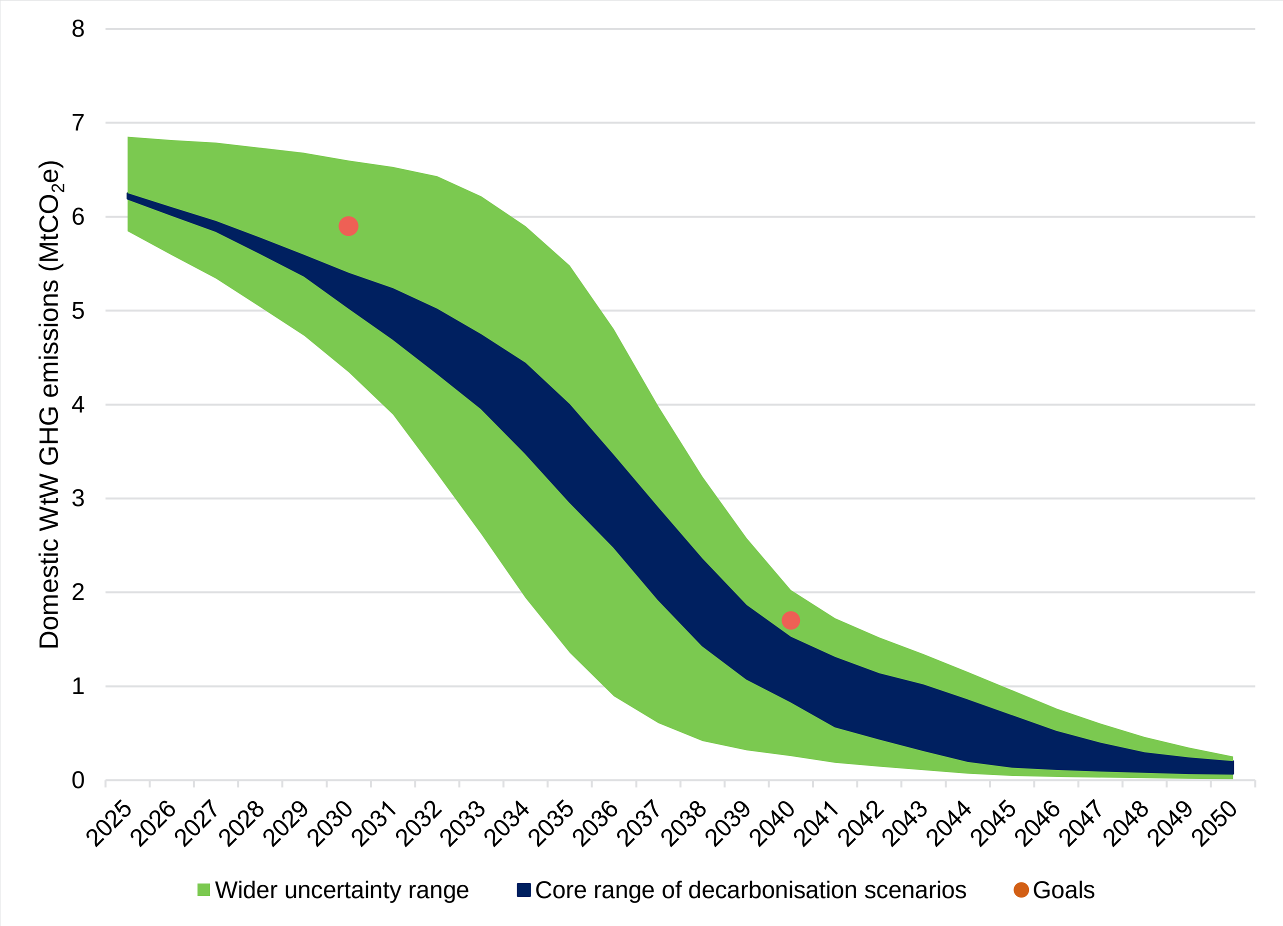
6. Conclusions

6.1 The full range of illustrative decarbonisation scenarios for the UK domestic maritime sector are presented together in Figure 20, showing the extent of the uncertainty testing we have carried out. One of the key conclusions of this modelling is that, although our decarbonisation goals are challenging and there may be risks to meeting them, we are confident that our interim goals can be met with the key policies announced in the Maritime Decarbonisation Strategy, and our 2050 fuel lifecycle emissions minimised as far as possible. The introduction of domestic maritime fuel regulations, expansion of the UK ETS to domestic maritime, and the development of international regulations drive the majority of decarbonisation needed to meet our proposed interim goals for domestic maritime and contribute to our wider UK Net Zero target. However, the uncertainty demonstrated by our modelling also shows that we need to maintain a high level of ambition, both in the ongoing development of existing policy, and when considering future measures.

6.2 One such area of uncertainty relates to emissions from inland waterways. Alongside the development of more accurate modelling of these inland waterway vessels, we will also consider policy that will directly encourage their decarbonisation, beginning with a call for evidence on measures to reduce emissions from smaller vessels and targeted sectors, which was published alongside the strategy.

6.3 As part of the ongoing development of our maritime emissions model, we will keep all assumptions under review and update them as appropriate in future iterations of this modelling. We will also look to continue to expand our evidence base and modelling capability in areas that are currently underrepresented within the model.

Figure 20. Full range of WtW greenhouse gas emissions from UK domestic maritime vessels under our illustrative decarbonisation scenarios (excluding inland waterways)



Note: Figure 20 shows the full range of estimated annual lifecycle (WtW) greenhouse gas emissions from UK domestic maritime under our illustrative decarbonisation scenarios, compared to the decarbonisation goals published in the strategy. The core uncertainty range (the central dark green band) only varies policy uncertainties, while the outer light green bands reflect wider uncertainty testing (under 'best' and 'worst case for emissions' assumptions). Emissions are measured in Mt CO_2e, and trajectories and goals do not include emissions from inland waterways.