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ECONOMIC RESEARCH ON THE IMPACTS OF CARBON PRICING ON THE UK DOMESTIC MARITIME SECTOR

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Department for Transport
Great Minster House
33 Horseferry Road
London
SW1P 4DR

Any enquiries regarding this publication should be sent to us at
www.gov.uk/government/organisations/department-for-transport

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1 Executive summary

1.1 Summary of findings

This study has used the best available data and evidence to explore the risk of carbon leakage, internal carbon displacement and competitive impacts if UK domestic maritime were to be included in the UK Emissions Trading Scheme (ETS). It focuses on three particular routes between Great Britain (GB) and Northern Ireland (NI) that were identified and agreed with the Department for Transport (DfT) and the Department for Energy Security and Net Zero (DESNZ) as meriting focused analysis.

The three routes for focused analysis account for significant GB to NI maritime traffic. They are largely served by vessels reliant on fossil fuels and there are, in theory, potential substitute options for operators and/or customers. Although the details of how UK domestic maritime could be included in the UK ETS are being considered (such as the scale of vessels to be included, for example), this analysis has been taken forward on the basis of particular assumptions about the scope of the UK ETS and EU ETS.

The UK ETS currently covers emissions from domestic aviation (flights within the UK) and flights to the European Economic Area (EEA) as agreed in the UK-EU Trade and Cooperation Agreement (TCA). Flights from the EEA to the UK are covered by the EU ETS (UK ETS Authority, 2022).[1] The UK ETS does not currently cover emissions from non-electrified road or rail, or emissions from domestic or international shipping. For the purpose of this report, the 'UK ETS proposal' consists of maintaining the current UK ETS policy for aviation, non-electrified road and rail, and international shipping, and bringing emissions from domestic maritime only, for vessels over 5,000 gross tonnage, into the UK ETS. This is based on the lead option described in the March 2022 consultation (UK ETS Authority, 2022).

The EU ETS currently covers aviation emissions for flights between airports located in the EEA, and flights departing from the EEA and arriving in the UK (European Commission, 2022).[2] The EU ETS does not currently cover emissions from non-electrified road or rail,[3] or emissions from domestic or international shipping. For the purpose of this report, the 'EU ETS proposal' consists of maintaining the current EU ETS policy for aviation and non-electrified rail and road, and for vessels over 5,000

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[1] We note that from 1 January 2023, flights from GB to Switzerland are included in the UK ETS. Flights from NI to Switzerland will be included once the Northern Ireland Assembly is able to progress legislation. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1101633/developing-uk-ets-consultation-government-response.pdf

[2] This is the scope of aviation emissions in the EU ETS until 31 December 2023. After this date it is expected that the EU ETS will apply to all flights from, to, and within the EEA. As this is not yet current policy, the analysis does not assume this extension happens. https://climate.ec.europa.eu/eu-action/transport-emissions/reducing-emissions-aviation_en

[3] The EU is considering introducing a new, separate ETS system (EU ETS II) for buildings and road transport, and the initial plan was to introduce this in 2027. Due to limitations of the modelling in this analysis, the impact of this separate ETS system could only be assessed qualitatively. Therefore, this is not included as part of the central 'EU ETS' proposal (base case) but is discussed elsewhere in the analysis as part of alternative scenarios.

gross tonnage, bringing 100% of emissions from intra-EU maritime journeys, and 50% of emissions from international maritime journeys (which either start or end in the EU), into the EU ETS.[4]

The main findings of this analysis are:

1. The carbon cost exposure on the three GB-NI routes on which this analysis focuses (Belfast to Liverpool; Heysham to Warrenpoint; and Southampton to Belfast) is likely to provide a strong incentive to accelerate decarbonisation, therefore addressing one of the key barriers to decarbonisation (Frontier et al., 2019).[5]
2. The risk of carbon leakage is considered to be low across all three GB-NI routes analysed if the ‘EU ETS proposal’ were in place. Including shipping in the EU ETS reduces the cost differential between the GB-NI route and other potential substitute options that would, in theory and if chosen, aim to limit exposure to the UK ETS. This risk would be even lower if the International Maritime Organization (IMO) pursues an ambitious decarbonisation policy framework for international shipping in the future. The risk of carbon leakage could therefore be higher if the ‘EU ETS proposal’ were not in place.
3. The risk of internal carbon displacement (which would involve shifting to modes of transport other than UK domestic maritime) is considered to be low across all three GB-NI routes analysed. This is primarily because of the limited opportunity for such shifts given the need to cross water between GB and NI.
4. The risk of competitive disadvantage is considered to be low across the three GB-NI routes considered if the ‘EU ETS proposal’ were in place. As with carbon leakage, this is because the cost differential with competing journey options is lower if both the UK and EU have carbon pricing mechanisms in place. The risk would therefore be higher if the ‘EU ETS proposal’ were not in place.
5. The assessment of risk would be different if international maritime emissions were not included in the EU ETS, as would be the case if the ‘EU ETS proposal’ were in place. In such a case, the risk of carbon leakage could be high across all three case study GB-NI routes, due to the incentive to avoid the UK ETS by switching to an indirect route via the Republic of Ireland. Furthermore, there could be differential competitiveness effects associated with the ‘UK ETS proposal’ depending on the size of operators, given the potential barriers to decarbonisation for small operators (Frontier et al., 2019)[6] and across different vessel types.
6. Indicative switching analysis suggests that a very high UK ETS allowance price[7] (far in excess of the current UK ETS allowance price) would be likely to be needed for a material reduction in UK

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[4] It is worth noting that were there to be changes to the EU ETS that were more aggressive in terms of the covering of international maritime emissions than outlined in the ‘EU ETS proposal’, the risks of carbon leakage, internal carbon displacement, and competitive disadvantage would be even lower than outlined in the base case of this report.

[5] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

[6] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

[7] For the purpose of this report, ‘carbon price’, ‘allowance price’ and ‘ETS price’ are used interchangeably. All terms refer to the amount an operator would need to pay per tonne of carbon dioxide equivalent that they emit. The same terminology is used whether discussing the UK ETS or the EU ETS.

domestic maritime demand to be observed. Although there are substantial uncertainties in the analysis, even under cautious assumptions a high allowance price would be likely to be needed. This suggests a significant change in UK domestic maritime traffic would not be likely following its inclusion in the UK ETS as per the 'UK ETS proposal'.

1.2 Background and objectives of this study

In 2019, the UK Government implemented a legally binding net zero target for greenhouse gas emissions (GHGs) (BEIS, 2019). This states that in 2050, any emissions must be offset by an equivalent amount through measures such as planting trees or technology such as carbon capture and storage. To achieve this goal, the UK Government and Devolved Administrations have committed to further develop the UK ETS to incorporate more sectors of the UK economy. With this in mind, the UK ETS Authority released a consultation in 2022 regarding the potential inclusion of domestic maritime within the UK ETS by the mid-2020s. While the precise design of the scheme is subject to the outcomes of the consultation, this analysis considers the 'UK ETS proposal' as defined above.

Given the interaction between international and domestic maritime, the markets in which these operate, and the potential behavioural responses by operators and customers to the inclusion of domestic maritime shipping in the UK ETS, it is important to understand the potential risks of carbon leakage, internal carbon displacement and competitive disadvantage that this may cause.

This study defines these terms as:

- **Carbon leakage:** The displacement of greenhouse gas emissions from domestic maritime journeys included in the UK ETS due to different levels of carbon pricing or climate regulation across jurisdictions. Where leakage occurs, this means that a reduction in the greenhouse gas emissions from domestic maritime journeys included in the UK ETS would not reduce global greenhouse gas emissions by the same quantity.

- **Internal carbon displacement:** The displacement of greenhouse gas emissions from domestic maritime journeys included in the UK ETS to other sectors of the UK economy, due to different levels of carbon pricing or climate regulation. Where displacement occurs, this means that a reduction in the greenhouse gas emissions from domestic maritime journeys included in the UK ETS would not reduce UK greenhouse gas emissions by the same quantity.

- **Competitive disadvantage:** Due to the introduction of a carbon pricing policy, competitive disadvantage would arise if businesses in the UK domestic maritime sector experience a significant adverse impact on their competitiveness compared to competitors. This means that they would not be able to thrive as businesses compared to their competitors (therefore losing market share, for example). Carbon pricing is one of a range of factors that could cause competitive disadvantage. However, carbon pricing will not always lead to competitive disadvantage. For there to be competitive disadvantage, common factors would include the extent to which operators face significant carbon cost exposure and whether they have competing options available (such as switching to either indirect routes or other forms of transport, or other operators who face relatively lower barriers to decarbonisation).

The Department for Transport (DfT) and the Department for Business, Energy and Industrial Strategy (BEIS) therefore commissioned this research in late 2022 to gain a better understanding of these potential risks to inform the planning and design for including domestic maritime in the UK ETS. The findings were delivered to DfT and the Department for Energy Security and Net Zero (DESNZ) in early 2023.

This report qualitatively assesses these three risks, with a focus on three particular routes between GB and NI.

Analytical approach and limitations

Understanding the potential risk of carbon leakage, internal carbon displacement and competitive disadvantage on specific routes is challenging. There is limited UK-specific evidence on key aspects of UK domestic maritime activity and of the likely behavioural responses. For example, the potential responses of domestic maritime operators to voyage cost changes, the potential responses of their customers to any subsequent price changes (where costs are passed through), the share of voyage costs[8] accounted for by fuel (the element of voyage costs that would increase if a carbon price were imposed) and how these factors vary depending on the vessel types or the nature of cargo carried. These aspects have been reflected in the indicative quantitative analysis in this study by using sensitivity ranges.

There are also likely to be practical considerations which have not been possible to take into account within the scope of this analysis, such as the feasibility of operators changing their operating models; current market factors such as contractual arrangements; and the practical constraints at ports if vessel patterns and port calls were to change.

To understand the geography of domestic maritime activity, the analysis uses the most sophisticated and spatially detailed data available: satellite and terrestrial data collected through the automatic identification system (AIS). This is an automatic tracking system that uses transceivers on ships and is used by vessel traffic services (VTS). IMO regulations require AIS transceivers to be fitted onboard all ships in excess of 300 gross tonnage (GT) that are engaged in international voyages, cargo ships in excess of 500GT even if not engaged in international voyages and all passenger ships irrespective of size. Although this means the AIS data does not cover the entire population of UK domestic maritime vessels, and is therefore subject to limitations, the data is fit for purpose for this study.

The raw global AIS data provides basic information such as vessel positions over time and their speed, draft and a unique vessel identifier. This data was processed using the same approach as was used for the 4th IMO GHG study[9] and refined to select only the journeys that took place between any of the GB and NI ports of interest and between any two GB ports of interest in the year 2021.[10]

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[8] Defined for the purposes of this study as the variable costs associated with a specific voyage which include fuel and port charges. Capital costs are not included.

[9] https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

[10] 2019 data was also used to determine the routes of interest, however was not used in the further analysis of these routes.

The data derived from AIS is not intended to be an emissions inventory but is valuable in building an understanding of voyage patterns for UK domestic maritime and identifying routes for which there may be significant carbon emissions. By focusing on voyages of at least 6 hours' duration, the derived AIS data provides information on the characteristics of those voyages, for example, vessel size and type, average emissions intensity of vessels and total emissions. The data analysis method used means that short journeys are difficult to accurately identify because data from satellites and terrestrial receivers is captured at intervals which may not be sufficiently frequent to capture such journeys. To address this limitation, other sources of data, such as DfT published statistics, have been used to understand the levels of other vessel activity (primarily for passenger ferry activity between domestic origin and destination ports). In addition, a second level of analysis was undertaken for the three GB-NI routes assessed in this study using a much finer level of granularity of AIS data to provide greater confidence in route-specific information.

Several other evidence and data sources have been used to inform the analysis including a rapid evidence review of academic and grey literature; publicly available mapping software (Google Maps); publicly available journey planners; and information provided online by port authorities and official government statistics.[11]

The AIS derived data and other sources were triangulated through a six-step methodology to deliver the analysis in this study. Firstly, a theory of change was developed to underpin the analysis. This describes the mechanisms through which carbon pricing could be expected to feed through into changes in the behaviour of operators and customers. This accounts for potential responses relating to direct point-to-point journeys and indirect re-routing options to avoid the carbon price that results from UK domestic maritime being included in the UK ETS.

The second stage identified the key factors that determine the degree of risk of carbon leakage, internal carbon displacement and competitive disadvantage. The factors considered are:

1. **Carbon cost exposure:** Routes with ship types with high emission intensities and minimal short term abatement options are considered to have a high carbon cost exposure and would therefore be impacted by the introduction of a carbon price based on their fossil fuel consumption. In those cases, the UK ETS would be considered to fulfil its role if it encourages those vessels to reduce their emissions through abatement investment or other actions. If this is not feasible, the carbon cost associated with their need to purchase ETS allowances would be likely to be passed through to customers, which could in turn affect the customers' choices relating to how to move their cargo.
2. **Likelihood of cost pass-through:** Operators would be more likely to pass through carbon costs (i.e. to increase the price they charge their customers to cover their higher costs) when market conditions mean their ability to sustainably absorb any cost changes is minimal (e.g. a highly competitive environment). This in turn increases the likelihood of customer responses (all else being equal). This is dependent on the markets in which the operators operate and can vary by vessel type.

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[11] It was not possible within the scope of this work to directly contact shipbroking companies or other stakeholders.

3. **Likelihood of a shift to substitute options:** Customers may respond to an increase in shipping transport costs (where carbon costs have been passed through) by substituting to other transport modes where this is feasible, or to other routes that are not subject to a similar carbon cost. This is dependent on the alternatives available, whether they are feasible for the cargo or passengers being transported and the time and financial cost implications of using the alternative mode/route options.
4. **Potential degree of customer response:** Different types of customers will have different levels of price sensitivity. This is likely to be dependent on the characteristics of the cargo or passengers being transported (e.g. time sensitivity).

The third stage involved characterising the different vessel types that operate on UK domestic voyages. For this study, 19 vessel types[12] were included in the AIS data derived by UMAS in order to understand the nature of their activity and which types were prevalent on different routes. The size and type of vessel are important, not only because of their associated emissions and scale of activity, but also in relation to the potential operator responses. This is because different types of vessels may be associated with different business models and serve different customers who will have their own set of responses depending on the type of cargo (or passengers) carried (such as whether it is time-sensitive; low value-high volume etc.). In general, this analysis found that Ferry-RoPax, Ro-Ro and General Cargo vessels typically would be associated with high levels of cost pass-through (these operators have low profit margins) and typically compete with other modes of transport. Cruise ships and chemical tankers were considered to be associated with lower expected levels of customer response to any cost pass-through, given the limited alternative options available. In the case of cruise vessels, it is the experience of being on board the cruise liner that is an important driver of demand, which limits the likelihood of switching to other modes. Other vessel types had far less prevalence in UK domestic maritime activity and hence were not assessed in detail.

The fourth stage of the analysis identified three GB-NI routes of interest by examining vessel activity captured in the AIS derived data and applying the stages above. The selected routes were: Heysham to Warrenpoint; Belfast to Liverpool; and Belfast to Southampton.

The further stages of the analysis involved qualitative analysis and indicative quantitative ‘switching’ analysis (exploring what level of carbon price may be associated with a given reduction in demand under a given range of assumptions). A rating of low, medium or high has been used to describe the risk of carbon leakage, internal carbon displacement and competitive disadvantage, defined for this study as:

- low risk refers to the case in which the effect under consideration (i.e. carbon leakage, internal carbon displacement or competitive disadvantage) is unlikely to be observed;
- medium risk refers to the case in which the effect under consideration could feasibly be observed and if so, the emissions at risk of displacement or carbon leakage would be among the top ten highest of GB to NI routes, or there could feasibly be competitive disadvantage; and

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[12] Bulk carrier, Chemical tanker, Container General Cargo, Liquified gas tanker, Oil tanker, other liquids tanker, Ferry-pax only, Cruise, Ferry-RoPax, Refrigerated bulk, Ro-Ro, Vehicle, Yacht, Service – tug, Miscellaneous – fishing, Offshore, Service – other, and Miscellaneous - other

- high risk refers to the case in which the effect under consideration is likely to be observed and if so, the emissions at risk of displacement or carbon leakage would be among the top ten highest of GB to NI routes, or there could likely be competitive disadvantage.

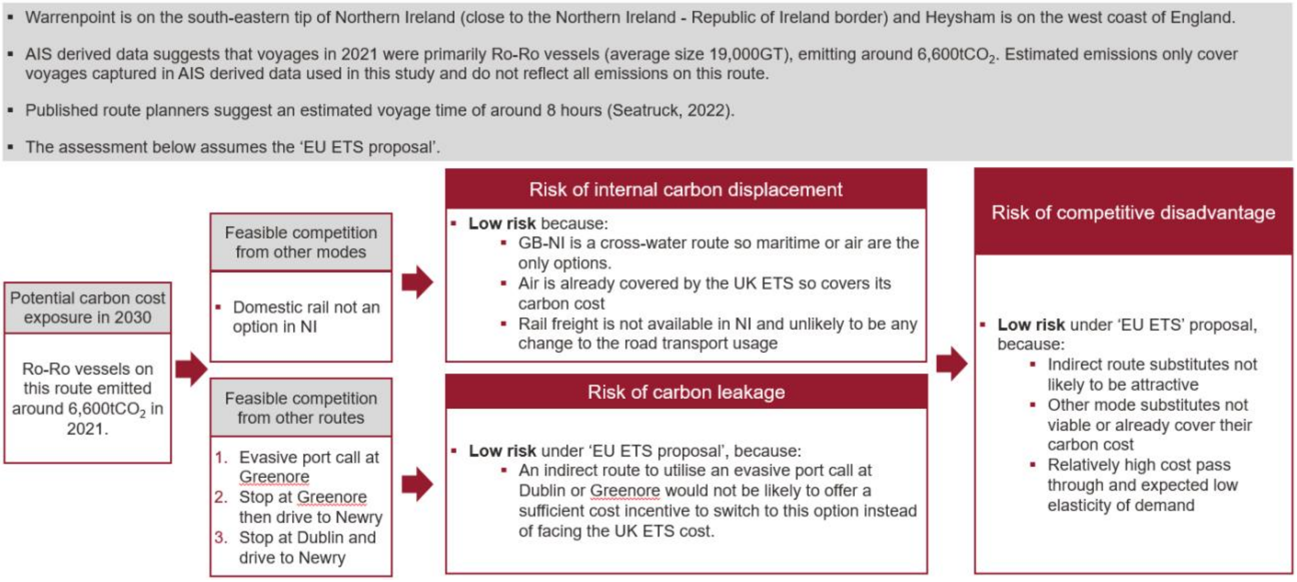
The risks have been qualitatively assessed by looking at a range of data, maps and port-specific operational information to assess the potential viability of alternative transport options and potential alternative indirect routes.

1.3 Findings

This analysis is qualitative because detailed modelling of the potential response of the UK domestic maritime sector to its inclusion in the UK ETS was not possible within the timeframe of this analysis. For the three GB-NI routes qualitatively assessed in this study, the key findings of the analysis are below. These findings are to be interpreted with the following contextual factors in mind:

- firstly, the analysis has been undertaken using best available data on the *current* vessel types (2021), voyage patterns and fuel consumption. These factors influence the extent of carbon cost exposure.
- secondly, the analysis assumes the current uptake of decarbonisation technology is low, in part because of the absence of a carbon price (alongside other barriers), which is what the inclusion of UK domestic maritime in the UK ETS is intended to address.
- thirdly, the scope of the EU ETS and the level of carbon price facing parties participating in the EU ETS are expected to evolve. For this study, projected 2030 carbon prices have been assumed for participants in the EU ETS, and the ‘EU ETS proposal’ has been assumed in the base case. Road and rail emissions in the EU could also face a carbon price in the future. If so, the consequences are crucially important to the findings and so are discussed where relevant below.
- fourthly, all results are sensitive to the assumptions on fuel price, UK ETS price, the EU ETS price, the coverage of the EU ETS, the proportion of voyage costs accounted for by fuel, the elasticity of demand and the percentage of cost-pass through. For example, the lower fuel costs are as a share of total voyage costs, the higher the UK ETS allowance price would need to be to result in a particular level of behaviour change.

Figure 1 Case study 1: Heysham to Warrenpoint (primarily Ro-Ro vessels in operation on this route)



- Warrenpoint is on the south-eastern tip of Northern Ireland (close to the Northern Ireland - Republic of Ireland border) and Heysham is on the west coast of England.
- AIS derived data suggests that voyages in 2021 were primarily Ro-Ro vessels (average size 19,000GT), emitting around 6,600tCO_2. Estimated emissions only cover voyages captured in AIS derived data used in this study and do not reflect all emissions on this route.
- Published route planners suggest an estimated voyage time of around 8 hours (Seatruck, 2022).
- The assessment below assumes the 'EU ETS proposal'.

Potential carbon cost exposure in 2030

Ro-Ro vessels on this route emitted around 6,600tCO_2 in 2021.

Feasible competition from other modes

- Domestic rail not an option in NI

Feasible competition from other routes

1. Evasive port call at Greenore
2. Stop at Greenore then drive to Newry
3. Stop at Dublin and drive to Newry

Risk of internal carbon displacement

- **Low risk** because:
  - GB-NI is a cross-water route so maritime or air are the only options.
  - Air is already covered by the UK ETS so covers its carbon cost
  - Rail freight is not available in NI and unlikely to be any change to the road transport usage

Risk of carbon leakage

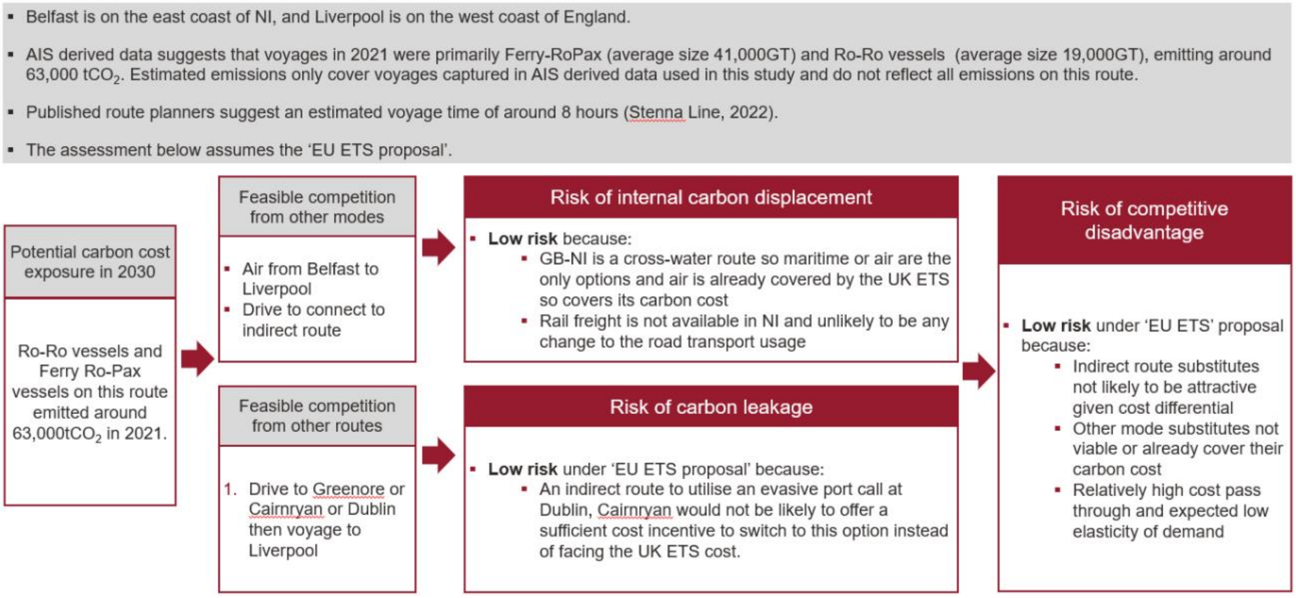
- **Low risk** under 'EU ETS proposal', because:
  - An indirect route to utilise an evasive port call at Dublin or Greenore would not be likely to offer a sufficient cost incentive to switch to this option instead of facing the UK ETS cost.

Risk of competitive disadvantage

- **Low risk** under 'EU ETS' proposal, because:
  - Indirect route substitutes not likely to be attractive
  - Other mode substitutes not viable or already cover their carbon cost
  - Relatively high cost pass through and expected low elasticity of demand

Source: *Frontier analysis – the estimated emissions only cover voyages captured in the AIS derived data used in this study and do not reflect all emissions on this route*

Figure 2 Case study 2: Belfast to Liverpool



- Belfast is on the east coast of NI, and Liverpool is on the west coast of England.
- AIS derived data suggests that voyages in 2021 were primarily Ferry-RoPax (average size 41,000GT) and Ro-Ro vessels (average size 19,000GT), emitting around 63,000 tCO_2. Estimated emissions only cover voyages captured in AIS derived data used in this study and do not reflect all emissions on this route.
- Published route planners suggest an estimated voyage time of around 8 hours (Stenna Line, 2022).
- The assessment below assumes the 'EU ETS proposal'.

Potential carbon cost exposure in 2030

Ro-Ro vessels and Ferry Ro-Pax vessels on this route emitted around 63,000tCO_2 in 2021.

Feasible competition from other modes

- Air from Belfast to Liverpool
- Drive to connect to indirect route

Feasible competition from other routes

1. Drive to Greenore or Cairnryan or Dublin then voyage to Liverpool

Risk of internal carbon displacement

- **Low risk** because:
  - GB-NI is a cross-water route so maritime or air are the only options and air is already covered by the UK ETS so covers its carbon cost
  - Rail freight is not available in NI and unlikely to be any change to the road transport usage

Risk of carbon leakage

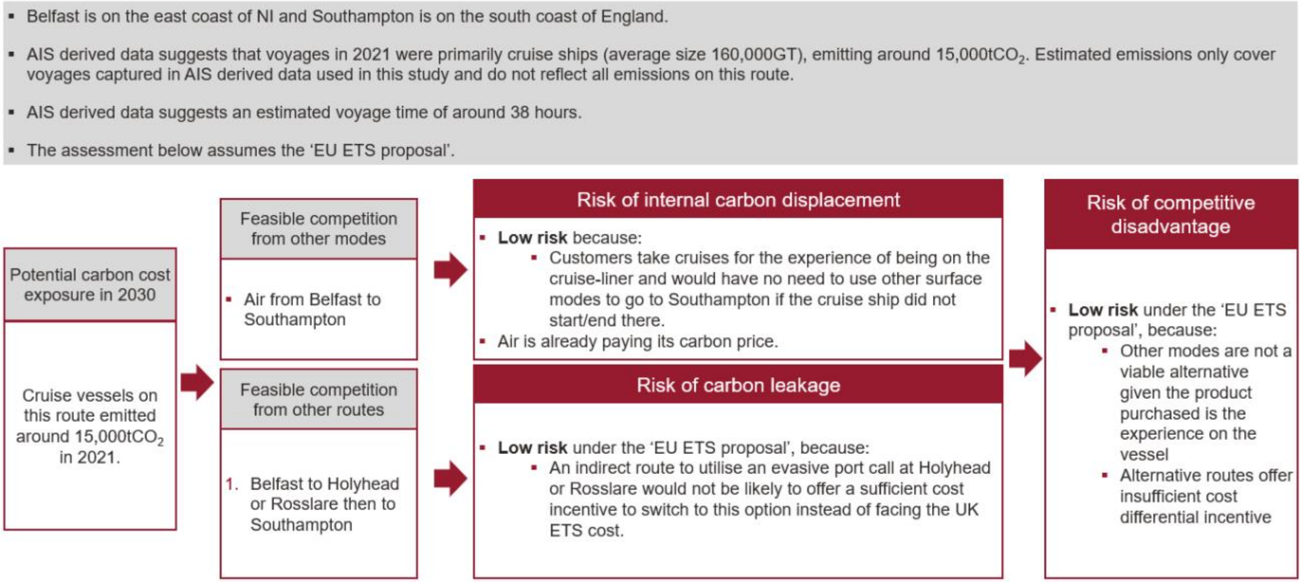
- **Low risk** under 'EU ETS proposal' because:
  - An indirect route to utilise an evasive port call at Dublin, Cairnryan would not be likely to offer a sufficient cost incentive to switch to this option instead of facing the UK ETS cost.

Risk of competitive disadvantage

- **Low risk** under 'EU ETS' proposal because:
  - Indirect route substitutes not likely to be attractive given cost differential
  - Other mode substitutes not viable or already cover their carbon cost
  - Relatively high cost pass through and expected low elasticity of demand

Source: *Frontier analysis - the estimated emissions only cover voyages captured in the AIS derived data used in this study and do not reflect all emissions on this route*

Figure 3 Case study 3: Belfast to Southampton (primarily cruise voyages)



- Belfast is on the east coast of NI and Southampton is on the south coast of England.
- AIS derived data suggests that voyages in 2021 were primarily cruise ships (average size 160,000GT), emitting around 15,000tCO_2. Estimated emissions only cover voyages captured in AIS derived data used in this study and do not reflect all emissions on this route.
- AIS derived data suggests an estimated voyage time of around 38 hours.
- The assessment below assumes the 'EU ETS proposal'.

Potential carbon cost exposure in 2030

Cruise vessels on this route emitted around 15,000tCO_2 in 2021.

Feasible competition from other modes

- Air from Belfast to Southampton

Feasible competition from other routes

1. Belfast to Holyhead or Rosslare then to Southampton

Risk of internal carbon displacement

- **Low risk** because:
  - Customers take cruises for the experience of being on the cruise-liner and would have no need to use other surface modes to go to Southampton if the cruise ship did not start/end there.
- Air is already paying its carbon price.

Risk of carbon leakage

- **Low risk** under the 'EU ETS proposal', because:
  - An indirect route to utilise an evasive port call at Holyhead or Rosslare would not be likely to offer a sufficient cost incentive to switch to this option instead of facing the UK ETS cost.

Risk of competitive disadvantage

- **Low risk** under the 'EU ETS proposal', because:
  - Other modes are not a viable alternative given the product purchased is the experience on the vessel
  - Alternative routes offer insufficient cost differential incentive

Source: *Frontier analysis - the estimated emissions only cover voyages captured in the AIS derived data used in this study and do not reflect all emissions on this route*

1.4 Headline findings

The main findings of the analysis are:

1. For the three GB-NI routes on which this analysis focuses (Belfast to Liverpool; Heysham to Warrenpoint; and Southampton to Belfast), the UK ETS is likely to provide a strong incentive to accelerate decarbonisation, therefore addressing one of the key barriers to decarbonisation (Frontier et al., 2019).[13] Prevalent vessel types on these three routes are currently primarily fossil-fuel based and so have carbon cost exposure which would be likely to decline over time as the sector decarbonises.

2. The risk of carbon leakage is considered to be low across all three GB-NI routes analysed if the 'EU ETS proposal' were in place. Carbon leakage refers to the case in which, in response to the carbon price, passengers and shipping operators switch to using an indirect route in the Republic of Ireland which would be an 'international' voyage rather than a UK 'domestic' voyage and therefore avoid the costs associated with the UK ETS. This would not be likely if those international voyages are covered as in the 'EU ETS proposal' because the cost saving would not be likely to provide sufficient incentive to switch. This risk would be even lower if the IMO were to implement ambitious decarbonisation policy measures. The risk of carbon leakage could therefore be higher if the 'EU ETS proposal' were not in place.

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[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

3. The risk of internal carbon displacement is considered to be low across all three GB-NI routes analysed. Internal carbon leakage refers to the case in which, in response to the carbon price, customers switch to another mode of transport that is not covered by a carbon price. Given GB-NI routes, by definition, require crossing water, this aspect is unavoidable unless using air travel, which is not feasible for some cargo. While it may be feasible for some substitution of maritime for air in some cases, in any case, air travel is already subject to a carbon price. Any shift to non-electrified surface transport modes would only affect short legs of the journey so would be unlikely to provide an incentive to switch given the additional time involved in road travel. This risk is lower still if non-electrified road transport is included in the EU ETS.

4. The risk of competitive disadvantage is considered to be low across the three GB-NI routes considered if the 'EU ETS proposal' were in place**.** Competitive disadvantage refers to the case in which parties within the domestic maritime sector experience a disadvantage (e.g. higher costs) relative to their competitors. In this case, the competitors to UK domestic maritime on the three GB-NI routes include the indirect routes stopping off in the Republic of Ireland then transferring to road transport (which has a low risk, as described above). The risk could therefore be higher if the 'EU ETS proposal' were not in place.

5. The assessment of risk would be different if the 'EU ETS proposal' were not in place. In such a case, the risk of carbon leakage could be high across all three case study GB-NI routes, due to the incentive to avoid the UK ETS by switching to an indirect route via the Republic of Ireland. Furthermore, there could be differential competitiveness effects of including domestic maritime in the UK ETS, depending on the size of operators given the potential barriers to decarbonisation for small operators (Frontier et al., 2019)[14] and across different vessel types. However, at the time of writing, European maritime traffic is expected to be included in the EU ETS, as set out above.

6. Very high carbon prices would be likely to be needed for a material impact on UK domestic maritime demand to be observed. Indicative switching analysis suggests that a very high UK ETS allowance price (far in excess of the current UK ETS allowance price) would be likely to be needed for a material reduction in UK domestic maritime demand to be observed. Although there are substantial uncertainties in the analysis, even under cautious assumptions a high allowance price would be needed. This suggests a significant change in UK domestic maritime traffic would not be likely following its inclusion in the UK ETS.

7. **On the basis of available evidence, the analysis suggests that the effects of a carbon price are likely to vary across vessel types.** Operators of Ferry-RoPax, Ro-Ro and General Cargo vessels are likely to pass the costs through to customers in the short term as they typically have lower profit margins than other vessel types such as cruise vessels or chemical tankers. The risk would be dependent on whether alternative options are subject to a carbon price, such as the EU ETS.

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[14] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

2 Policy context and aims of the study

In 2019, the UK Government implemented a legally binding net zero target for greenhouse gas emissions (GHGs) (BEIS, 2019). This states that in 2050, any emissions must be offset by an equivalent amount through measures such as planting trees or technology such as carbon capture and storage. This builds on the Climate Change Act 2008, which mandated that the UK sets five-yearly carbon budgets which put legal limits on emissions that can be produced during each period, aligned with the target for 2050. The Sixth Carbon Budget, which the government has legislated for, requires a 77% reduction in net GHG emissions compared to 1990 levels for the years 2033 to 2037 (UK ETS Authority, 2022).

In 2021, the UK Government published the Net Zero Strategy. This included policies and proposals for decarbonising all sectors by 2050 (HM Government, 2021). This sits alongside the Industrial Decarbonisation Strategy, which described a net zero compliant path for industry, whilst maintaining competitiveness (UK ETS Authority, 2022).

The UK Government and Devolved Administrations are committed to using carbon pricing - through the UK Emissions Trading Scheme (UK ETS) - as a key policy lever to ensure the UK reaches its climate targets. The UK ETS requires sectors and operators covered by the scheme to surrender allowances equivalent to the amount of CO_2e they emit each year. This means they face a carbon price which provides an incentive for emissions to be reduced. The UK ETS was established following the UK's departure from the European Union (EU). Prior to this, the UK was a part of the EU Emissions Trading Scheme (EU ETS) (UK ETS Authority, 2022). Currently, the scheme covers energy intensive industries, the power generation sector and aviation (BEIS, 2022). For the purpose of this report, 'carbon price', 'allowance price' and 'ETS price' are used interchangeably. All terms refer to the amount an operator would need to pay per tonne of carbon dioxide equivalent that they emit. The same terminology is used whether discussing the UK ETS or the EU ETS.

The UK Government and Devolved Administrations have committed to further develop the UK ETS. In 2022, a consultation outlined potential changes to the existing scheme such as the inclusion of new sectors (UK ETS Authority, 2022). One sector proposed for inclusion in the UK ETS was domestic maritime. The lead proposal for inclusion is for this to be on a vessel-activity basis for vessels at or above 5,000GT and to come into effect by the mid-2020s.

The DfT 'UK Domestic Maritime Decarbonisation Consultation: Plotting the Course to Zero' states that while progress has already been made to reduce the carbon intensity of shipping, more work is needed to successfully transition the domestic maritime sector to a net zero GHG industry by 2050 at the latest (DfT, 2022a). Domestic shipping currently accounts for around 5% of UK domestic transport GHG emissions; more than the UK rail and bus network combined (UK ETS Authority, 2022). While the inclusion of UK domestic maritime in an expanded UK ETS would be expected to provide incentives to decarbonise, there may also be risks that need to be carefully managed. Such effects could include internal carbon displacement, carbon leakage and competitive disadvantage (each of these are defined for the purposes of this study in Chapter 3).

The Department for Transport (DfT) and the Department for Business, Energy and Industrial Strategy (BEIS) have therefore commissioned this research to develop robust evidence on the extent to which the inclusion of domestic maritime in the UK ETS could lead to carbon leakage, internal carbon displacement or competitive disadvantage. The findings were delivered to DfT and the Department for Energy Security and Net Zero (DESNZ). The aims of this research are to:

a. Identify the key factors that determine the risk of carbon leakage, internal carbon displacement and competitive disadvantage, if UK domestic maritime joins the UK ETS. This includes exploring the competition the sector faces (e.g. from other transport modes); and analysis of the causal mechanisms through which these effects could arise.
b. Identify which indirect routes are the key competitors of direct maritime journeys between Great Britain (GB) and Northern Ireland (NI) i.e. they have a maritime leg between GB and the Republic of Ireland (ROI) and a land transport leg between ROI and NI. This is to enable an assessment of how the inclusion of maritime routes between GB and NI in the UK ETS could impact on competition between direct and indirect routes.
c. Qualitatively assess the extent to which the inclusion of maritime routes between GB and NI could lead to internal carbon displacement, carbon leakage and competitive disadvantage in respect to 3 case study journeys under a variety of different policy scenarios. The scenarios vary assumptions around key design dimensions of the UK ETS and EU ETS. Indicative switching analysis explores the potential carbon prices associated with different magnitudes of impact on demand (with sensitivity ranges).

There are many uncertainties in this form of analysis which qualitatively assesses the potential responses of maritime operators and maritime customers to the inclusion of domestic maritime in the UK ETS. Such responses are also likely to be affected by what is assumed about the scale and coverage of the EU ETS. It is important to recognise the limited published academic evidence on some of the key assumptions that have been made to undertake this work. Best available evidence has been used and referenced accordingly with sensitivity analysis undertaken to enhance rigour. The qualitative assessment presented in this report triangulates evidence sources. Limitations and assumptions are further described in Chapter 4.

3 Carbon pricing in maritime

In this chapter, the current regulatory landscape relevant to this analysis is summarised. Commentary is provided on how this may change in the future, alongside the definitions of internal carbon displacement, carbon leakage and competitive disadvantage.

3.1 Current and future regulatory landscape for UK domestic shipping

There are currently no specific sectoral targets for UK domestic or international shipping GHG emissions. Domestic policy relating to emissions of GHGs from the maritime sector is based around the Climate Change Act 2008, under which the Government sets five-yearly carbon budgets that restrict the amount of GHGs the UK can legally emit in a five-year period. Emissions from domestic shipping are included in both the carbon budgets and the 2050 target (DfT, 2019). For the Sixth Carbon budget, emissions from international shipping have now been added (DfT, 2021a).

In 2021, the UK Government published the Transport Decarbonisation Plan, which sets out the government's decarbonisation commitments across the transport sector. In this, it committed to assessing how economic instruments could be used to accelerate the decarbonisation of the domestic maritime sector (DfT, 2021a). With this in mind, the UK ETS Authority released a consultation in 2022 regarding the potential inclusion of domestic maritime shipping within the UK ETS by the mid-2020s. International maritime is not currently being considered for inclusion in the UK ETS, with the decarbonisation of international shipping being pursued via the work of the International Marine Organization (IMO) (UK ETS Authority, 2022).

The UK ETS is a 'cap and trade' system for reducing emissions. This involves setting a cap on the total amount of GHGs that can be emitted by the sectors covered by the scheme and reducing this over time to meet the UK's carbon reduction commitments. The sectors and participants within the scheme receive free allowances and/or buy emission allowances, which they can then trade with one another. At the end of each year, the entities covered by the scheme then surrender their allowances to cover their emissions for that year. The aim of this market-based approach to reducing emissions is for those reductions to take place in the sectors and/or firms where it is cheapest to do so.

The current coverage of the UK ETS includes energy intensive industries, the power generation sector and emissions from domestic aviation (flights within the UK) and flights to the European Economic Area (EEA) as agreed in the UK-EU Trade and Co-operation Agreement (TCA). Flights from the EEA to the UK are covered by the EU ETS (UK ETS Authority, 2022).[15] The UK ETS does not currently cover emissions from non-electrified road or rail, or emissions from domestic or international shipping. The rationale for including domestic maritime in the UK ETS is because the current prices of maritime fuel do not reflect the social costs (i.e. the negative externality) of the greenhouse gas and air pollutant emissions that are released when maritime fuel is consumed. This means there is not a strong enough

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[15] We note that from 1 January 2023, flights from GB to Switzerland are included in the UK ETS. Flights from NI to Switzerland will be included once the NI Assembly is able to progress legislation. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1101633/developing-uk-ets-consultation-government-response.pdf

incentive for ship owners and/or operators to invest in emission reduction options. By pricing the carbon emitted in line with its social cost through the UK ETS (i.e. internalising the externality), the aim is to incentivise investment in decarbonisation options. The inclusion of domestic maritime shipping may also lead to additional benefits for the operation and effectiveness of the scheme. By expanding the pool of market participants involved in the UK ETS, this may also improve the trading liquidity of carbon allowances and ensure that decarbonisation options are taking place in a cost-effective manner.

The lead option for including UK domestic maritime shipping in the UK ETS proposes that vessels over 5,000 gross tonnage (GT) are included and that it is applied to ship owners or operators on the basis of vessel activity (UK ETS Authority, 2022). On this basis, journeys within the UK ETS would only include UK-UK routes, including between GB and NI. International journeys, or journeys between the UK and Crown Dependencies and Overseas Territories are not proposed to be covered.

For the purpose of this report the ‘UK ETS proposal’ consists of maintaining the current UK ETS policy for aviation, non-electrified road and rail, and international shipping, and bringing emissions from domestic maritime only, for vessels over 5,000 gross tonnage into the UK ETS. This is based on the lead option described in the March 2022 consultation (UK ETS Authority, 2022).

Given the interaction between international and domestic maritime, the markets in which it operates, and the potential responses by operators and customers to the inclusion of domestic maritime shipping in the UK ETS (see Section 6 for further details on potential responses), it is important to understand the potential risks of internal carbon displacement, carbon leakage and competitive disadvantage that this may cause. For the purposes of this study these terms are defined as:

Carbon leakage: The displacement of greenhouse gas emissions from domestic maritime journeys included in the UK ETS due to different levels of carbon pricing or climate regulation across jurisdictions. Where leakage occurs, this means that a reduction in the greenhouse gas emissions from domestic maritime journeys included in the UK ETS would not reduce global greenhouse gas emissions by the same quantity.

Internal carbon displacement: The displacement of greenhouse gas emissions from domestic maritime journeys included in the UK ETS to other sectors of the UK economy, due to different levels of carbon pricing or climate regulation. Where displacement occurs, this means that a reduction in the greenhouse gas emissions from domestic maritime journeys included in the UK ETS would not reduce UK greenhouse gas emissions by the same quantity.

Competitive disadvantage: Due to the introduction of a carbon pricing policy, competitive disadvantage would arise if businesses in the UK domestic maritime sector experience a significant adverse impact on their competitiveness compared to competitors. This means that they would not be able to thrive as businesses compared to their competitors (therefore losing market share, for example). Carbon pricing is one of a range of factors that could cause competitive disadvantage. However, carbon pricing will not always lead to competitive disadvantage. For there to be competitive disadvantage, common factors would include the extent to which operators face significant carbon cost exposure and whether they have competing options available (such as switching to either indirect routes or other forms of transport, or other operators who face relatively lower barriers to decarbonisation).

For the purposes of this study, operators are considered to directly provide and operate domestic maritime services. Customers of maritime services include couriers, distributors and ferry / cruise passengers. In the context of fishing and offshore, the operator of the vessel and the customer of maritime services are likely to be the same entity. For example, the vessel operator would directly undertake fishing at sea.

In understanding the risks of internal carbon displacement, carbon leakage and competitive disadvantage, the current form and future evolution of the EU ETS is also important. This is because the UK shares a land border with ROI, which is in the EU and presents additional opportunities for responses by operators and customers (see Section 6 for details of possible responses). The EU ETS currently covers aviation emissions for flights between airports located in the EEA, and flights departing from the EEA and arriving in the UK.[16] The EU ETS does not currently cover emissions from non-electrified road or rail,[17] or emissions from domestic or international shipping.

As is the case for the UK ETS, the EU is also looking to expand the coverage of the EU ETS. While later sections explore this in more detail, at a high level the EU has agreed to expand the EU ETS to include maritime[18] and to set up a new ETS system for road transport (although some details are yet to be confirmed) (Council of the EU, 2022). For the purpose of this report, the ‘EU ETS proposal’ consists of maintaining the current EU ETS policy for aviation and non-electrified rail and road, and for vessels over 5,000 gross tonnage, bringing 100% of emissions from intra-EU maritime journeys, and 50% of emissions from international maritime journeys which either start or end in the EU, into the EU ETS. Given the policy uncertainties and exploratory nature of this work, scenarios have been considered in relation to the scope and evolution of the UK ETS and EU ETS and their respective carbon prices. These scenarios are outlined in Chapter 4.

3.1.1 International maritime regulation

In 2016, to support the aims of reducing emissions of pollutants and GHGs from international maritime, the IMO adopted the mandatory IMO Data Collection System (DCS) for ships. This required ships over 5,000GT to collect and report fuel oil consumption data. In 2019, the first calendar year of data collection was completed (IMO, 2021).

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[16] This is the scope of aviation emissions in the EU ETS until 31 December 2023. After this date it is expected that the EU ETS will apply to all flights from, to, and within the EEA. As this is not yet current policy, we do not assume this extension happens as part of our analysis. https://climate.ec.europa.eu/eu-action/transport-emissions/reducing-emissions-aviation_en

[17] The EU is considering introducing a new, separate ETS system (EU ETS II) for buildings and road transport, and the initial plan was to introduce this in 2027. Due to limitations of the modelling in this analysis, the impact of this separate ETS system could only be assessed qualitatively. Therefore the analysis does not consider this as part of the central ‘EU ETS’ proposal (base case), but this is discussed elsewhere as part of alternative scenarios. https://ec.europa.eu/info/sites/default/files/revision-eu-ets_with-annex_en_0.pdf, page 19

[18] The Council and Parliament agreed on a gradual introduction of obligations for shipping companies to surrender allowances: 40% for verified emissions from 2024, 70% for 2025 and 100% for 2026.

In April 2018, the IMO adopted the Initial Strategy on the reduction of GHG emissions from shipping. This policy framework set out the key ambitions to reduce annual GHG emissions from international shipping by at least 50% by 2050, compared with their level in 2008. It also committed to working towards phasing out GHG emissions from shipping entirely as soon as possible in this century, and reducing the carbon intensity[19] of international shipping (to reduce CO_2 emissions per transport work), as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008 (IMO, 2021).

In June 2021, the IMO adopted key short-term measures aimed at cutting the carbon intensity of all ships by at least 40% by 2030, in line with the ambitions set out in the IMO Initial Strategy. To improve the energy efficiency of ships, these measures combine technical and operational approaches. For example, all ships will have to calculate their Energy Efficiency EXisting Ship Index (EEXI) and ships over 5,000GT will establish their annual operational carbon intensity indicator (CII) and CII rating (IMO, 2021).

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[19] Carbon intensity measures how efficiently a ship transports goods or passengers and is given in grams of CO_2 emitted per cargo-carrying capacity and nautical mile

4 Methodology

This chapter describes the evidence sources utilised in this analysis and the methodological steps undertaken, along with the limitations in the data and analysis.

4.1 Evidence used

4.1.1 Rapid evidence assessment

To inform the analysis described below, a rapid evidence assessment was undertaken, tailored to the objectives of this work. The review covered:

- **grey literature**: including work published by National Governments, European Parliament, Non-Governmental Organisations (NGOs) and research institutes; and
- **academic literature:** sourced from keyword (e.g. “Maritime Carbon Pricing”, “Competitiveness Impacts of Carbon Pricing”, “Carbon Pricing and Mode Shift” and “Carbon leakage risks to shipping from emissions trading systems”) searches of academic databases.

Topics on which evidence was researched include the following:

- competitiveness effects of carbon pricing on the maritime sector;
- the proportion of voyage costs that is typically accounted for by fuel;
- levels of cost pass-through observed in different maritime sub-sectors;
- carbon leakage and the methods used by operators and customers to avoid incurring additional costs following the introduction of carbon prices (e.g. evasive port calls); and
- price elasticity of demand for maritime shipping.

4.1.2 Automatic Identification System (AIS) data[20]

AIS data is the most sophisticated and spatially detailed data available. It has been used as a core data source underpinning this analysis: it uses satellite and terrestrial data collected through the automatic identification system (AIS). This is an automatic tracking system that uses transceivers on ships and is used by vessel traffic services (VTS). The primary purpose of AIS data is to provide information about ship locations to other ships and coastal authorities.

IMO regulations require AIS transceivers to be fitted onboard all ships in excess of 300GT that are engaged in international voyages, cargo ships in excess of 500GT even if not engaged in international voyages and all passenger ships irrespective of size. This means the AIS data does not cover the entire population of vessels and is therefore subject to limitations (outlined in Section 4.3). The AIS derived data is not intended to be a UK emissions inventory but is valuable in building an understanding of voyage patterns along with the characteristics of those voyages for which AIS data

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[20] All of the raw AIS data was originally sourced from Spire Global (www.spire.com). The analysis used throughout this report relies on AIS derived data which is the outputs of UMAS analysis of the raw data.

is available. The raw global AIS data provides basic information such as vessel positions over time (and hence speed), draft and a unique vessel identifier. Each identifier is then used to obtain more detailed vessel information from a vessel database supplied by IHS Markit. UMAS analysts have combined these vessel particulars with the vessel speeds to estimate the fuel consumption and emissions of the global AIS-equipped vessel fleet. UMAS then applied a post-processing algorithm to divide the vessel tracks and emissions into discrete journeys suitable for this project. Finally, this global dataset was then refined to select only the journeys that took place between two GB ports and journeys that took place between GB and NI ports to generate the 'AIS-derived' dataset used for all analysis.

Data includes vessel size and type, average emissions intensity of vessels and their total emissions. Its value is in identifying routes for which there may be significant carbon emissions. The journey identification algorithm used in the global 4th IMO GHG study[21] was initially used here derive the number of journeys on each route. This algorithm primarily considers the Speed Over Ground (SOG) reported and the distance between the vessel and its closest port at any time (based on GPS-coordinates). When a vessel is estimated to be travelling at a SOG below one nautical mile per hour, AIS messages from that vessel are treated as a cluster. A cluster of AIS messages is considered a stop if a) the distance to its nearest port is small[22], b) the time at port is sufficiently large[23] and c) the distance between the cluster itself and both its neighbouring clusters is sufficiently large.[24]

However, the journey identification post-processing step used in the global 4th IMO GHG study was not optimised to capture short domestic journeys. For example, the algorithm runs on vessel track data aggregated to hourly points. This means that short journeys and short port turn arounds are difficult to accurately capture. Short passenger ferry voyages may have completed multiple journeys in the time between the capture of consecutive data snapshots. This can lead to frequent short journeys appearing as less frequent longer journeys within the dataset.

In order to capture these short voyages and fast port turnarounds, an additional approach was developed and implemented using the raw AIS data, on key case study routes. Firstly, a new voyage identification method was carried out based on the recorded navigational status in the raw AIS messages for each vessel.[25] Under this method a voyage is deemed to have begun when the AIS data indicates that the vessel has moved approximately 1-2km from the berth location. Similarly, the end of a voyage is judged to have occurred when the vessel's AIS message returns to the at berth/port value.

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[21] https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

[22] Ranging from 5 to 30 nautical miles

[23] Ranging from 6 to 12 hours as a minimum

[24] Ranging from 30 to 60 nautical miles

[25] In particular the vessel is deemed to be at berth/port if the navigational status has value '5'.

To match port locations to names, port matching was carried out using the locations of each port.[26] The port location codes recorded by the ships themselves are very inconsistent over small city-size regions. Therefore, the emissions for all voyages starting or ending within a box around the areas of interest with multiple individual ports were aggregated (e.g. Liverpool and Belfast).

Voyage distance is then computed as the distance between the last observed AIS at berth message and the first such at the end of the voyage. This method is successful in capturing ferry routes and many shorter cargo voyages. However, it relies on the efficiency of captains in sending the ‘at berth’ navigational status. For routes longer than about 6 hours with longer turn round times, the original base algorithm captures routes relatively reliably and so in order to capture as many voyages across the fleet as possible, the voyage inventories were merged from both methods (on case study routes).

To ensure quality in the subset of data used to understand voyage patterns, the data used for this analysis was intentionally constrained to only include UK domestic maritime activity on voyages which exceed 6 hours. Although the AIS derived data therefore only identifies a subset of voyages, this minimum voyage time cut-off provides confidence that the data captures full voyage lengths and associated fuel and emissions for the voyages analysed. Where the original (IMO4) approach does not correctly identify/disaggregate the shorter journeys, the emissions associated with them are excluded from the data. Above the 6-hour cut-off, we have sufficient hour samples to overcome the limitations of the hourly sampling issue. For the short port turn-around issue, on two key routes,[27] the additional method (described above) was deployed that used higher frequency AIS data and the navigational status to confidently identify the port calls and journeys. This additional approach did lead to an updated voyage count on the Heysham-Warrenpoint route (only this route needed to be adjusted in this way).

The derived AIS data contains 19 vessel types[28] each of which can be mapped to IHS Markit ship types (268 vessel types in total).

For the case study analysis, derived AIS data (drawn from both satellite and terrestrial receivers) has been aggregated and statistical models have been applied which facilitate the analysis of domestic maritime activity on specific routes. In particular, the modelling estimates the number of voyages between different ports, according to the vessel size, type and year. Further analysis was then undertaken to estimate average voyage times, average voyage distances, fuel consumption and associated emissions from these voyages.

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[26] This matching was firstly undertaken using a distance tolerance of approximately 1-2km. If there was a failure to match, a second filter of approximately 10km was applied. Therefore, port-matching assumes that all ports are separated by at least 1-2 km.

[27] The method was deployed on Heysham-Warrenpoint and Belfast-Liverpool. After undertaking this analysis no adjustment was needed on Belfast-Liverpool as the original data was confirmed to be accurate. However, the voyage count on Heysham-Warrenpoint was updated. The third case study’s common vessel types and average voyage duration mean that the risk of misidentification was low and therefore the additional method was not needed.

[28] Bulk carrier, Chemical tanker, Container General Cargo, Liquified gas tanker, Oil tanker, other liquids tanker, Ferry-pax only, Cruise, Ferry-RoPax, Refrigerated bulk, Ro-Ro, Vehicle, Yacht, Service – tug, Miscellaneous – fishing, Offshore, Service – other, and Miscellaneous - other

Both 2021 and 2019 AIS derived data were analysed to avoid over reliance on domestic shipping patterns during the COVID-19 pandemic.

4.1.3 Other available data

A variety of data sources have fed into the qualitative and quantitative analyses undertaken. In some cases, these sources of information facilitated cross-checks and addressed limitations of the AIS derived data. In other cases, these data sources allowed for a more accurate triangulation which fed into the subsequent assessment. These sources include:

- ferry passenger volume data (DfT, 2022c);
- fuel price data (Frontier Economics, UMAS & E4tech, 2019a);
- data on vessel voyage costs (Bialystocki & Konovessis, 2016) (Mallouppas, Yfantis, Ktoris, & Ioannou, 2022);
- EU ETS price forecasts (ICIS, 2022); and
- elasticities of demand (Merkel, Johansson, Lindgren, & Vierth, 2022).

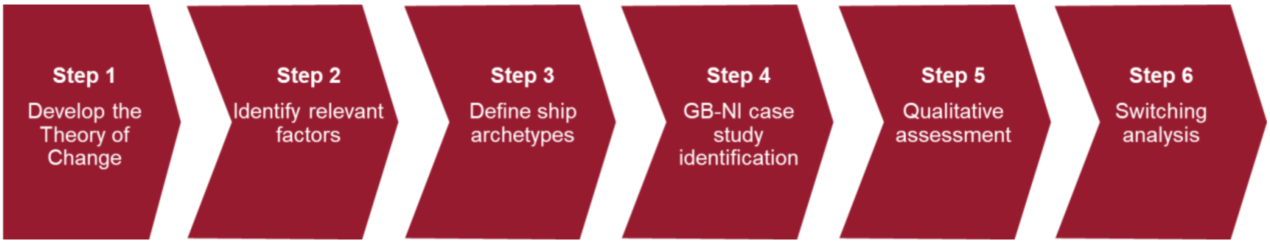
4.1.4 Geographic and logistical information

Publicly available mapping software (Google Maps) was used to identify possible alternative routes. Public journey planners were used to estimate the time specific journeys could take to complete (Google Maps). Information provided online by port authorities (e.g. Peel Ports Group (2022b)), shipping operators (e.g. Seatruck (2022)) and official government statistics (e.g. (DfT, 2022b)) were also used to assess feasibility of indirect routes and verify the AIS derived data.

4.2 Approach undertaken

As set out in Chapter 2, the aim of this work is to develop robust evidence on the extent to which the inclusion of domestic maritime in the UK ETS could lead to carbon leakage, internal carbon displacement and competitive disadvantage. A six-step methodology as shown below was designed and implemented.

Figure 4 Approach



Source : Frontier Economics

4.2.1 Step 1: Develop the Theory of Change

Firstly, a conceptual theory of change was developed to underpin the analysis. This generated a logic model that was generic to all voyages that are direct routes (e.g. potential responses assuming the ‘UK ETS proposal’ does not lead to a change in the origin and destination ports) and a separate logic model relating to indirect routes (which considers potential responses by operators and maritime customers if the route is changed to involve non-UK jurisdiction as a result of the inclusion of domestic maritime in the UK ETS). These logic models illustrate the mechanisms by which the ‘UK ETS proposal’ could impact both operator behaviour and customer behaviour (see Section 3 for definitions of operators and customers).

These logic models describe the channels through which the ‘UK ETS proposal’ could in some circumstances result in risks of competitive disadvantage, carbon leakage or internal carbon displacement. The likelihood of these risks materialising has been assessed qualitatively in subsequent stages of work.

4.2.2 Step 2: Identify factors that increase the likelihood of risks

Next, factors that determine the risk of carbon leakage, internal carbon displacement or competitive disadvantage on certain routes and vessel types were identified. These factors included the vessel’s carbon cost exposure, the likelihood of cost pass-through, how likely it was that there could be a shift to substitute modes of transport and the potential degree of customer response. These factors then informed the consideration of the degree of risk which could apply to the different vessel types (Step 3), the choice of case study routes (Step 4) and provided the framework by which the qualitative risk assessment is carried out on each of the selected routes (Step 5).

4.2.3 Step 3: Define ship archetypes

Next, it was necessary to identify the main vessel types (referred to here as archetypes) which collectively accounted for the bulk of carbon emissions on GB-NI routes captured in the AIS derived data used in this study. Subsequent analyses then focused on these commonly occurring vessel archetypes on each case study route.

The extent to which the four factors in Step 2 apply to each of the relevant vessel archetypes was considered. This indicated which vessel archetypes were more likely to be subject to competitive disadvantage, carbon leakage or internal carbon displacement following the inclusion of domestic maritime shipping in the UK ETS.

4.2.4 Step 4: Identify GB-NI case studies

Three case study routes between GB and NI were identified for further in-depth quantitative and qualitative analysis of internal carbon displacement, carbon leakage and competitive disadvantage following the inclusion of domestic maritime in UK ETS. The process is described below.

Firstly, AIS derived data from 2021 was used to identify the top 10 GB-NI routes which accounted for the highest amount of total annual CO_2 emissions captured in this data. These 10 routes formed the longlist of potential case studies. This list was filtered down to those of most interest by considering the following characteristics:

- routes with the relatively highest total CO_2 emissions (based on the AIS derived data);
- routes with a relatively high average carbon intensity (based on the AIS derived data);
- routes with a relatively high total number of ferry passengers (DfT, 2022c);
- routes which pass ROI on their way to their destination in NI (based on visual inspection of route); and
- routes which have an origin or destination port in NI which is near the border with ROI (based on visual inspection of the geographical location of the destination port).

Insufficient data on cargo values and cargo types meant that this could not inform the analysis at this stage.

4.2.5 Step 5: Qualitative assessment

The potential risk of competitive disadvantage, carbon leakage or internal carbon displacement was then qualitatively assessed for each of the three selected routes.

This qualitative analysis used a framework based on the factors identified as part of Step 2 (carbon cost exposure, likelihood of cost pass-through, likelihood to shift to substitute modes, potential degree of customer response). The AIS derived data for each case study provided information on the vessel types on those routes and hence the relevant vessel archetypes specific to each case study route.

The risks of carbon leakage, internal carbon displacement and competitive disadvantage have been qualitatively assessed by looking at a range of data, maps and port-specific operations.[29]

A three-category qualitative rating (low risk, medium risk, high risk) is applied to each risk in each case based on the available evidence and academic expert judgement. The ratings are defined for this study as:

- low risk refers to the case in which the effect under consideration is unlikely to be observed;
- medium risk refers to the case in which the effect under consideration could feasibly be observed and if so, the emissions at risk of displacement or carbon leakage would be among the top ten highest of GB to NI routes, or there is a feasible risk of competitive disadvantage; and
- high risk refers to the case in which the effect under consideration is likely to be observed and if so, the emissions at risk of displacement or carbon leakage would be among the top ten highest of GB to NI routes, or there is a likely risk of competitive disadvantage.

4.2.6 Step 6: Switching analysis

The final stage of the methodology consists of indicative switching analysis. This analysis provides a high-level indication of the potential estimated magnitude of change in UK domestic maritime demand

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[29] Secondary sources of information have been used in this report. Direct engagement with operators and couriers was out of scope.

on each route associated with a rise in voyage costs driven by the introduction of domestic maritime into the UK ETS. This is subject to considerable uncertainty and results should therefore be interpreted with caution. Changes to assumptions can have a material impact on the final results and have been explored through sensitivity testing.

The switching analysis involves comparing the total voyage costs of a given voyage if it were undertaken on an indirect route (subject to the scenario-specific EU ETS) which could be considered as a counterfactual, with the total voyage costs of the same voyage on a direct route (subject to the UK ETS) which can be considered the 'with intervention' case. It is assumed for the purposes of this switching analysis that the volume of carbon emitted on each of the direct and indirect options within the case study is the same.[30] The differential in voyage costs between each option is then estimated to calculate the potential change in UK domestic shipping demand on each route associated with the price change. This differential arises due to differences in the coverage of the UK ETS and the EU ETS and/or differing carbon prices in the UK and EU ETS.

For this switching analysis, the AIS derived data was combined with different assumptions to explore the potential magnitude of impact on demand from a carbon price:

Published estimates of the share of voyage costs accounted for by fuel (these estimates are averaged across different vessel types as it was not possible given available data and the scope of this work to apply differential assumptions to each voyage type) (Bialystocki & Konovessis, 2016) (Mallouppas, Yfantis, Ktoris, & Ioannou, 2022). The assumed proportion across all vessel types is 50%, this is based on high quality peer reviewed research (with a sensitivity applying a lower value of 30%, as per the cited literature).[31]

Existing research (RBB Economics, 2014) notes that theoretical economic models indicate that pass-through (when a business changes the prices of the products or services it supplies following a change in its costs) of industry-wide cost changes increases with the intensity of competition. Given the competitive dynamics of the domestic shipping industry, a cost pass-through rate of 100% was assumed in this case. If this assumption did not hold and the pass-through rate was less than 100%, then customer responses would be smaller (as the price increases would be lower) and operators would have greater incentives to invest in long-term abatement options (as they are bearing more of the higher voyage costs themselves).

A published meta-analysis of estimates of the price elasticity of demand for short sea shipping (Merkel, Johansson, Lindgren, & Vierth, 2022).[32] While the actual elasticity will vary according to the

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[30] In reality emissions could be different on the direct and indirect route based on fuel use, which is broadly a function of vessel type and journey time and speed. Vessel type tends to be optimised for its purpose, and therefore is potentially less likely to differ between the direct and indirect route than journey time is. In the bulk of cases, journey time on the indirect route will be at least as long as on the direct route, if not longer. Therefore assuming emissions are the same across both routes is a conservative assumption, as emissions on the indirect route may be slightly greater, meaning that switching is slightly less desirable and therefore slightly less likely to occur than indicated.

[31] This assumption is based on historic values for the share of voyage costs that are fuel and is likely to differ by vessel type. Given the uncertainty in this value in the future and by vessel type, sensitivity analysis has been performed.

[32] It is appropriate to apply the price elasticity of demand to the change in voyage cost caused by the UK ETS because 100% cost pass-through is assumed, as outlined above.

cargo being transported and the alternative transport options available, it is assumed that the elasticity is the same for all vessel types with a median value of -0.19 and this is accompanied by sensitivity analysis with the range -0.9 (25th percentile) to -0.1 (75th percentile).

Fuel price forecasts for marine diesel oil (MDO), heavy fuel oil (HFO) and liquefied natural gas (LNG) from Frontier Economics, UMAS and E4tech (2019a) were used. It has not been possible within the scope of this work to provide updated forecasts or to run a sensitivity analysis on these forecasts. The forecasts for 2030 were chosen because 2030 EU ETS price forecasts have also been used.

Having combined these estimates, the switching analysis aims to explore what level of UK ETS allowance prices could be associated with a 10%, 15% and 20% reduction in UK shipping demand (relative to 2021 activity). All pricing assumptions relate to 2030. The 'EU ETS proposal' was chosen as the 'base case'. Scenario 9 is similar but also includes non-electrified road transport in the EU ETS. However, this scenario was assessed qualitatively so it was not a suitable base case. The illustrative 10, 15 and 20 percentage reductions in maritime demand were chosen for the indicative analysis as they are illustrative of significant impacts.

The UK ETS allowance prices (i.e. carbon prices) that could be associated with a 10, 15 or 20% reduction in demand under Scenario 3 were then applied (as fixed values) across the remaining alternative policy scenarios (see Table 1) and sensitivities. The estimated change in demand was assessed, relative to the Scenario 3 base case.[33] [34] [35] For the scenarios where road emissions are included in a separate EU ETS, the results are discussed qualitatively, as it was beyond the scope of this work to calculate the switching to road and rail quantitatively.

All results are sensitive to the assumptions on the 2030 fuel price, EU ETS price, proportion of voyage costs accounted for by fuel, elasticity of demand and percent of cost-pass through.[36] Sensitivity analysis has been undertaken to reflect these uncertainties.

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[33] These scenarios were jointly agreed with the client prior to carrying out the analysis. Three ICIS EU ETS price forecasts for 2030 (2022) were used.

[34] In this way, readers can compare changes in UK shipping demand across different scenarios for a given carbon price, rather than comparing required carbon prices across different scenarios for a given change in UK shipping demand. It was beyond the scope of this work to calculate both; however the model has been designed in a flexible way and can be adapted to calculate these additional metrics. The model has been shared with DfT.

[35] The focus of the switching analysis is on the relativity of international and domestic maritime prices under different scenarios. Without gathering further data on road and rail journey costs and emissions, which was out of scope of this report, it was not possible with the data available to explicitly model the impact of road being included in a separate EU ETS. This means scenarios 8 to 10 have been assessed qualitatively.

[36] The effect of these cost increases on the risk of wider competitive disadvantage for operators beyond the voyage cost increase would depend on several factors. For example, cost pass-through may be hindered in the short term for some operators if they have pre-agreed price contracts in place with customers. Where operators have already invested to reduce their carbon cost exposure before the 'UK ETS proposal' was introduced, such operators could be at a competitive advantage relative to other domestic operators on the same route who have not.

Table 1 Policy scenarios

Scenario	Description
1	GB / NI to ROI emissions not included in the EU ETS - Current situation for road and rail
2	50% of GB / NI to ROI emissions included in the EU ETS – High EU ETS Allowance Price - Current situation for road and rail
3	50% of GB / NI to ROI emissions included in the EU ETS – Central EU ETS Allowance Price - Current situation for road and rail
4	50% of GB / NI to ROI emissions included in the EU ETS – Low EU ETS Allowance Price - Current situation for road and rail
5	100% of GB / NI to ROI emissions included in the EU ETS – High EU ETS Allowance Price - Current situation for road and rail
6	100% of GB / NI to ROI emissions included in the EU ETS – Central EU ETS Allowance Price - Current situation for road and rail
7	100% of GB / NI to ROI emissions included in the EU ETS – Low EU ETS Allowance Price - Current situation for road and rail
8	50% of GB / NI to ROI emissions included in the EU ETS – High EU ETS Allowance Price - Road transport within the EU included in a separate ETS
9	50% of GB / NI to ROI emissions included in the EU ETS – Central EU ETS Allowance Price - Road transport within the EU included in a separate ETS
10	50% of GB / NI to ROI emissions included in the EU ETS – Low EU ETS Allowance Price - Road transport within the EU included in a separate ETS

Source: Frontier Economics

4.3 Limitations

4.3.1 Data

To enhance the robustness of this analysis, a range of data and evidence sources were used. A key source was the real time location data collected via AIS transponders. While AIS data is very granular, it does not cover all maritime vessels (as noted above). Based on the approach taken in this study, for domestic shipping data produced using the AIS derived data, the degree of uncertainty associated is larger than with international voyages. This is because the time period between snapshot data collections on vessel locations is too long relative to the duration of some voyages (which could be 20-30 minutes). This means that when the AIS derived data is used to characterise a sequence of port calls, it is more accurate for voyages in excess of 6 hours and those voyages which involve the vessel being berthed for longer time periods. The data is therefore limited in its ability to detect short turn around voyages (e.g. which include ferries) as described above. The dataset also does not include offshore installations such as Volve, which are not in UK territorial waters and does not include data for voyages where the origin or the destination port could not be determined. AIS data does not include emissions from vessels that are too small to have a transceiver (though these voyages would be below the proposed size threshold for inclusion in the UK ETS under our definition of the 'UK ETS proposal'). Therefore, it should be noted that the emission estimates included in this report only reflect the emissions of voyages that are captured in the AIS derived data and that this does not cover all UK domestic shipping emissions included in the UK's National Atmospheric Emissions Inventory.

To overcome these limitations, other data sources were used where necessary. This includes using published statistics on port activity, particularly for passenger ferries, along with published timetables and EU Measuring, Reporting and Verification (MRV) (where possible) to better capture the actual number of journeys for the chosen case study routes.

The derived AIS data used in this study was discussed with a leading academic expert and cross validation checks were undertaken to provide confidence that the data was appropriate for this analysis. Specifically, DfT publish port level statistics on the volume of goods transported by direction. This is useful as a validation of activity for some routes where the analysis identifies Ro-Ro activity. This cross-check indicated that the derived AIS data was consistent with the published DfT information. A comparison was also undertaken on other routes using published ferry schedules to check the order of magnitude of voyage counts. Again the AIS derived data was consistent with that public information. Finally, a comparison of emissions (by vessel type) captured in the derived AIS data to emissions included in the EU MRV data was carried out. It is difficult to draw any conclusions from comparing these datasets due to the impact of COVID-19 on both datasets. However, overall, there was broad alignment across the majority of vessel types. For some vessel types there were significant differences with EU MRV data, but these differences could potentially be explained by interannual variability. Without further information, it is not possible to be conclusive.

4.3.2 Switching analysis

A high-level switching analysis was undertaken to provide an indication of the potential scale of UK allowance price that could be needed for a material reduction in UK domestic maritime demand to be observed. This analysis is subject to considerable uncertainty and results should therefore be interpreted with caution. The analysis looks at the year 2030 and therefore relies on assumptions regarding future fuel prices and future EU ETS carbon price levels. As outlined above, fuel prices as a proportion of voyage costs are assumed to be 50% for all vessel types, though a sensitivity of 30% has been explored. This is a simplifying assumption which is consistent with the average from the best available academic studies, though it is important to recognise that this is not an assumption for which robust evidence exists. Evidence does exist on actual fuel costs incurred by individual operators via for example company accounts. However, inconsistency in definitions used and the applicability of these accounts to UK domestic maritime shipping mean that these sources are not sufficiently robust to inform this analysis.

There is no robust data available on the responsiveness of UK domestic maritime demand to changes in maritime costs (the 'price elasticity of demand for domestic shipping'). Academic evidence has therefore been used, to derive the value of -0.19, within the range -0.1 to -0.9 (Merkel at al., 2022). This is assumed to be constant across vessel types, though in practice this is not likely to be the case as there are likely to be variations by cargo type and vessel type. For this reason, sensitivity analysis has been undertaken using the full range of values.

4.3.3 Representativeness of the year from which activity data is used

Although the analysis has been undertaken with the aim of considering the potential effects in 2030 (therefore assumptions on 2030 fuel prices are used, for example), the route-specific nature of the analysis means that no forecasts exist of UK domestic maritime activity on the three case study routes. Current activity levels are therefore used. The year 2021 was used as the main year to estimate UK domestic maritime activity because this was the most recent full year of data available when this analysis was undertaken. However, in 2021, the world was still in a global pandemic and although most shipping activity had resumed following restrictions in 2020, activity levels were still likely to have been affected. This is particularly true for cruise vessels, for example, which were not allowed to operate for some of 2020 and hence operators changed their routes and operations to maximise their operations in 2021. For example, in 2021, when sailings resumed, many changed their itineraries to offer a UK-centred cruise (McGillivray, 2021). To address some of these issues, 2019 data was also assessed.

5 UK domestic maritime descriptive context

This chapter describes the characteristics of UK domestic maritime shipping. It also does this specifically for GB-NI routes, given the focus on these routes for the three case studies.

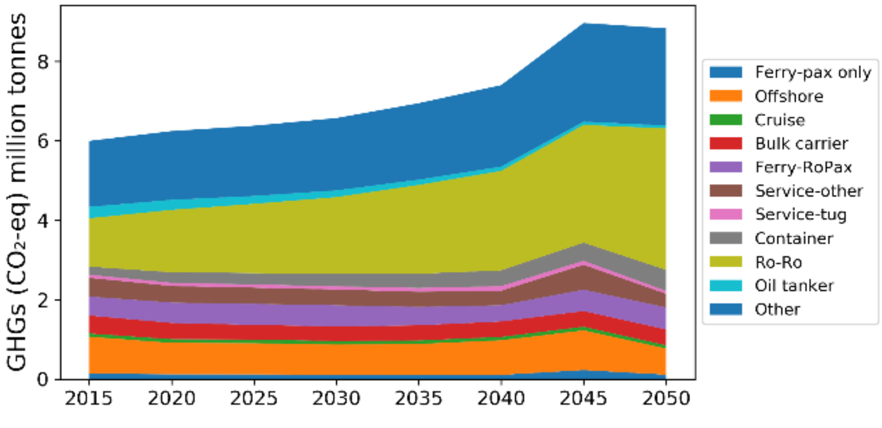
5.1 The current and projected state of UK domestic shipping

As contextual information, this section presents projections from a previous study completed by Frontier Economics, UMAS and E4tech. These projections provide evidence on how UK domestic shipping emissions and fuel use could change in the future in the absence of further government intervention. However, it should be noted that projections of this nature are subject to a number of uncertainties and further analytical work could lead to different conclusions. In addition, this modelling was completed in 2019, so it does not reflect any subsequent developments. For further details on these projections please see Frontier Economics, UMAS and E4tech (2019a).

UK domestic shipping is defined as shipping activity that starts and ends at a UK port, for example a ferry between two UK ports.

Figure 5 presents the emissions projections for UK domestic maritime, split by ship type, from the previous study. This shows that, without further government intervention, emissions were estimated to increase over time. Vessel types that account for the majority of emissions were Ro-Ro and offshore.

Figure 5 Projected domestic maritime shipping emissions by ship type (without intervention)

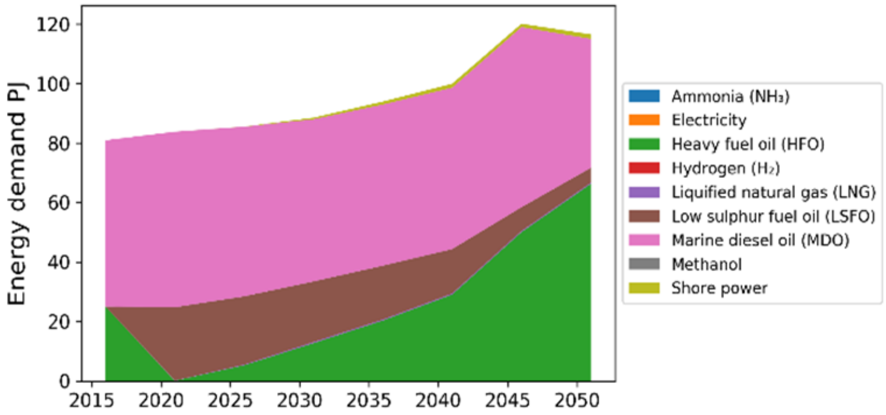


Source: (Frontier Economics, UMAS & E4tech, 2019a)

Note: The key is in reverse order compared to the chart, so the top blue bar is 'other' rather than 'Ferry-pax only'.

In terms of shipping fuel, Figure 6 shows that, in these projections, it was estimated that marine diesel oil (MDO) is currently the main fuel used for UK domestic maritime shipping and is forecast to continue to be a significant fuel in the future, without further government intervention. Heavy fuel oil (HFO) was estimated to make up a minority of fuel used currently but its role was estimated to grow in the future in these projections, with low sulphur fuel oil (LSFO) also expected to play a role in the next few decades in these projections. The reasons for the growth in the use of HFO in these projections are explained in Frontier Economics, UMAS and E4tech (2019a). Other fuels are estimated to make up a very small proportion without further government intervention in these projections.

Figure 6 Projected domestic maritime fuel use (without intervention)



Source: (Frontier Economics, UMAS & E4tech, 2019a)

5.2 UMAS analysis of AIS data

As described in Chapter 4, AIS data uses transceivers on ships to capture the real time location of vessels. Using processed AIS data, summary statistics can be produced to characterise the main ship types captured by this data for UK domestic maritime shipping.[37] The UMAS analysis of the AIS data is not however intended to be an emissions inventory and has a number of limitations as described in previous sections of this report, so this analysis does not capture all of the domestic shipping emissions that are included in the UK's National Atmospheric Emissions Inventory. There are also differences between the projections from Frontier Economics, UMAS & E4tech (2019a) and the UMAS analysis based on AIS data from 2021.[38] This data is however the most appropriate source to characterise origin-destination voyages in terms of vessel types, fuel used, emissions intensity and other aspects and in building an understanding of voyage patterns for UK domestic maritime.[39]

As shown in Table 2, for journeys captured in the UMAS analysis of AIS data in 2021, the top three vessel types by CO_2 emissions were cruise ships, Ferry-RoPax and offshore vessels. Together, these ship types were responsible for nearly half of the CO_2 emissions captured in the AIS derived data. The high prevalence of cruise ships in 2021 was likely due to a large increase in the number of domestic cruises due to COVID-19 (McGillivray, 2021). For voyages on GB-NI routes only in 2021 that are captured in the AIS derived data, Table 3 shows that the composition of ship types is different

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[37] For analysis using the AIS derived data, the definition of each ship type is the same as that used in the Fourth IMO GHG Study (IMO, 2020)

[38] The coverage and limitations of the AIS derived data are outlined in Chapter 4.

[39] For more details on when it is appropriate to use this data, please see chapters 1.2 and 4.3.1.

to the UK as whole, with a much higher prevalence of Ferry-RoPax and Ro-Ro vessels. Collectively, these two ship types account for a large proportion of all emissions that are captured within the UMAS analysis of AIS data on GB-NI routes in 2021. However, given the limitations of the UMAS analysis described in this report, it should be noted that the distribution of UK domestic maritime emissions between ship types shown in these tables only reflects the voyages that are captured in the AIS derived data used in this study. These distributions do not therefore match how the total UK domestic shipping emissions included in the UK's National Atmospheric Emissions Inventory are distributed between ship types.

Table 2 UK domestic maritime emissions by ship type (for journeys captured in the UMAS analysis of AIS data used in this study only)

Ship type	Percentage of total CO_2 emissions in 2021 captured in the AIS derived data
Cruise	21%
Ferry-RoPax	15%
Offshore	11%
Oil tanker	9%
Service – other	7%
Chemical tanker	7%
Ro-Ro	6%
Other (<100,000t)	24%

Source: AIS derived data used in this study, 2021. Note that this is not an inventory of all UK domestic maritime and reflects only what has been feasible to include in the derived AIS data.

Note: There are 18 different ship types captured in the AIS derived data for UK domestic maritime shipping. This table relates to vessels of all gross tonnages. The vessels in the 'other' category are each responsible for fewer than 5% of emissions. Given that the UMAS analysis of the AIS data cannot be treated as an inventory, it is not appropriate to further specify vessel types with low emissions totals.

Table 3 GB-NI domestic maritime emissions by ship type (for journeys captured by the UMAS analysis of the AIS data only)

Ship type	Percentage of total CO_2 emissions in 2021 captured in the AIS derived data
Ferry-RoPax	39%
Ro-Ro	25%
Cruise	16%
General cargo	9%
Chemical tanker	5%
Other	7%

Source: AIS derived data used in this study, 2021. Note that this is not an inventory of all UK domestic maritime and reflects only what has been feasible to include in the derived AIS data.

Note: There are 14 different ship types captured in the AIS derived data for GB-NI domestic maritime shipping routes. This table relates to vessels of all gross tonnages. Figures may not sum to 100% due to rounding.

Table 4 shows the distribution of emissions by vessel size that are captured in the UMAS analysis of AIS data. Larger vessels (above 5,000GT) are responsible for the majority of UK domestic maritime emissions captured in the AIS derived data used in this study. In addition, relative to the average for all UK domestic maritime captured in this data, larger vessels (above 5,000GT) are responsible for a larger share of the emissions on the GB-NI voyages captured in the AIS derived data used in this study. The limitations of the UMAS analysis of the AIS data must be borne in mind, though the analysis is indicative of the potential difference in vessel composition of GB-NI routes and GB-GB routes and are robust for the purposes of our analysis. However, given the limitations of the UMAS analysis described in this report, it should be noted that the distribution of UK domestic maritime emissions by ship size shown in the table below only reflects the voyages that are captured in the AIS derived data used in this study. This distribution does not therefore match how the total UK domestic shipping emissions included in the UK's National Atmospheric Emissions Inventory are distributed between ship sizes.

Table 4 Composition of emissions by vessel size captured by the UMAS analysis of AIS data

Vessel size (GT)	Proportion of UK domestic maritime emissions captured in the AIS derived data (%)	Proportion of GB-NI domestic maritime emissions captured in the AIS derived data (%)
5,000 and above	62%	86%
4,000 and above	66%	87%
3,000 and above	74%	90%
2,000 and above	82%	96%
1,000 and above	87%	98%

Source: AIS derived data used in this study, 2021. Note that this is not an inventory of all UK domestic maritime and reflects only what has been feasible to include in the derived AIS data.

6 Theory of change

This chapter presents the theory of change reflecting the channels through which the effects of the 'UK ETS proposal' could feed through into responses by operators and maritime customers. This relates to Step 1 of the methodology, with two logic models presented: a direct routes logic model and an indirect routes logic model. For the direct routes logic model, this only concerns potential responses on direct routes (e.g. that go from Heysham in GB to Warrenpoint in NI). In other words, what could happen if the route is not changed. In contrast, the indirect routes logic model only considers the potential responses by operators and maritime customers on indirect routes (i.e. if the route is changed). For example, travelling from Heysham in GB to Greencastle in ROI and then driving from Greencastle to Warrenpoint and beyond.

The logic models are generic in that they apply to both GB-GB and GB-NI routes. In this analysis, they have been specifically applied to GB-NI routes.

Together, these logic models describe the potential responses of ship operators following the introduction of the 'UK ETS proposal' and also the response of the wider market to the ship operators' potential responses. The assessment of the potential risks of carbon leakage, internal carbon displacement and competitive disadvantage are not specific to a particular scenario. Instead, they outline the potential risks in general and what pre-conditions would be necessary in order for that risk to arise. The assessment of risks under specific scenarios is provided for the three GB-NI case studies in Chapter 8.

6.1 Direct routes logic model

Under the 'UK ETS proposal', shipping operators will face the prospect of higher costs, as they now pay a price for their GHG emissions. This is because fuels currently used in domestic maritime shipping emit GHGs when consumed (see Chapter 3).

Figure 7 below details part 1 of the direct routes logic model. The column labelled 1 in Figure 7 refers to the different options that shipping operators may consider in responding to this carbon cost exposure. The top four categories relate to the different types of abatement options outlined in Frontier Economics, UMAS & E4tech (2019b). Each of these would likely reduce the GHG emissions of domestic maritime operators and therefore their exposure to the UK ETS carbon price. Of these four options, only the following two may entail a risk of both carbon leakage and internal carbon displacement:

Operating changes that increase efficiency: This relates to changes in operator behaviour such as reducing their operating speeds (i.e. slow steaming) to reduce their fuel consumption or increasing energy efficiency through other methods so as to reduce carbon cost exposure. This could lead to carbon leakage and/or internal carbon displacement if slower speeds on voyages covered by the UK ETS are compensated by faster speeds on voyages (or alternative transport modes) which are not covered by the UK or EU ETS.

Switch to alternative fuels and energy sources and related machinery: This refers to switching to a low emission or zero emission energy source to minimise carbon cost exposure. For a risk of carbon leakage and/internal carbon displacement to occur, this would require the alternative fuel or energy to not be paying its carbon price for the upstream emissions associated with its production (e.g. if emissions associated with hydrogen production were not subject to carbon pricing). In the case of electrification, this is unlikely as electricity generation is already covered under the UK ETS (and the EU ETS in the case of generation in NI). Also, investing in technologies that increase energy efficiency and investing in technologies that facilitate carbon capture and storage could both lead to upstream emissions associated with producing those technologies, this could lead to internal carbon displacement.

In addition to changing how operators use their vessels and investing in new technologies, shipping operators could also respond by changing the vessel they use. This includes:

Purchasing a new vessel that emits less GHGs and scrapping the older, more polluting vessel: This could lead to a risk of carbon leakage and/or internal carbon displacement (columns 2 and 3) if the upstream emissions associated with producing the new vessel are not subject to a carbon price.

Selling higher-emission vessels to ship operators in other countries: Rather than retiring the older, more polluting vessel, the operator may sell this vessel for use in another country. They could then purchase a replacement vessel, which emits fewer GHG emissions (and therefore would incur a lower carbon cost from its operation). This could lead to a risk of carbon leakage (column 2) if the vessel being sold is then operated in a jurisdiction that is not part of an equivalent carbon pricing scheme.

Re-assigning vessels between domestic and international routes: To reduce their carbon cost exposure, operators may re-assign their fleet, exchanging any potentially more fuel-efficient vessels that were being used for international voyages to domestic voyages and vice versa. As the more fuel-efficient vessels emit fewer GHG emissions, their carbon costs are reduced. If the more polluting re-assigned vessel is not part of an equivalent carbon pricing scheme, this could lead to a risk of carbon leakage. This risk is reduced under the ‘EU ETS’ proposal.

Shifting vessel sizes to just below the proposed 5,000GT threshold: Under our definition of the ‘UK ETS proposal’, vessels under 5,000GT would be exempt. Operators could respond by purchasing vessels which fall just under the 5,000GT threshold. This could lead to a risk of carbon leakage and/or internal carbon displacement (columns 2 and 3).

The final two options included in column 1 involve operators purchasing UK ETS allowances to continue operating and/or choosing to reduce the number of voyages they operate due to their higher cost. Neither of these entail a risk of carbon leakage or internal carbon displacement but they do imply competitiveness effects due to the increase in voyage costs and/or reduction in revenues.

Overall, each of the potential operator responses in the logic model to the carbon cost may involve higher costs (time and/or financial) or lower revenues.[40] For this reason, in the short term, operators are likely to choose to pass the higher cost through to their customers. This in turn, could lead to competitive disadvantage for domestic maritime shipping operators relative to other modes of transport (column 4). Alternatively, operators may choose to bear the higher costs themselves which would lead to reduced profit margins. In the long term, this could lead to some providers exiting the market. This may also limit the extent to which providers have the funds to invest in abatement options themselves.

In the longer term, operators may respond to higher costs by investing in technological or operational abatement options to minimise the increase in voyage costs. For example, Frontier Economics, UMAS & E4tech (2019a) examined how much emissions could be reduced by implementing different abatement options and at what cost for each additional tonne of emissions. That study concluded that in 2031 38% of BAU emissions could be abated at a cost of less than £88/tCO_2e (2018 prices), which was BEIS's carbon price projection for that year (note – for the purposes of this analysis, the £88/tCO_2e estimate represents a social cost per tonne of CO_2e abated rather than a private sector cost). However, this investment in abatement options is subject to certain barriers (e.g. imperfect information on abatement options) (Frontier Economics, UMAS & E4tech, 2019c).

The choice of an operator to invest in any one of these will depend on the operating and capital costs of each option, the ability and willingness of operators to pass through these costs onto their customers and the price of the UK ETS allowance (including their expectation of how it may change in the future).

As shown in Figure 7, the response of operators interacts with several other market participants. Ports may respond to the operators' response. For example, if operators decide to invest in new lower-carbon fuels (e.g. hydrogen) for their vessels, then ports may need to invest in new infrastructure to support this, therefore impacting their costs.[41] This interaction may have implications for port charges. Likewise, if ports do not make these infrastructure investments, then this would hinder the uptake of abatement options, making it more likely that UK ETS allowances would need to be purchased.

As noted above, operators may decide to pass-through some or all of their costs to their customers. These customers may then respond themselves in turn. The degree of cost pass-through is however dependent on the markets in which operators operate, which can vary by vessel type (see Chapter 7). Taken together, the collective responses of ports, domestic maritime operators and customers could lead to potential changes in GHG emissions and air quality. It is worth noting that under some responses, e.g. the use of ammonia as an alternative fuel, while GHG emissions may fall, the use of this fuel may not be associated with falls in other pollutants such as NO_x (Frontier Economics, UMAS & E4tech, 2019a).

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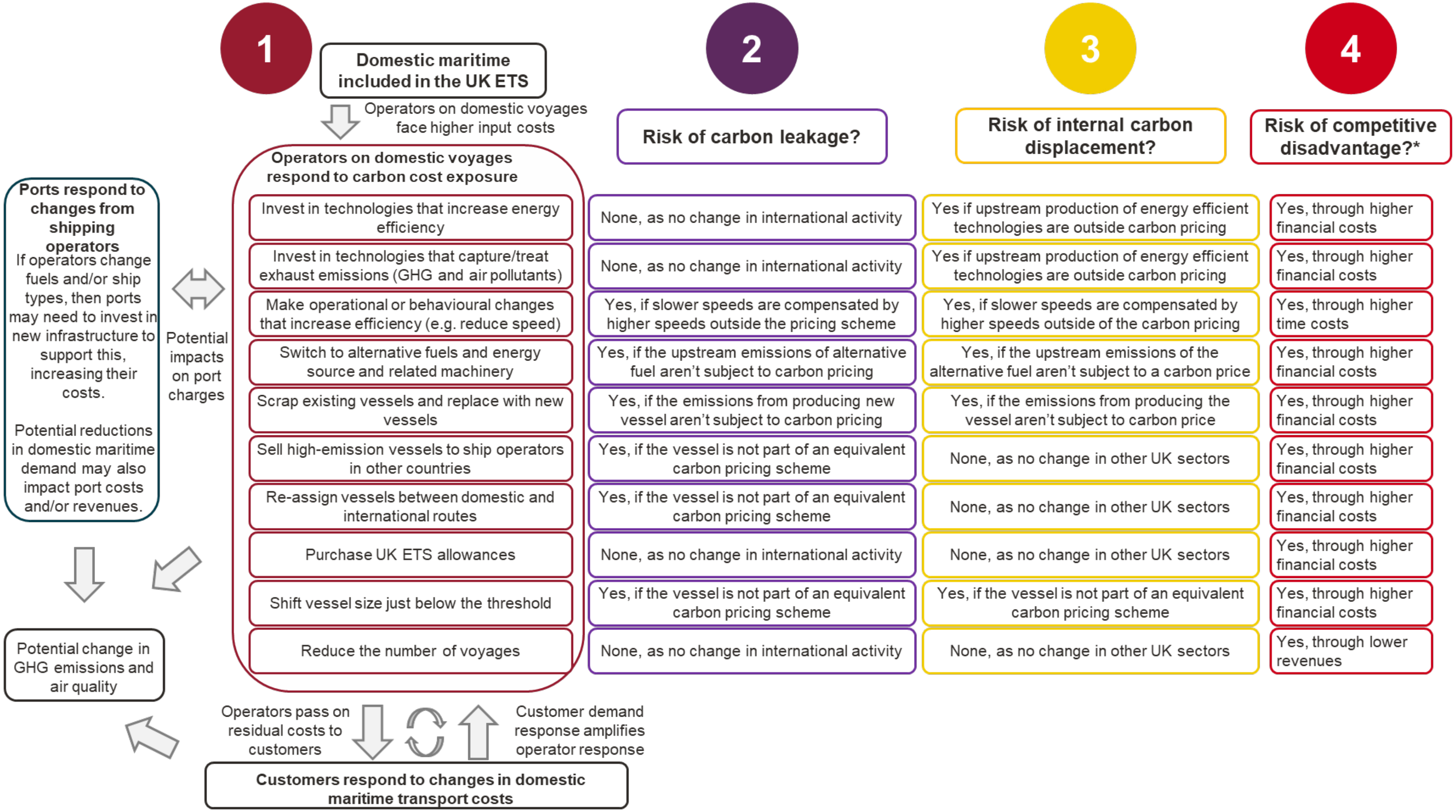
[40] While most responses involve higher costs, some options e.g., energy efficiency measures may lead to overall savings over time, despite an initial cost outlay.

[41] This could lead to competitive disadvantage for ports.

Figure 7 Direct logic model, part 1: responses from operators of domestic voyages



Domestic maritime included in the UK ETS

Operators on domestic voyages face higher input costs

1 **Operators on domestic voyages respond to carbon cost exposure**	2 **Risk of carbon leakage?**	3 **Risk of internal carbon displacement?**	4 **Risk of competitive disadvantage?***
Invest in technologies that increase energy efficiency	None, as no change in international activity	Yes if upstream production of energy efficient technologies are outside carbon pricing	Yes, through higher financial costs
Invest in technologies that capture/treat exhaust emissions (GHG and air pollutants)	None, as no change in international activity	Yes if upstream production of energy efficient technologies are outside carbon pricing	Yes, through higher financial costs
Make operational or behavioural changes that increase efficiency (e.g. reduce speed)	Yes, if slower speeds are compensated by higher speeds outside the pricing scheme	Yes, if slower speeds are compensated by higher speeds outside of the carbon pricing	Yes, through higher time costs
Switch to alternative fuels and energy source and related machinery	Yes, if the upstream emissions of alternative fuel aren’t subject to carbon pricing	Yes, if the upstream emissions of the alternative fuel aren’t subject to a carbon price	Yes, through higher financial costs
Scrap existing vessels and replace with new vessels	Yes, if the emissions from producing new vessel aren’t subject to carbon pricing	Yes, if the emissions from producing the vessel aren’t subject to carbon price	Yes, through higher financial costs
Sell high-emission vessels to ship operators in other countries	Yes, if the vessel is not part of an equivalent carbon pricing scheme	None, as no change in other UK sectors	Yes, through higher financial costs
Re-assign vessels between domestic and international routes	Yes, if the vessel is not part of an equivalent carbon pricing scheme	None, as no change in other UK sectors	Yes, through higher financial costs
Purchase UK ETS allowances	None, as no change in international activity	None, as no change in other UK sectors	Yes, through higher financial costs
Shift vessel size just below the threshold	Yes, if the vessel is not part of an equivalent carbon pricing scheme	Yes, if the vessel is not part of an equivalent carbon pricing scheme	Yes, through higher financial costs
Reduce the number of voyages	None, as no change in international activity	None, as no change in other UK sectors	Yes, through lower revenues

Ports respond to changes from shipping operators

If operators change fuels and/or ship types, then ports may need to invest in new infrastructure to support this, increasing their costs.

Potential reductions in domestic maritime demand may also impact port costs and/or revenues.

Potential impacts on port charges

Potential change in GHG emissions and air quality

Operators pass on residual costs to customers

Customer demand response amplifies operator response

Customers respond to changes in domestic maritime transport costs

Source: Frontier Economics

*Note: *The risk of competitive disadvantage relates to UK domestic maritime operators*

Figure 8 shows the second part of the direct logic model, concerning both the responses of customers of maritime services to changes in domestic maritime transport prices and indirect demand responses (such as changes in demand for road, rail or air transport). Here, customers of maritime services are considered to be, for example, couriers, distributors and ferry passengers. In the context of fishing and offshore, the operator of the vessel and the customer of the maritime service are likely to be the same entity. For example, the vessel operator would directly undertake fishing at sea.

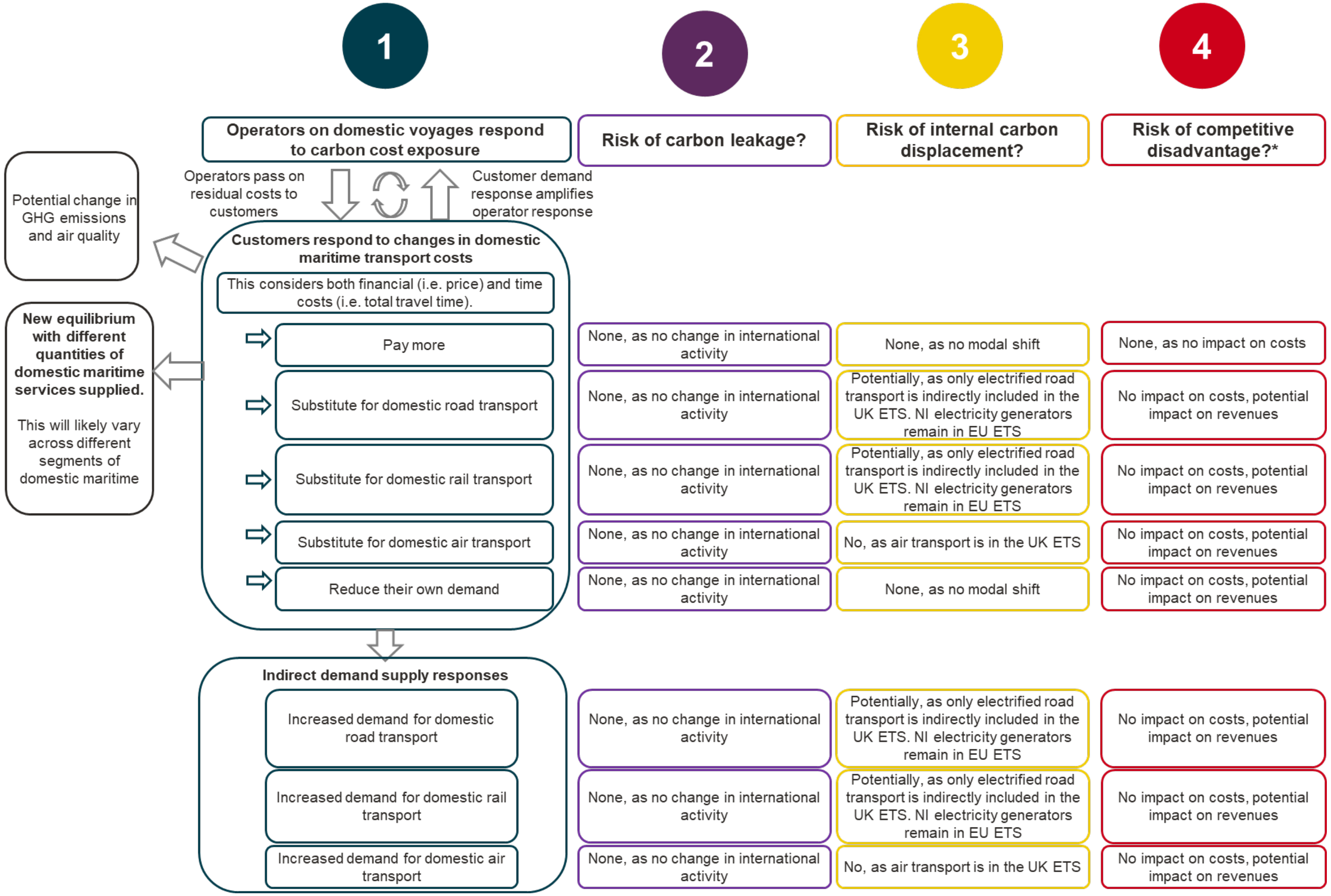
Customers of maritime services will decide how to respond to these potentially higher prices by considering both the financial and time costs associated with alternatives (as per column 1 in Figure 8). For example, customers may decide to simply pay more for the services or reduce their level of demand for domestic maritime services. Alternatively, they may decide to switch to an alternative form of domestic transport. For example, instead of taking a direct ferry from say Belfast to Liverpool, passengers may decide to take a direct flight instead.

In the case of customers changing modes, this has the potential to lead to a risk of internal carbon displacement (see column 3). For air transport, there is a lower risk, given that aviation is included in the UK ETS. For road and rail, only electrified forms of each transport mode are included in the UK ETS. A risk of internal carbon displacement could arise if there is a full or partial modal shift from UK domestic maritime shipping to non-electrified road and/or rail in the UK. Indirect routes involving stops in e.g. ROI are considered in the indirect logic model.

Taking into account the response of customers, this may lead to a new equilibrium with different quantities of domestic maritime services supplied. This will likely vary across different segments of domestic maritime shipping, given the different competitive dynamics and customer types in each. On an aggregate level, responses may lead to an increase in demand for alternative modes of transport (road, rail and air transport), leading to the same risks of internal carbon displacement (see column 3) and competitive disadvantage (see column 4) discussed in the previous paragraph.

Overall, the existing evidence suggests that demand for domestic shipping is inelastic (for the sector/mode as a whole). For example, a meta-analysis by Merkel et. Al (2022) found the median own-price elasticity of short sea shipping was −0.19 across many different studies (within the range -0.1 to -0.9). This elasticity includes some switching away to other modes or indirect routes where this is feasible. Therefore, any demand response may be relatively muted. There is however uncertainty in this estimate, with the actual elasticity likely to vary according to the cargo being transported and the alternative transport options available.

Figure 8 Direct logic model, part 2: customers and indirect demand responses



Potential change in GHG emissions and air quality

New equilibrium with different quantities of domestic maritime services supplied.

This will likely vary across different segments of domestic maritime

Operators pass on residual costs to customers

Customer demand response amplifies operator response

1	2	3	4
Operators on domestic voyages respond to carbon cost exposure	**Risk of carbon leakage?**	**Risk of internal carbon displacement?**	**Risk of competitive disadvantage?***
Customers respond to changes in domestic maritime transport costs This considers both financial (i.e. price) and time costs (i.e. total travel time).			
Pay more	None, as no change in international activity	None, as no modal shift	None, as no impact on costs
Substitute for domestic road transport	None, as no change in international activity	Potentially, as only electrified road transport is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs, potential impact on revenues
Substitute for domestic rail transport	None, as no change in international activity	Potentially, as only electrified road transport is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs, potential impact on revenues
Substitute for domestic air transport	None, as no change in international activity	No, as air transport is in the UK ETS	No impact on costs, potential impact on revenues
Reduce their own demand	None, as no change in international activity	None, as no modal shift	No impact on costs, potential impact on revenues
Indirect demand supply responses			
Increased demand for domestic road transport	None, as no change in international activity	Potentially, as only electrified road transport is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs, potential impact on revenues
Increased demand for domestic rail transport	None, as no change in international activity	Potentially, as only electrified road transport is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs, potential impact on revenues
Increased demand for domestic air transport	None, as no change in international activity	No, as air transport is in the UK ETS	No impact on costs, potential impact on revenues

Source: Frontier Economics

*Note: *The risk of competitive disadvantage relates to UK domestic maritime operators*

6.2 Indirect routes logic model

Figure 9 presents the first part of the indirect logic model. This concerns the potential responses of domestic UK maritime operators via indirect routes (indirect routes refer to changes in the original origin or destination port and involvement of non-UK jurisdiction as a result of the inclusion of domestic maritime in the UK ETS) (column 1 in Figure 9).[42] There are three options available to operators:

Change the portfolio of services offered. This could involve increasing or decreasing the frequency of services on existing routes and/or setting up new routes or closing existing routes. In the context of GB-NI, this could involve for example establishing new services to ports in ROI (at or near the border with NI) and reducing the frequency of existing routes to NI.[43] This could lead to a risk of carbon leakage if the new route between the UK and ROI was not subject to an equivalent carbon pricing scheme.

Cross-subsidise a more costly direct route with a less costly indirect route. A provider may choose to maintain a route which has become more costly as a result of the UK ETS. In order for this to be financially viable it may be that in some cases operators need to cross-subsidise that route by introducing a new less costly route (e.g. between ROI and GB). This could lead to carbon leakage (see column 2 in Figure 9).

Undertake an evasive port call. Operators may choose to add in an additional port stop outside of the UK (e.g. ROI) on a direct route between GB and NI. This is so that the journey is classified as international and therefore not subject to the UK ETS. This could lead to a risk of carbon leakage if that now international journey is not part of an equivalent carbon pricing scheme (see column 2 in Figure 9).

As these options all involve indirect routes via a jurisdiction outside of the UK, there is little risk of internal carbon displacement (see column 3 in Figure 9).[44] There is, however, a risk of competitive disadvantage from higher financial costs (see column 4 in Figure 9). For example, undertaking an evasive port call means operators incur both an extra set of port charges and wait additional time at the extra port call as well as potentially consuming more fuel. As per the direct logic model, whether an operator decides to engage in any of these options will depend on the operating and capital costs of each, their ability and willingness to pass through these costs onto their customers and the price of UK ETS allowances (including their expectation of how it may change in the future).

As shown in Figure 9, the response of operators interacts with several other market participants. Ports may respond to operators' changes. For example, some ports may experience an increase or decrease in the volume or traffic, therefore impacting their costs and/or revenues.[45] This may then lead to a change in port charges. As shown in the direct logic model, operators may decide to pass

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[42] It is worth noting that operators could operate both direct and indirect routes.

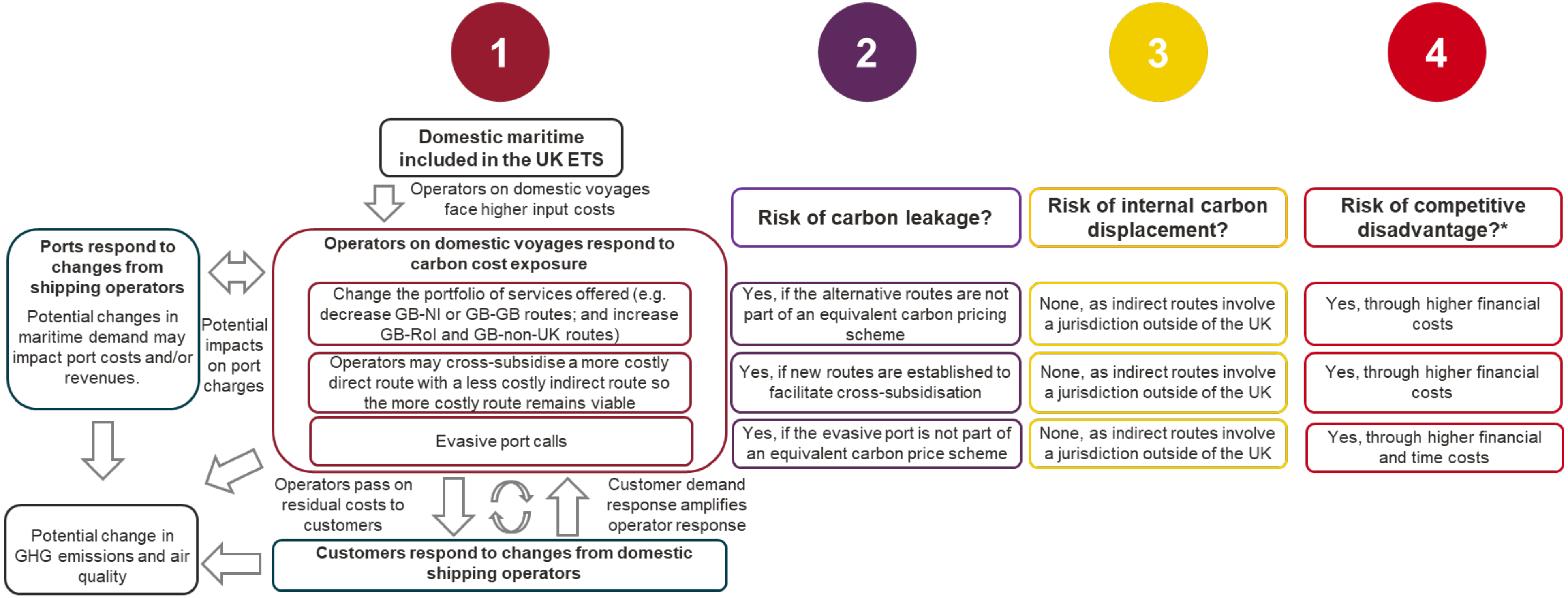
[43] Market factors such as existing contractual arrangements may limit the ability of operators to change or set up new routes (Frontier Economics, UMAS & E4tech, 2019c).

[44] This would only arise if the indirect route led to greater surface transport travel in the UK, for example.

[45] This could lead to competitive disadvantage for ports.

through some or all of their costs to their customers, who will in turn respond. The degree of cost pass-through is dependent on the markets in which operators operate, which can vary by vessel type (see Chapter 7). Taken together, the collective responses of ports, domestic maritime operators and customers could lead to changes in GHG emissions and air quality impacts. The precise impacts will depend on the specific responses that occur.

Figure 9 Indirect logic model, part 1: responses from operators of domestic voyages



Source: *Frontier Economics*

Note: **The risk of competitive disadvantage relates to UK domestic maritime operators*

Figure 10 shows the second part of the indirect logic model. This concerns responses of customers to changes in domestic maritime transport costs. Customers are defined in the same way as in the direct logic model and as before, decide how to respond by considering both the financial and time costs associated with alternatives (see column 1 in Figure 10). In the case of time costs, these could be significant for some indirect routes. The key difference to the direct logic model is that options for those customers wishing to transport cargo and those who are passengers, are now separated. This is because in the case of those customers transporting goods, taking an indirect route would involve changing their operating model. Given the reliance on just-in-time deliveries in some logistics chains, changing to an indirect route could lead to additional costs.

For customers transporting cargo and passengers, they may decide to pay more or reduce their level of demand for domestic maritime services. Alternatively, they may take an indirect route, potentially combining different modes of transport. For example, instead of travelling directly from Belfast to Liverpool via domestic maritime, customers may decide to drive from Belfast to Dublin and then travel via international maritime from Dublin to Liverpool. There are however many different transport mode combinations, with the logic model outlining four of these in the context of GB-NI routes (although similar combinations of transport options could apply to GB-GB routes).

Regarding the risks of carbon leakage and internal carbon displacement (columns 2 and 3), these occur when part or all of the journey shift to an alternative transport mode that is not covered by an equivalent carbon price. For carbon leakage (column 2), this risk is at its highest in the context of GB-NI routes if the EU does not cover international maritime journeys, non-electrified road and non-electrified rail in the EU ETS. For internal carbon displacement (column 3), the risk is higher when a modal shift occurs to non-electrified road or rail within the UK.[46] Any modal shift towards aviation, whether international or domestic, is unlikely to lead to a risk of carbon leakage or internal carbon displacement as both the UK and EU include aviation in their respective emission trading schemes. For competitive disadvantage (column 4), there is a risk to UK domestic maritime operators from lower revenues when the indirect route involves a modal shift away from domestic maritime.

Taking into account the response of customers, this may lead to a new equilibrium with different quantities of domestic maritime services supplied. As in the direct logic model, this will likely vary across different segments of domestic maritime shipping, given the different competitive dynamics and customer types in each. The customer responses may also lead to indirect demand responses (see Figure 11). On an aggregate level, these responses may lead to an increase in demand for alternative modes of transport (road, rail and air transport), leading to the same risks of internal carbon displacement (column 3) and competitive disadvantage (column 4) discussed in the previous paragraph.

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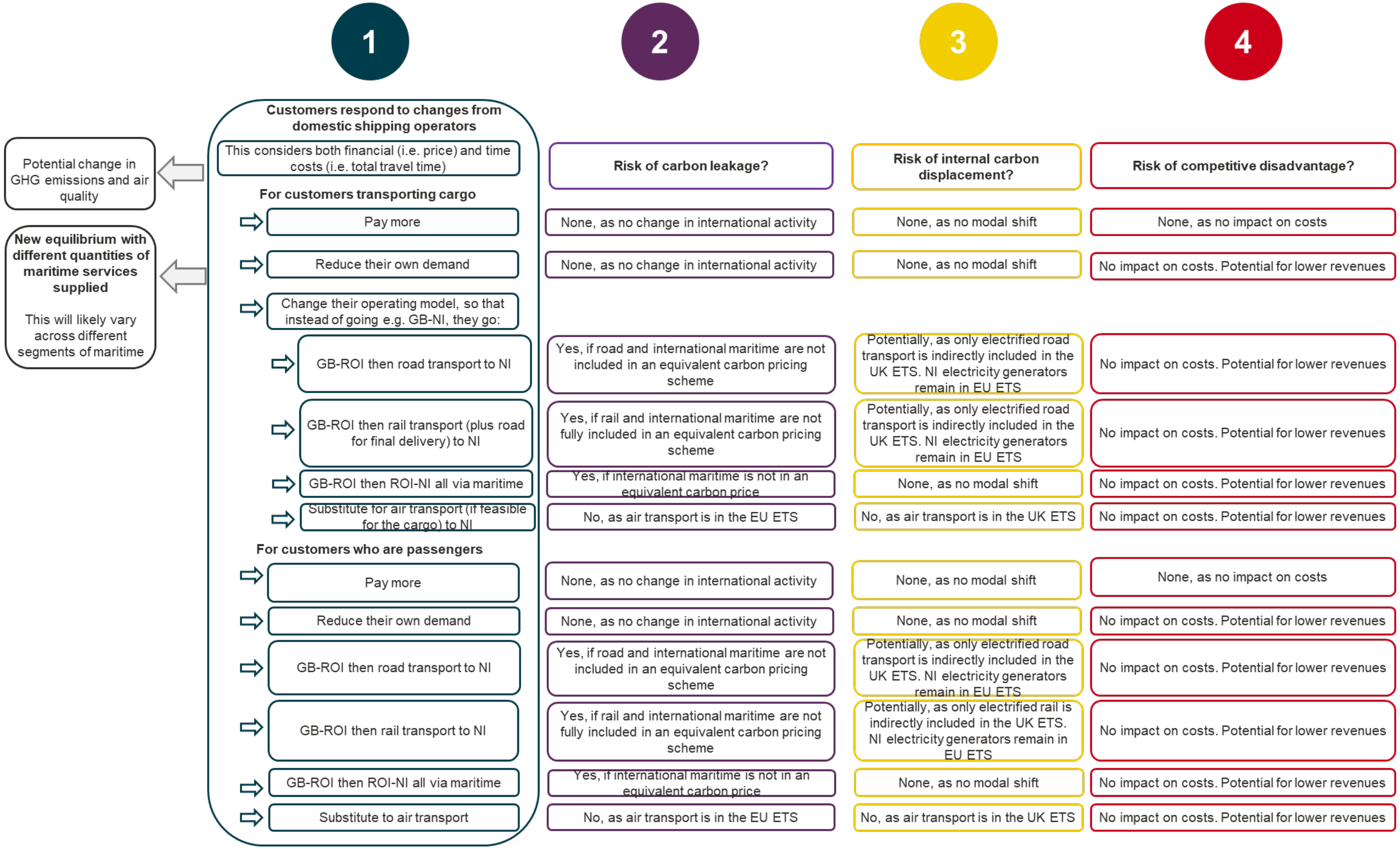
[46] NI electricity generators remain in EU ETS.

Figure 10 Indirect logic model, part 2: customer responses



Potential change in GHG emissions and air quality

New equilibrium with different quantities of maritime services supplied

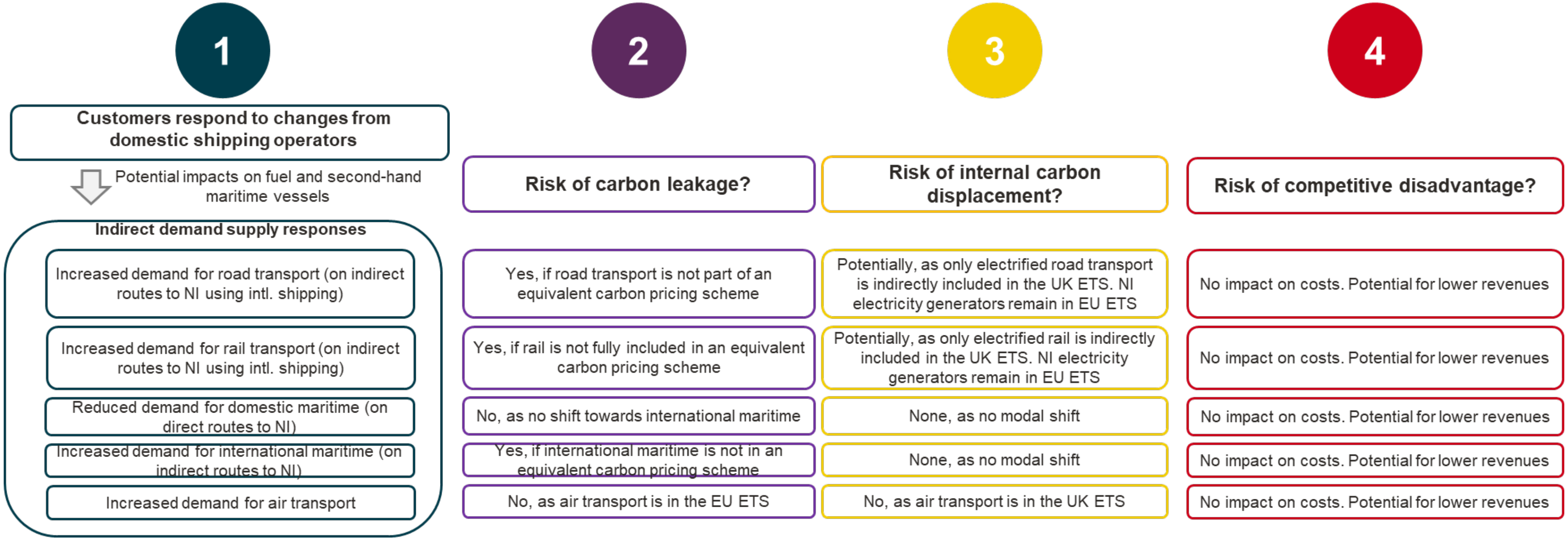
This will likely vary across different segments of maritime

1	2	3	4
Customers respond to changes from domestic shipping operators This considers both financial (i.e. price) and time costs (i.e. total travel time)	**Risk of carbon leakage?**	**Risk of internal carbon displacement?**	**Risk of competitive disadvantage?**
For customers transporting cargo			
Pay more	None, as no change in international activity	None, as no modal shift	None, as no impact on costs
Reduce their own demand	None, as no change in international activity	None, as no modal shift	No impact on costs. Potential for lower revenues
Change their operating model, so that instead of going e.g. GB-NI, they go:			
GB-ROI then road transport to NI	Yes, if road and international maritime are not included in an equivalent carbon pricing scheme	Potentially, as only electrified road transport is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs. Potential for lower revenues
GB-ROI then rail transport (plus road for final delivery) to NI	Yes, if rail and international maritime are not fully included in an equivalent carbon pricing scheme	Potentially, as only electrified road transport is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs. Potential for lower revenues
GB-ROI then ROI-NI all via maritime	Yes, if international maritime is not in an equivalent carbon price	None, as no modal shift	No impact on costs. Potential for lower revenues
Substitute for air transport (if feasible for the cargo) to NI	No, as air transport is in the EU ETS	No, as air transport is in the UK ETS	No impact on costs. Potential for lower revenues
For customers who are passengers			
Pay more	None, as no change in international activity	None, as no modal shift	None, as no impact on costs
Reduce their own demand	None, as no change in international activity	None, as no modal shift	No impact on costs. Potential for lower revenues
GB-ROI then road transport to NI	Yes, if road and international maritime are not included in an equivalent carbon pricing scheme	Potentially, as only electrified road transport is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs. Potential for lower revenues
GB-ROI then rail transport to NI	Yes, if rail and international maritime are not fully included in an equivalent carbon pricing scheme	Potentially, as only electrified rail is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs. Potential for lower revenues
GB-ROI then ROI-NI all via maritime	Yes, if international maritime is not in an equivalent carbon price	None, as no modal shift	No impact on costs. Potential for lower revenues
Substitute to air transport	No, as air transport is in the EU ETS	No, as air transport is in the UK ETS	No impact on costs. Potential for lower revenues

Source: Frontier Economics

*Note: *The risk of competitive disadvantage relates to UK domestic maritime operators*

Figure 11 Indirect logic model, part 3: indirect demand responses



1

Customers respond to changes from domestic shipping operators

Potential impacts on fuel and second-hand maritime vessels

1 Indirect demand supply responses	2 Risk of carbon leakage?	3 Risk of internal carbon displacement?	4 Risk of competitive disadvantage?
Increased demand for road transport (on indirect routes to NI using intl. shipping)	Yes, if road transport is not part of an equivalent carbon pricing scheme	Potentially, as only electrified road transport is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs. Potential for lower revenues
Increased demand for rail transport (on indirect routes to NI using intl. shipping)	Yes, if rail is not fully included in an equivalent carbon pricing scheme	Potentially, as only electrified rail is indirectly included in the UK ETS. NI electricity generators remain in EU ETS	No impact on costs. Potential for lower revenues
Reduced demand for domestic maritime (on direct routes to NI)	No, as no shift towards international maritime	None, as no modal shift	No impact on costs. Potential for lower revenues
Increased demand for international maritime (on indirect routes to NI)	Yes, if international maritime is not in an equivalent carbon pricing scheme	None, as no modal shift	No impact on costs. Potential for lower revenues
Increased demand for air transport	No, as air transport is in the EU ETS	No, as air transport is in the UK ETS	No impact on costs. Potential for lower revenues

Source: Frontier Economics

*Note: *The risk of competitive disadvantage relates to UK domestic maritime operators*

7 Conditions under which carbon leakage, internal carbon displacement and competitive disadvantage are more likely

This chapter refers to Steps 2, 3 and 4 of the methodology.

7.1 Relevant factors to assess

In line with Step 2 of the methodology, factors which were likely to influence the level of competitive disadvantage, carbon leakage or internal carbon displacement on certain routes and vessel types were identified.

The following four factors were identified during this stage of work:

- Carbon cost exposure: Routes with ship types with high emission intensities and minimal short term abatement options are considered to have a high carbon cost exposure;
- Likelihood of cost pass-through: Operators are more likely to pass through costs fully on more competitive routes (where the ability to sustainably absorb any cost changes is minimal). This in turn increases the likelihood of customer responses (all else being equal);
- Likelihood of a shift to substitute modes: Customers may respond to an increase in shipping transport costs (driven by carbon prices that have been passed through) by substituting to other transport modes where this is feasible; and
- Potential degree of customer response: Different types of customers will have different levels of price sensitivity. For example, customers of domestic maritime cargo may be more price sensitive than cruise ship passengers (who are purchasing a luxury good). This will influence the magnitude of customer response to the inclusion of domestic maritime within UK ETS.

These factors collectively informed the choice of case study routes (Step 4) and the qualitative risk assessment which has been carried out on each of the selected routes (Step 5).

7.2 Development of shipping archetypes

7.2.1 Emissions by vessel type

For GB-NI routes in 2021, Chapter 5 showed that there were 19 different types of vessels recorded in the data derived from AIS, with the top five collectively accounting for the majority of 2021 GB-NI emissions captured in this data. To identify vessels which have material emissions, archetypes were developed for vessels which accounted for 5% or more of total GB-NI emissions in 2021 captured in the AIS derived data. These were: Ferry-RoPax; Ro-Ro; Cruise; General Cargo; and Chemical Tankers. These archetypes were then taken forward for further analysis to enable a more detailed analysis of the risks of carbon leakage, internal carbon displacement and competitive disadvantage.

7.2.2 Variation in the presence of the factors by vessel type

The extent to which the four Step 2 factors noted above are likely to be present for each of the five vessel archetypes was considered and the results of this assessment are presented below. This has been informed by the review of existing evidence (including Papatheodorou 2006, Stopford 2008, Cooke 2019, Notteboom 2020, SHIPAX 2020, IMO 2020, Global Maritime Forum 2021 A, Global Maritime Forum 2021 B, WightLink, 2023), the commercial arrangements which exist, the AIS derived data and academic maritime expert judgement.

Based on this assessment, the factors are more likely to be present for Ferry-RoPax, Ro-Ro and General Cargo vessels. This is driven by the likely high levels of cost pass-through (they operate with low margins) and risk of modal shift (customers may have alternative options). The factors were less likely to be present for cruise ships and chemical tankers.

Table 5 Vessel archetype risk factor assessment

Vessel archetype	Carbon cost exposure	Likelihood of cost pass-through	Likelihood of modal shift	Potential degree of customer response
Ferry-RoPax	Higher emissions intensity (relative to other archetypes). Relatively high potential to use alternative fuels. Higher customer sensitivity to pollution, increases incentives to use lower carbon fuels.	Operators generally earn low margins in this competitive industry. This increases the likelihood of cost pass-through.	Shipping operators are unlikely to change vessels, as these are usually bespoke to the given route. Ro-Pax operations may compete with full Ro-Ro vessels and container ships. Indirect road-based routes could be taken, as the cargo is already being loaded onto trucks. Indirect routes using rail can be used in some circumstances. However, there are no rail freight operations in NI. (Department for Infrastructure & Department of Transport, 2021)	Speed is key for Ro-Ro customers on these vessels (as cargo is more likely to be time sensitive), so container shipping and long indirect routes are less likely to be attractive. For passengers, if speed and/or price is key then they may switch to flying. It has not been possible within the scope of this work to undertake a direct comparison of current sea passenger prices relative to domestic air travel costs.
Ro-Ro	Medium emissions intensity (relative to other archetypes).	Operators generally earn low margins in this highly competitive industry. This increases the	This archetype may compete with the Ro-Ro part of Ferry-RoPax, with demand likely higher in summer (when Ferry-	Speed is key for customers on these vessels (as cargo is more likely to be time sensitive), so container

Vessel archetype	Carbon cost exposure	Likelihood of cost pass-through	Likelihood of modal shift	Potential degree of customer response
		likelihood of cost pass-through.	RoPax is busier) and lower in winter (when Ferry-RoPax is quieter). Competes with container ships and indirect road-based routes, given the flexibility with the cargo already being loaded onto trucks. Indirect routes using rail cannot be used, as there are no rail freight operations in NI.	shipping and long indirect routes are less likely to be attractive.
Cruise	Higher emissions intensity (relative to other archetypes). High likely customer sensitivity to pollution, so greater incentive to use lower carbon fuels.	Cruise prices are driven less by their costs, as a large proportion of revenue comes from onboard sales. Cruise ships operate in a moderately competitive industry. This reduces the likelihood of cost pass-through.	As this is passenger based, it is easier for cruise ships to change the ports they stop at (and so a greater chance of evasive port calls) or to not stop at a port but anchor off instead nearby.	Cruise ships are a luxury good and so are more driven by quality than price. If additional port calls lead to a reduction in quality, then there may be a customer response. Alternative modes for passengers include flying or using Ferry-RoPax and road to drive to their destination.
General cargo	Lower emissions intensity (relative to other archetypes).	Very low margins in this highly competitive industry. This increases the likelihood of cost pass-through.	General cargo can carry containers, break bulk and aggregate bulk amongst others. As such, cargo is likely to be substitutable to other maritime vessel types or forms of transport (e.g. road). Indirect routes using rail cannot be used, as there are no rail freight operations in NI. Given lower time urgency, this vessel type is more likely to engage in evasive port calls.	Customers are highly sensitive to price and have the lowest time sensitivity compared to other modes of transport. Typically, this mode is generally used for lower value goods (e.g. cement).

Vessel archetype	Carbon cost exposure	Likelihood of cost pass-through	Likelihood of modal shift	Potential degree of customer response
Chemical tanker	Medium emissions intensity (relative to other archetypes).	A less competitive market. This reduces the likelihood of cost pass-through.	Unlikely to be able to switch transport modes, given the large volumes involved.	Customers are unlikely to be able to respond, given the lack of alternative transport options available.

Source: *Frontier Economics based on review of Papatheodorou 2006, Stopford 2008, Cooke 2019, Notteboom 2020, SHIPAX 2020, IMO 2020, Global Maritime Forum 2021 A, Global Maritime Forum 2021 B, WightLink, 2023*

7.3 Identifying GB-NI case study routes

Three case study routes between GB and NI have been identified for qualitative analysis of the potential risk of competitive disadvantage, carbon leakage and internal carbon displacement. This process began with a longlist that was filtered to the shortlist and identification of three routes.

7.3.1 Longlist

AIS derived data for 2021 was used to identify the 10 GB-NI routes which accounted for the highest amount of total annual CO_2 emissions captured in the data. This is presented in Table 6.

Table 6 Top origin-destination GB-NI pairs ranked by 2021 CO_2 emissions included in analysis of data derived from AIS

Rank	OD pair	Total CO_2 emissions (tonnes)	Average CO_2 emission intensity (tonnes per nautical mile)	Total number of ferry passengers (thousands)*
1	Liverpool-Belfast	69,000	0.45	230
2	**Belfast-Liverpool**	**66,000**	**0.50**	**230**
3	**Belfast-Southampton**	**16,000**	**0.91**	**-**
4	Belfast-Heysham	8,000	0.34	-
5	Heysham-Belfast	7,500	0.32	-
6	**Heysham-Warrenpoint**	**6,600**	**0.33**	**-**
7	Southampton-Belfast	5,700	0.47	-
8	Cairnryan-Larne	5,400	1.09	198
9	Warrenpoint-Heysham	5,100	0.31	-
10	Greencastle-Heysham	3,700	0.45	-

*Source: UMAS analysis of AIS data for 2021. *DfT National Sea Passenger statistics (DfT, 2022c): as the data only provides the total for the whole route, the figures have been divided by two.*

*Note: Routes in **bold** are the chosen three GB-NI case studies. As noted elsewhere emission figures refer only to those captured in the analysis of AIS data and do not reflect the total emissions on these routes.*

7.3.2 Shortlist

The 10 potential routes were then narrowed, and three case studies were selected. The selected case studies were agreed with the client. The chosen GB-NI case studies were:

- **Heysham-Warrenpoint** (primarily Ro-Ro vessels): This route is in top 10 highest total CO_2 emissions captured in the AIS derived data; it passes ROI on its way to its destination and has a destination port in NI which is near the border with ROI. Warrenpoint is considerable closer to the border with ROI than any of the other NI ports included in the longlist above.
- **Belfast-Liverpool** (primarily Ferry-RoPax & Ro-Ro vessels): This route has the second highest total CO_2 emissions captured in the AIS derived data and accounts for the highest number of ferry passengers.
- **Belfast-Southampton** (primarily Cruise ships): This route is the third highest in terms of total CO_2 emissions captured in the AIS derived data as well as having the second highest emission intensity. It also passes ROI on its way to its destination.

These case studies collectively reflect the following characteristics:

- Routes with the highest total CO_2 emissions (based on the AIS derived data). Heysham-Warrenpoint is in the top ten routes in terms of CO_2 emissions (based on the AIS derived data), Belfast-Liverpool is the second highest and Belfast-Southampton is third highest;
- Routes with a high average carbon intensity (based on the AIS derived data). Belfast-Southampton is second highest in terms of emission intensity (based on the AIS derived data);
- Routes with a high total number of ferry passengers (DfT, 2022c). Belfast-Liverpool has the highest number of ferry passengers according to DfT data;
- Routes which pass the ROI on their way to their destination in NI (based on a visual inspection of the route). Both Heysham-Warrenpoint and Belfast-Southampton pass ROI for a significant proportion of their journeys; and
- Routes which have an origin or destination port in NI which is near the border with ROI (based on a visual inspection of the destination port). Warrenpoint is very near the border between NI and ROI.

8 Case study analysis

This chapter presents the analysis for each of the three GB-NI case studies. Each case study begins with an overview of the route and then considers the potential competing options to this direct UK domestic maritime route in the form of alternative indirect maritime routes that could be taken and alternative modes of transport that could be used. Based on this and the types of vessels (and implicitly the cargo they carry) on the route, a qualitative assessment of the risks of carbon leakage, internal carbon displacement and competitive disadvantage is presented. This qualitative assessment draws together data and evidence from various sources such as the AIS derived data, published studies, economic theory and academic expert judgement. To complement this, illustrative switching analysis is presented, with the aim of providing an indicative assessment of the magnitude of carbon prices in the UK ETS that may be associated with particular magnitudes of changes in shipping demand. A summary of the key findings and their implications for the overall risk of carbon leakage, internal carbon displacement and competitive disadvantage across the qualitative and quantitative analysis concludes the analysis.

8.1 Case study 1: Heysham to Warrenpoint

8.1.1 Route overview

The first case study analysed is Heysham (GB) to Warrenpoint (NI). Figure 12 shows a map of the route, with Warrenpoint located on the south-eastern tip of NI (close to the NI-ROI border) and Heysham on the west coast of England. Table 7 shows that, for voyages captured in the AIS derived data used in this study, voyages in 2021 on this route were primarily made by Ro-Ro vessels, emitting around 6,600tCO_2 in that year.[47] The average Ro-Ro ship size on this route was around 19,000GT – this is significantly above the threshold of 5,000GT in the ‘UK ETS proposal’, meaning these vessels would, under our definition of the proposal, be included within the UK ETS. Using published route planners, this voyage is estimated to take around 8 hours (Seatruck, 2022). This is close to the median voyage duration recorded in the UMAS analysis of the AIS data in Table 7 in 2021.[48]

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[47] The Warrenpoint to Heysham route in 2021 had a similar composition of ship types.

[48] Actual journey times (which the AIS derived data records) may vary from advertised voyage lengths. This is because of delays, congestion and weather conditions.

Figure 12 Heysham to Warrenpoint route map

Source: *Google Maps*

Table 7 Heysham to Warrenpoint route summary statistics for voyages captured in AIS derived data (2021)

Ship Type	Total CO_2 emitted (t)	Average emissions intensity (tCO_2/nm)	Median distance travelled (nm)	Median voyage duration (hours)	Average ship size (GT)
Ro-Ro	6,600	0.33	127	10	19,000

Source: *AIS derived data used in this study. The estimates only cover voyages captured in the AIS derived data used in this study and do not reflect all voyages on this route.*

To understand how typical the types of vessels on this route are relative to the types of vessels the two ports handle across all routes, evidence is triangulated across a range of sources. UMAS analysis of the AIS data has been validated by reviewing other sources of data (such as timetables) to confirm that these two ports predominantly handle Ro-Ro vessels and have the capability to accommodate other types of vessels but currently do so to a lesser degree than Ro-Ro. The detailed evidence is outlined below.

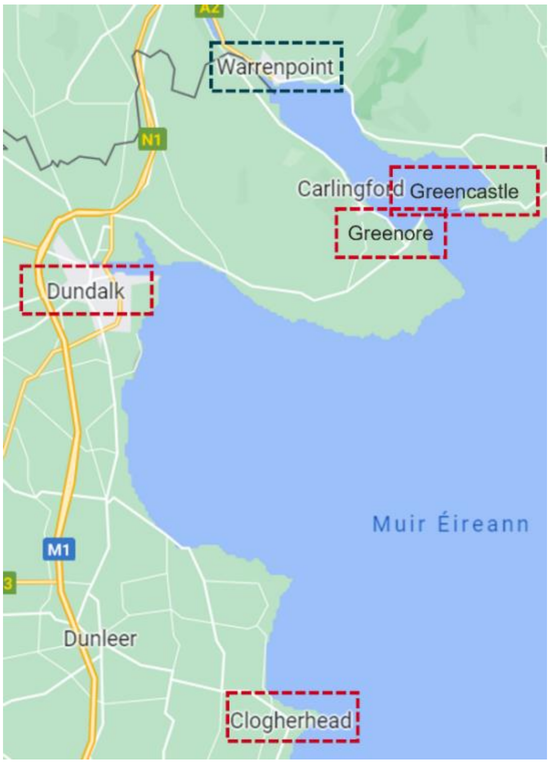
Heysham Port is capable of handling Ro-Ro, vehicle, offshore, agri-bulk, project cargo and energy products (Peel Ports Group, 2022b). Seatruck Ferries currently offers a Ro-Ro ferry service to Warrenpoint twice a day (Seatruck, 2022). This corroborates with UMAS analysis of the AIS data as well as official statistics, which shows that Heysham Port handled 2,054 Ro-Ro vessel arrivals in 2021 (DfT, 2022b). From UMAS analysis of the AIS data, the top five destinations for Ro-Ro vessels departing Heysham Port were: Belfast, Warrenpoint, Dublin, Greencastle and Liverpool Bay Terminal.

Warrenpoint Port is capable of handling Ro-Ro, container, cruise, break bulk, bulk and project consignments (Warrenpoint Port, 2022a). Seatruck Ferries currently offers a twice daily Ro-Ro ferry service to Heysham and is working towards offering a container service in 2023 (Warrenpoint Port, 2022b). This corroborates with UMAS analysis of the AIS data which shows a majority of vessels being Ro-Ro and general cargo, as well as official statistics, which show that Warrenpoint Port handled 44 tankers, 566 Ro-Ro, 91 container ships and 267 dry cargo vessel arrivals in 2021 (DfT, 2022b). From UMAS analysis of the AIS data, vessels arriving at Warrenpoint Port were predominantly found to be coming from Heysham, Liverpool and Greenore.

8.1.2 Competing options to the direct UK domestic maritime route

The next step involves identifying potential indirect maritime routes via different ports and modes of transport that could be used by operators (if they amend their operating models) or by customers, to avoid using a route that would be subject to the UK ETS (and hence likely have a higher transport cost). Figure 13 includes a map with ports that are in close proximity to Warrenpoint. To assess whether these ports can accommodate Ro-Ro vessels, official government data, port websites and the AIS derived data were examined. The results of this assessment are outlined in Table 8. This shows that Dundalk and Clogherhead port do not handle Ro-Ro vessels (or Ferry-RoPax vessels, which are similar).[49] For this reason, these ports are ruled out as ports for potential indirect routes. While Dublin is not geographically close to Warrenpoint, given the high volume of voyages from Heysham to Dublin (the latter is a major Ro-Ro port (Central Statistics Office, 2022)), Dublin has been considered as a potential option (not shown in the map below but included in Figure 24 in Annex B).

Figure 13 Options for alternative ports to Warrenpoint



Source: Google Maps

Note: Dublin is not included in this map. It is located further south (beyond Clogherhead).

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[49] This may change in the future, but analysis of such implications is outside the scope of this report.

Table 8 Options for alternative ports to Warrenpoint

Ports	Country	UMAS analysis of AIS Data	Port Websites	Official Statistics
Greenore	Republic of Ireland	This port handled Ferry-RoPax and Ro-Ro vessels in 2021.	This port handles non-containerised cargo such as bulk and general cargo (Greenore Port, 2022).	Not included in dataset of Ro-Ro and container handling ports, suggesting no significant activity at this port (Central Statistics Office, 2022).
Dundalk	Republic of Ireland	Ferry-RoPax or Ro-Ro unlikely in 2021.	This port handles general cargo and dredger vessels (MarineTraffic, 2022a).	Not included in dataset of Ro-Ro and container handling ports suggesting no significant activity at this port (Central Statistics Office, 2022).
Clogherhead	Republic of Ireland	Ferry-RoPax or Ro-Ro unlikely in 2021.	This port handles fishing and trawler vessels (Marine Traffic, 2022b).	Not included in dataset of Ro-Ro and container handling ports suggesting no significant activity at this port (Central Statistics Office, 2022).
Dublin	Republic of Ireland	This port handled Ferry-RoPax and Ro-Ro vessels in 2021.	This port handles Ro-Ro, RoPax, container, bulk solid, bulk liquid and cruise vessels (Dublin Port Company, 2022).	Included in dataset of Ro-Ro and container handling ports suggesting no significant activity at this port (Central Statistics Office, 2022).
Greencastle	Northern Ireland	This port handled Ferry-RoPax and Ro-Ro vessels in 2021.	This port handles fishing, trawler and passenger vessels (MarineTraffic, 2022c).	Not included in dataset of Ro-Ro and container handling ports suggesting no significant activity at this port (Northern Ireland Statistics and Research Agency, 2022).

Having identified potential alternative ports, a total of four potential indirect routes were identified and assessed. A summary of the results is outlined in Table 9, split into operator and customers responses. Further detail on each of these indirect routes is outlined in Annex B

Table 9 Summary of indirect routes from Heysham to Warrenpoint

Route Type	Route	Time Estimate*	Feasible alternative route?
Direct	Heysham to Warrenpoint	Total: 8hr journey time	N/A
Indirect (Operator response)	(1) Heysham to Greenore to Warrenpoint (all maritime)	Total: 8hr journey time	Potentially feasible:

Route Type	Route	Time Estimate*	Feasible alternative route?
			Operators could feasibly perform an evasive port call at Greenore.
Indirect (Customer response)	(2) Heysham to Greenore to Greencastle (all maritime)	Greenore is close to Warrenpoint (circa 8hrs). Greenore to Greencastle takes 20 minutes. Total: 8hrs 20 minutes	Potentially feasible: Customers could go to Greenore and then transfer cargo to a second ship from Greenore to Greencastle, which involves operation and time costs. This is potentially feasible for Ferry-RoPax (as services currently run between Greenore and Greencastle). For Ro-Ro, no services currently exist for this vessel type, so this is less likely to be feasible.
	(3) Heysham to Greenore (maritime), then drive via road to Newry	Greenore is close to Heysham (circa 8hrs). Greenore to Newry is a 26 min drive Total: 8hrs 26 minutes journey time	Potentially feasible: Operators could call at Greenore (as per indirect route (1) above). Customers could use road transport from Greenore to Newry with little additional travel time incurred
	(4a) Heysham to Dublin to Warrenpoint (all maritime)	Heysham to Dublin via ship (8.5hrs) Dublin to Warrenpoint via ship (no services currently)	Unlikely to be feasible: There are currently no services from Dublin to Warrenpoint. If there were, this could take a material amount of additional time.
	(4b) Heysham to Dublin (maritime) to Warrenpoint (via rail)	Heysham to Dublin (8.5hrs) Dublin to Warrenpoint via rail (no rail freight operations exist in NI)	Unlikely to be feasible: There are no rail freight operations in NI.
	(4c) Heysham to Dublin (maritime), then drive via road to Newry	Heysham to Dublin (8.5hrs) Dublin to Newry is a 1hr 33 minutes' drive Total: 10hrs journey time	Potentially feasible: While the alternative route is feasible, an increase in total journey time of 25% is significant and may deter operators from switching to this route in some cases.

Source: *Various – see Annex B for details*

Note: **Time estimates are based on port-to-port travel and do not include the extra time required for stopping and unloading (including any customs checks where relevant). The total journey time for customers will depend on the ultimate origin and destination of the cargo and/or passengers.*

From a practical perspective – not accounting for relative costs – indirect route 1 was found likely to be theoretically feasible and would involve the operator undertaking an evasive port call at Greenore in ROI to avoid paying the UK carbon price. Of the remaining indirect routes, only indirect routes 3 and 4c were found to be potentially feasible. These both involve customers shifting to a maritime route involving a stop at a port in ROI and then using road transport to travel to their final destination from ROI into NI. It is worth noting that in addition to the extra time taken via an indirect route, stopping in ROI first instead of NI would require additional customs checks and loading/unloading time that could involve additional time and financial costs. However it was beyond the scope of this work to look into these additional time and financial costs in detail.

8.1.3 Qualitative assessment

Having assessed that the Heysham to Warrenpoint journey has three theoretically feasible options for alternative indirect routes via ROI, the next step is the qualitative assessment of the risks of carbon leakage, internal carbon displacement and competitive disadvantage. This involves combining the qualitative assessment of risk factors performed for the Ro-Ro vessel archetype in Chapter 7 with the indirect route analysis above and results are outlined in Table 10.

Table 10 Qualitative assessment of risk factors based on vessel archetype

Vessel archetype:	Ro-Ro
Carbon cost exposure	Ro-Ro vessels are relatively emissions intensive with the main abatement option involving a shift to alternative fuels.
Likelihood of cost pass-through	Operators typically earn low margins in this highly competitive industry. This increases the likelihood of cost pass-through since operators are not able to sustainably absorb cost changes.
Likelihood of a shift to substitute options	Competes with the Ro-Ro part of Ferry-RoPax, with demand likely higher in summer (when Ferry-RoPax is busier) and lower in winter (when Ferry-RoPax is quieter). Competes with container ships and indirect road-based routes, given the flexibility with the cargo already being loaded onto trucks. Indirect routes using rail cannot be used, as there are no rail freight operations in NI (Department for Infrastructure (NI) & Department of Transport (NI), All Island Strategic Rail Review, 2021). Competes with indirect routes, particularly indirect route 1 as operators could feasibly perform an evasive port call at Greenore.
Potential degree of customer response	Speed is key for customers on these vessels (as cargo is more likely to be time sensitive), so container shipping and long indirect routes are less likely to be attractive.

Source: Frontier Economics, based on review of evidence. See Section 7 for further details of sources

Table 11 Qualitative assessment of the risk of carbon leakage, internal carbon displacement and competitive disadvantage

Vessel archetype:	Ro-Ro
Risk of carbon leakage	**Low: if the 'EU ETS proposal' were in place** Although there are theoretically feasible alternative options by switching to a port in the ROI, this is not likely to occur if the 'EU ETS proposal' were in place. This is because the cost advantage from avoiding a UK port and stopping in the ROI instead to avoid the UK ETS is minimised if operators were still subject to a carbon price, as under the 'EU ETS proposal'. The risk is lower still if the IMO introduces ambitious climate policy. If international maritime journeys into the ROI are not covered within the EU ETS, then the risk of carbon leakage could be high.
Risk of internal carbon displacement	**Low: the need to cross the water minimises the scope for surface transport to be a viable alternative** There are no domestic rail freight services in NI, so no risk of a modal shift to this type of transport. In terms of displacement to road, once the cargo is within NI it is likely to travel in a similar route as it would have done prior to the introduction of domestic maritime shipping in the UK ETS. Loading and unloading cargo adds time and cost making this less attractive.
Risk of competitive disadvantage	**Low: if the 'EU ETS proposal' were in place** Substitute and competing options to the direct UK domestic maritime route are not able to offer a more competitive alternative if they are covered within the EU ETS. If those options are not covered by the EU ETS, then the risk would be high.

Source: Frontier Economics

8.1.4 Indicative quantitative assessment

To complement the qualitative analysis above, it can be helpful to consider the potential order of magnitude of carbon prices within the UK ETS that could be associated with a particular scale of effect on shipping demand. To explore this, indicative 'switching analysis' has been undertaken.

The base case is the 'EU ETS proposal', which is Scenario 3 of the policy scenarios outlined in Section 4.2.6. This indicative analysis suggests that on the basis of the assumptions made, for there to be a 10% reduction in demand on this shipping route, the UK ETS price would need to be £173/tCO_2. For a 15% reduction in demand it would need to be £238/tCO_2 and for a 20% reduction in demand it would need to reach £302/tCO_2. There are inevitable uncertainties in this analysis and hence varying some of the assumptions reveals that UK ETS carbon prices would need to be higher still for these changes in demand to be observed. For example, this would be the case if the responsiveness of demand to price changes were lower than considered in the base case; or if fuel prices were higher than assumed in the base case; or if fuel were to account for a lower share of voyage costs. This suggests that very high carbon prices would be needed for a material change in demand to be observed. Furthermore, it should be noted that these estimated UK ETS allowance prices are purely hypothetical estimates and that they do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

This is shown in Table 12, which also presents results from applying alternative assumptions from those used in the base case (assuming the carbon prices are fixed across alternative policy scenarios and sensitivities, as previously explained in Section 4.2.6). The analysis suggests the following:

- a higher EU ETS price makes it less likely that UK demand reduces because there is less incentive to switch to routes covered by the EU ETS;
- if fuel is a smaller proportion of voyage costs – 30% rather than 50% - this leads to a lower reduction in UK shipping demand because the carbon cost is equivalent to an increase in fossil fuel cost and so because this is a lower proportion of voyage costs, overall costs change by a lower amount and so does demand.
- if price elasticity of demand is lower – -0.1 instead of -0.19 – then the reductions in UK domestic shipping demand are lower because customers are less responsive to the price change.

The estimated UK ETS prices shown in the table below represent the estimated UK allowance prices that would hypothetically be required in order for there to be 10%, 15% and 20% reductions in demand on the case study route under the base case (Scenario 3). Therefore, it should be noted that the estimated UK ETS allowance prices shown in the table below are purely hypothetical and do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

Table 12 Indicative switching analysis for Ro-Ro vessels in the Heysham to Warrenpoint case study

Scenario	**Sensitivity**	**Change in UK domestic Ro-Ro demand on Heysham to Warrenpoint route for the following hypothetical estimated UK ETS prices:**		
		£173/tCO_2	**£238/tCO_2**	**£302/tCO_2**
3	Base Case	-10%	-15%	-20%
2	High EU ETS price	-9%	-13%	-18%
4	Low EU ETS price	-12%	-17%	-22%
3	Fuel is 30% of voyage costs	-6%	-10%	-13%
3	Quartile 3 elasticity (-0.1)	-5%	-8%	-11%

Source: Frontier Economics analysis. The three EU ETS allowance price forecasts for 2030 are based on ICIS (2022) analysis and were provided by DESNZ.

Note: A full list of results across all policy scenarios is available in Annex B.

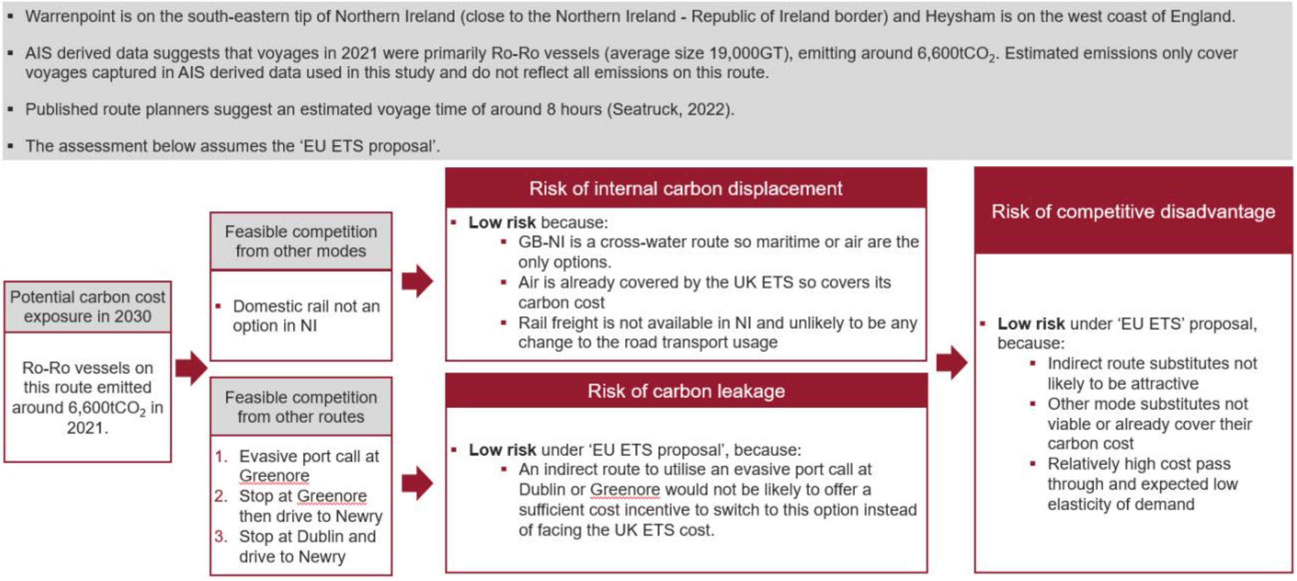
The analysis looks at other possible policy scenarios:

- If 100% of international maritime emissions were to be covered by the EU ETS, then the reduction in UK domestic shipping demand from including domestic shipping in the UK ETS would be lower than in the base case (across all EU ETS price scenarios looked at). This is because there would be a much narrower difference in voyage costs between direct GB-NI routes and indirect routes, making the substitution to those routes far less likely.
- Were road transport to be included in a separate EU ETS then it would also pay its external costs of carbon, meaning that alternative transport modes involving road for moving cargo are less attractive than in the base case. Therefore, reductions in domestic shipping demand from including UK domestic shipping in the UK ETS would likely be lower than in the base case.
- If maritime emissions were not covered in the EU ETS, then the reduction in UK domestic shipping demand from including domestic shipping in the UK ETS would be greater than in the base case, because indirect shipping routes could become substantially cheaper in comparison.
- In the longer-term, these vessels may be able to switch their fuel to low-carbon options or abate in other ways such as air lubrication and wind assistance. Were this to be possible, then the carbon cost exposure would be less pronounced, leading to lower reductions in UK domestic shipping demand. However it is beyond the scope of this report to look into the drivers and enablers of these longer-term investments.

8.1.5 Key findings

Taking the qualitative assessment and illustrative quantitative assessment together, a summary of the risks of carbon leakage, internal carbon displacement and competitive disadvantage is provided below for this case study. The assessment of risks primarily relates to the short term.[50]

Figure 14 Overview of Key Findings



- Warrenpoint is on the south-eastern tip of Northern Ireland (close to the Northern Ireland - Republic of Ireland border) and Heysham is on the west coast of England.
- AIS derived data suggests that voyages in 2021 were primarily Ro-Ro vessels (average size 19,000GT), emitting around 6,600tCO_2. Estimated emissions only cover voyages captured in AIS derived data used in this study and do not reflect all emissions on this route.
- Published route planners suggest an estimated voyage time of around 8 hours (Seatruck, 2022).
- The assessment below assumes the 'EU ETS proposal'.

Potential carbon cost exposure in 2030

Ro-Ro vessels on this route emitted around 6,600tCO_2 in 2021.

Feasible competition from other modes

- Domestic rail not an option in NI

Feasible competition from other routes

1. Evasive port call at Greenore
2. Stop at Greenore then drive to Newry
3. Stop at Dublin and drive to Newry

Risk of internal carbon displacement

- **Low risk** because:
  - GB-NI is a cross-water route so maritime or air are the only options.
  - Air is already covered by the UK ETS so covers its carbon cost
  - Rail freight is not available in NI and unlikely to be any change to the road transport usage

Risk of carbon leakage

- **Low risk** under 'EU ETS proposal', because:
  - An indirect route to utilise an evasive port call at Dublin or Greenore would not be likely to offer a sufficient cost incentive to switch to this option instead of facing the UK ETS cost.

Risk of competitive disadvantage

- **Low risk** under 'EU ETS' proposal, because:
  - Indirect route substitutes not likely to be attractive
  - Other mode substitutes not viable or already cover their carbon cost
  - Relatively high cost pass through and expected low elasticity of demand

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[50] In the longer-term, these risks may fall as domestic maritime vessels and other transport modes decarbonise, though this also depends on the evolution of the cost of different energy sources. It was out of the scope of this report to consider these effects in detail.

Source: *Frontier Economics - the estimated emissions only cover voyages captured in the AIS derived data used in this study and do not reflect all emissions on this route.*

Carbon leakage

Overall, the potential risk of carbon leakage is considered low if the ‘EU ETS proposal’ were in place.

Based on the data available, it appears theoretically feasible that operators could undertake an evasive port call at Greenore in ROI. This is because Greenore is close to the border with NI (and to Warrenpoint). For customers, there are also feasible indirect routes via ports in ROI and which then involve driving to their final destination in NI. However, the additional time taken on such routes reduces the likelihood of those options being chosen by most customers due to their time-sensitivity.[51]

The indicative quantitative analysis suggests that if the ‘EU ETS proposal’ were in place, the potential decline in UK domestic shipping from switching to indirect routes is low. Carbon prices would need to reach £173/tCO_2 for there to be even a 10% reduction in demand and significantly higher for the reduction in demand to reach 15% or 20%. These values could be higher still, based on analysis which uses alternative assumptions. This should be compared to the £98/tCO_2 allowance price the UK ETS reached in August 2022 (Ember, 2022). If road is included in a separate EU ETS, it becomes even less likely that customers switch to indirect routes (some of which include non-electrified road transport). Furthermore, it should be noted that these estimated UK ETS allowance prices are purely hypothetical estimates and that they do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

Internal carbon displacement

Overall the potential risk of internal carbon displacement is low. The need to cross water means that maritime is needed for at least part of the journey. For the remaining part of the journey, once the cargo is within NI, there are no domestic rail freight services in NI, so no risk of a modal shift to this type of transport. For modal shift to road transport, cargo is likely to travel in a similar route as it would have done prior to the introduction of domestic maritime shipping in the UK ETS, meaning there is little risk of internal carbon displacement in this case.

Competitive disadvantage

Overall, there is a low risk of competitive disadvantage if the ‘EU ETS proposal’ were in place. This is because demand elasticity is expected to be low and there is only a low risk of carbon leakage and internal carbon displacement (as outlined in the sections above).

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[51] Evidence of customers being time-sensitive comes from industry-specific knowledge and expertise.

8.2 Case study 2: Belfast to Liverpool

8.2.1 Route overview

The second case study analysed is Belfast (NI) to Liverpool (GB). Figure 15 shows a map of the route, where Belfast is on the east coast of NI and Liverpool is on the west coast of England. Table 13 shows that voyages in 2021 on this route were primarily made by Ferry-RoPax and Ro-Ro vessels according to UMAS analysis of the AIS data. Together, for voyages captured in the AIS derived data used in this study, these ship types emitted a total of 63,000tCO_2, accounting for around 95% of total CO_2 emissions on this route.[52]

The average Ferry-RoPax ship size on this route was 41,000GT and the average Ro-Ro ship size 19,000GT; both of which are significantly above the proposed UK ETS threshold of 5,000GT under our definition of the ‘UK ETS proposal’.[53] This means that these vessels would be included within the UK ETS, under our definition of the ‘UK ETS proposal’. Using published route planners, this voyage is estimated to take around 8 hours (Stena Line, 2022b). This is close to the median voyage duration recorded in the UMAS analysis of the AIS data in 2021 (Table 13).[54]

Figure 15 Belfast to Liverpool route map

Source: Google Maps

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[52] The Liverpool to Belfast route in 2021 had a similar composition of ship types.

[53] It was out of scope for this study to look at vessels below 5,000GT.

[54] Actual journey times (which the AIS derived data records) may vary from advertised voyage lengths. This is because of delays, congestion and weather conditions.

Table 13 Belfast to Liverpool route summary statistics for voyages captured in AIS derived data (2021)

Ship Type	Total CO2 emitted (t)	Average emissions intensity (tCO2/nm)	Median distance travelled (nm)	Median voyage duration (hours)	Average ship size (GT)
Ferry-RoPax	**51,000**	**0.56**	**135**	**10**	**41,000**
Ro-Ro	**12,000**	**0.42**	**135**	**10**	**19,000**
Cruise	2,500	0.93	149	14	110,000
Chemical tanker	720	0.16	156	24	6,000
Oil tanker	220	0.11	141	25	1,500
General cargo	150	0.05	149	26	2,500
Liquefied gas tanker	78	0.25	158	85	3,500
Bulk carrier	73	0.21	165	23	30,000
Container	49	0.19	131	14	9,800

Source: *AIS derived data used in this study. The estimates only cover voyages captured in the AIS derived data used in this study and do not reflect all voyages on this route.*

Note: *The vessel types in bold are over the 5% of total emissions materiality threshold.*

In order to understand how typical the types of vessels on this route are relative to the types of vessels the two ports handle across all routes, evidence is triangulated across a range of sources. UMAS analysis of AIS data has been validated by reviewing other sources of data (such as timetables) to confirm that these two ports have the capabilities to handle many types of vessels but are currently servicing a larger proportion of Ferry-RoPax and Ro-Ro vessels. More details are below.

Belfast Port[55] is capable of handling Ferry-RoPax, liquid, dry and break bulk, cruise and offshore vessels (Belfast Harbour, 2022). Stena Line currently offers a twice daily Ferry-RoPax service to Liverpool (Stena Line, 2022b). This corroborates with UMAS analysis of AIS data as well as official statistics, which shows that Belfast Port handled 294 tankers, 3,699 Ro-Ro, 276 container, 1,211 dry cargo and 73 passenger[56] vessel arrivals in 2021 (DfT, 2022b). From UMAS analysis of AIS data, the top five destinations departing from Belfast Port were: Liverpool, Heysham, Greenock, Avonmouth and Dublin.

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[55] Belfast Port combines "Belfast" and "Newtonabbey" from the AIS derived dataset together. This is to ensure as close alignment as possible with the port definitions used by DfT.

[56] Passenger vessels refer to passenger and cruise vessels. Ferry-RoPax vessels are classified under the "Ro-Ro" category.

Liverpool Port[57] is capable of handling Ro-Ro, containers, dry bulk, liquid bulk, cruise, energy products, offshore and project cargo vessels (Peel Ports Group, 2022a). Stena Line currently offers a twice daily Ferry-RoPax service to Belfast (Stena Line, 2022b). This corroborates with UMAS analysis of the AIS data which shows a majority of vessels being Ro-Ro, Ferry-RoPax and general cargo, as well as official statistics, which show that Liverpool Port handled 1,161 tankers, 2,962 Ro-Ro, 642 container, 1,247 dry cargo and 93 passenger[56] vessel arrivals in 2021 (DfT, 2022b). From UMAS analysis of AIS data, the top five origin ports for vessels arriving at Liverpool Port were: Dublin, Belfast, Dulas Bay, Liverpool and Holyhead.

8.2.2 Competing options to the direct UK domestic maritime route

Next, potential indirect maritime routes via different ports and modes of transport are identified. Figure 16 includes a map with alternative ports that could theoretically be used to travel to Liverpool.[58] [59] To assess whether these ports can accommodate Ferry-RoPax and Ro-Ro vessels, official government data, port websites and UMAS analysis of AIS data were examined. The results of this assessment are outlined in Table 14. This shows that Dundalk Port does not handle Ro-Ro or Ferry-RoPax vessels. As such, Dundalk has been excluded as a potential indirect route.

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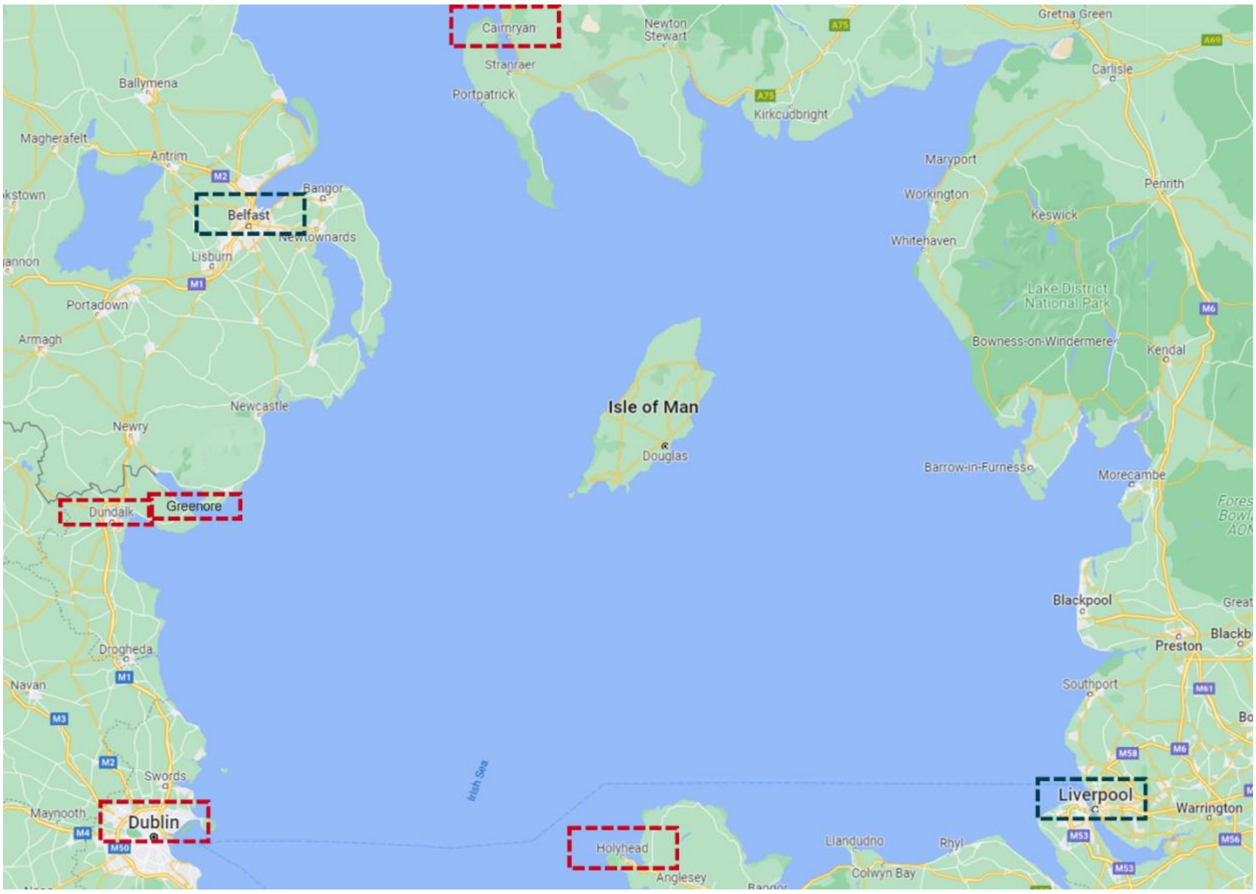
[57] Liverpool Port combines “Birkenhead”, “Bromborough”, “Eastham”, “Ellesmere”, “Garston”, “Liverpool”, “Rock Ferry”, “Seaforth”, “Stanlow”, “Tranmere” from the AIS derived data together. This is to ensure as close alignment as possible with the port definitions used by DfT.

[58] Cairnryan is included as a potential port the Belfast to Liverpool service could call at. This is because of the much shorter maritime journey between Belfast and Cairnryan (which could entail a lower carbon cost compared to the longer Belfast to Liverpool service).

[59] Specific route maps for all indirect routes can be found in the annex. Specific route arrows for multiple routes were not included in these upfront figures to avoid confusion.

Figure 16 Options for alternative ports to Liverpool



Source: *Google Maps*

Table 14 Options for alternative ports to Liverpool

Ports	Country	UMAS analysis AIS Data	Port Websites	Official Statistics
Greenore	Republic of Ireland	This port handled Ferry-RoPax and Ro-Ro vessels in 2021.	This port handles non-containerised cargo such as bulk and general cargo (Greenore Port, 2022).	Not included in dataset of Ro-Ro and container handling ports suggesting no significant activity at this port (Central Statistics Office, 2022).
Dundalk	Republic of Ireland	Ferry-RoPax or Ro-Ro unlikely in 2021.	This port handles general cargo and dredger vessels (MarineTraffic, 2022a).	Not included in dataset of Ro-Ro and container handling ports suggesting no significant activity at this port (Central Statistics Office, 2022).
Dublin	Republic of Ireland	This port handled Ferry-RoPax and Ro-Ro vessels in 2021.	This port handles Ro-Ro, RoPax, container, bulk solid, bulk liquid and cruise vessels	Included in dataset of Ro-Ro and container handling ports (Central Statistics Office, 2022).

Ports	Country	UMAS analysis AIS Data	Port Websites	Official Statistics
			(Dublin Port Company, 2022).	
Cairnryan	Great Britain	This port handled Ferry-RoPax vessels in 2021.	This port handles Ro-Ro, Ferry-RoPax and General Cargo (Port of Larne, 2022) (MarineTraffic, 2022d).	This port handled 2,090 Ro-Ro and 2 dry cargo vessel arrivals in 2021 (DfT, 2022b).

Having identified potential alternative ports, a total of four potential indirect routes were identified and assessed. A summary of the results is outlined in Table 15. Further details on each of these indirect routes is outlined in Annex B

Table 15 Summary of indirect routes from Belfast to Liverpool

Route Type	Route	Time Estimate*	Feasible alternative route?
Direct	Belfast to Liverpool	Total: 8hr journey time	N/A
Indirect (Customer response)	(1) Belfast to Greenore (maritime/road/rail) to Liverpool (maritime)	Belfast to Greenore via road takes 1 hr 9 min + Greenore to Liverpool via maritime (no services currently); OR Belfast to Greenore, then Greenore to Liverpool all via maritime (no services currently for either)	Unlikely to be feasible: There are no services from Belfast to Greenore, or Greenore to Liverpool. If Greenore to Liverpool took a similar time via Ferry-RoPax/Ro-Ro (and operators started this route), then driving from Belfast to Greenore and taking the Ferry-RoPax/Ro-Ro could be a potentially feasible route. However additional routes would have to become available for this to be potentially feasible.
	(2) Belfast to Cairnryan (maritime) to Liverpool (road/rail)	Belfast to Cairnryan (2 hr 22 min) Cairnryan to Liverpool via road (4 hr 32 min) Total: 6 hrs 54 minutes	Potentially feasible: There is currently an established Ferry-RoPax route between Belfast and Cairnryan and the total travel time (+ driving) is similar to the direct route. For Ro-Ro to be possible, a new service would have to be established.

Route Type	Route	Time Estimate*	Feasible alternative route?
	(3) Belfast to Dublin (maritime/road/rail) to Liverpool (maritime)	Belfast to Dublin via road (2 hr) Dublin to Liverpool (8 hr) Total: 10 hr journey time	Potentially feasible: While the alternative route is feasible for Ferry-RoPax, an increase in total journey time of 20% is relatively material. For Ro-Ro to be possible, a new service would have to be established.
	(4) Belfast to Liverpool (via air)	Total: 50 min journey time	Potentially feasible: This is a feasible route if passengers do not need to travel with their vehicle. Depending on the type of freight being transported, this could be feasible for high value light-weight items.

Source: *Various – see Annex B for details*

Note: **Time estimates are based on port-to-port travel and do not include the extra time required for stopping and unloading (including any customs checks where relevant). The total journey time for customers will depend on the ultimate origin and destination of the cargo and/or passengers.*

From a practical perspective – not accounting for relative costs – three of the four indirect routes were found to be potentially feasible. For routes 2 and 3, this would involve customers shifting to a maritime route either involving a port in ROI (Greenore/Dublin) or a port in GB with a shorter maritime journey (Cairnryan), with part of the new indirect journey involving road or rail transport. Route 4 entails substituting domestic maritime for air travel from Belfast to Liverpool. As was the case for case study 1, it is worth noting that in addition to the extra time taken via an indirect route, stopping in ROI first instead of NI would require additional customs checks and loading/unloading time that could involve additional time and financial costs.

8.2.3 Qualitative assessment

Having assessed that the Belfast to Liverpool journey has several theoretically feasible options for alternative indirect routes via ROI and/or through modal shifts, the next step is the qualitative assessment of the risks of carbon leakage, internal carbon displacement and competitive disadvantage, as was undertaken for case study 1. Table 16 is a repeat of the relevant elements of the vessel table in Chapter 7 and then the results of our assessment are in Table 17.

Table 16 Qualitative assessment of risk factors based on vessel archetype

Vessel archetype:	Ro-Ro	Ferry-RoPax
Carbon cost exposure	Ro-Ro vessels are relatively emissions intensive with the main abatement option involving a shift to alternative fuels.	Ferry-RoPax vessels are relatively emissions intensive with the main abatement option involving a shift to alternative fuels.
Likelihood of cost pass-through	Operators typically earn low margins in this competitive industry. This increases the likelihood of cost pass-through.	Operators typically earn low margins in this competitive industry. This increases the likelihood of cost pass-through.
Likelihood of a shift to substitute options	Competes with the Ro-Ro part of Ferry-RoPax, with demand likely higher in summer (when Ferry-RoPax is busier) and lower in winter (when Ferry-RoPax is quieter). Competes with container ships and indirect road-based routes, given the flexibility with the cargo already being loaded onto trucks. Indirect routes using rail cannot be used, as there are no rail freight operations in NI (Department for Infrastructure (NI) & Department of Transport (NI), All Island Strategic Rail Review, 2021). Competes with potentially feasible indirect routes which may involve additional time and financial costs.	Shipping operators are unlikely to change vessels, as these are usually bespoke to the given route. Ro-Pax operations may compete with full Ro-Ro vessels and container ships. Indirect road-based routes could be taken, as the cargo is already being loaded onto trucks. Indirect routes using rail can be used in some circumstances. However, there are no rail freight operations in NI (Department for Infrastructure (NI) & Department of Transport (NI), All Island Strategic Rail Review, 2021). Competes with potentially feasible indirect routes which may involve additional time and financial costs.
Potential degree of customer response	Speed is key for customers on these vessels (as cargo is more likely to be time sensitive), so switching to container shipping and long indirect routes are less likely to be attractive.	Speed is key for Ro-Ro customers on these vessels (as cargo is more likely to be time sensitive or perishable goods), so container shipping and long indirect routes are less likely to be attractive. For passengers, if speed and/or price is key then they may switch to flying.

Source: Frontier Economics, based on review of evidence. See Section 7 for further details of sources.

Table 17 Qualitative assessment of the risk of carbon leakage, internal carbon displacement and competitive disadvantage

Vessel archetype:	Ro-Ro	Ferry-RoPax
Risk of carbon leakage	**Low: if the 'EU ETS proposal' were in place** Although there are some potentially feasible alternative options (indirect routes 1 and 3) by switching to a port in the ROI, this is not likely to occur if the 'EU ETS proposal' were in place. This is because the cost advantage from avoiding a UK port and stopping in the ROI instead to avoid the UK ETS is minimised if operators were still subject to a carbon price, as in the 'EU ETS proposal'. The risk is lower still if the IMO introduces ambitious climate policies. These routes may also involve material increases to journey time and in some cases would require the establishment of new routes by operators (indirect routes 1, 2 and 3). If international maritime journeys into the ROI are not covered within the EU ETS, then the risk of carbon leakage could be high.	
Risk of internal carbon displacement	**Low: if the 'EU ETS proposal' were in place** For routes 1, 2 and 3 non-electrified vehicles drive through NI or GB to reach their destination (e.g. from Cairnryan to Liverpool) and are not covered by the UK ETS. However, for routes 1 and 3 this is not likely to occur if the 'EU ETS proposal' were in place, paying the EU ETS cost would lower the cost advantage of switching to indirect routes. In the case of route 2, there is currently no Ro-Ro service available, and for Ferry-RoPax (where there is a service available) the number of connections required to travel from Cairnryan to Liverpool means that any switch to rail and bus would be unlikely. For route 4, the risk of internal carbon displacement is low because aviation is part of the UK ETS and may not be feasible in most cases. If international maritime journeys into the ROI are not covered within the EU ETS, then the risk of internal carbon displacement is medium.	
Risk of competitive disadvantage	**Low: if the 'EU ETS proposal' were in place** Substitute and competing options to the direct UK domestic maritime route are not able to offer a more competitive alternative if they are covered within the EU ETS. If those options are not covered by the EU ETS, then the risk would be medium, as there are options for indirect routes and for switching to different modes leading to carbon leakage and internal carbon displacement and thus competitive disadvantage.	

Source: Frontier Economics

8.2.4 Indicative quantitative assessment

To complement the qualitative analysis above, we undertook an indicative quantitative analysis for this case study.

The base case is the ‘EU ETS proposal’, which is Scenario 3 of the policy scenarios outlined in Section 4.2.6. This indicative analysis suggests that on the basis of the assumptions made, for there to be a 10% reduction in demand on this shipping route for Ferry-RoPax, the UK ETS price would need to be £180/tCO_2 and it would need to be £169/tCO_2 to lead to a 10% reduction in demand on this route for Ro-Ro vessels. For the equivalent 15% reduction in demand for Ferry Ro-Pax the UK ETS price would need to be £249/tCO_2 and £232/tCO_2 for Ro-Ro vessels. And for a 20% reduction in demand for Ferry-RoPax the UK ETS price would need to reach £317/tCO_2 and £295/tCO_2 for the equivalent in Ro-Ro vessels. As mentioned in case study 1, there are inevitable uncertainties in this analysis and hence varying some of the assumptions reveals that UK ETS carbon prices would need to be higher still for these changes in demand to be observed. Furthermore, it should be noted that these estimated UK ETS allowance prices are purely hypothetical estimates and that they do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

This is shown in Table 18 and Table 19, which also presents results from applying alternative assumptions from those used in the base case (assuming the carbon prices are fixed across alternative policy scenarios and sensitivities, as previously explained in Section 4.2.6). The analysis suggests the following:

- a higher EU ETS price makes it less likely that UK demand reduces because there is less incentive to switch to routes covered by the EU ETS;
- if fuel is a smaller proportion of voyage costs – 30% rather than 50% - this leads to a lower reduction in UK shipping demand because the carbon cost is equivalent to an increase in fossil fuel cost and so because this is a lower proportion of voyage costs, overall costs change by a lower amount and so does demand; and
- if price elasticity of demand is lower – -0.1 instead of -0.19 – then the reductions in UK domestic shipping demand are lower because customers are less responsive to the price change.

The estimated UK ETS prices shown in the tables below represent the estimated UK allowance prices that would hypothetically be required in order for there to be 10%, 15% and 20% reductions in demand on the case study route under the base case (Scenario 3). Therefore, it should be noted that the estimated UK ETS allowance prices shown in the tables below are purely hypothetical and do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

Table 18 Indicative switching analysis for Ferry-RoPax vessels in the Belfast to Liverpool case study

Scenario	Sensitivity	Change in UK domestic Ferry-RoPax demand on the Belfast to Liverpool route for the following hypothetical estimated UK ETS prices:		
		£180/tCO_2	£249/tCO_2	£317/tCO_2
3	Base Case	-10%	-15%	-20%
2	High EU ETS price	-9%	-13%	-18%
4	Low EU ETS price	-12%	-17%	-22%
3	Fuel is 30% of voyage costs	-6%	-10%	-13%
3	Quartile 3 elasticity (-0.1)	-5%	-8%	-11%

Source: *Frontier Economics analysis. The three EU ETS allowance price forecasts for 2030 are based on ICIS (2022) analysis and were provided by DESNZ.*

Note: *A full list of results across all policy scenarios is available in Annex B.*

Table 19 Indicative switching analysis for Ro-Ro vessels in the Belfast to Liverpool case study

Scenario	Sensitivity	Change in UK domestic Ro-Ro demand on the Belfast to Liverpool route for the following hypothetical estimated UK ETS prices:		
		£169/tCO_2	£232/tCO_2	£295/tCO_2
3	Base Case	-10%	-15%	-20%
2	High EU ETS price	-9%	-13%	-18%
4	Low EU ETS price	-12%	-17%	-22%
3	Fuel is 30% of voyage costs	-6%	-10%	-13%
3	Quartile 3 elasticity (-0.1)	-5%	-8%	-11%

Source: *Frontier Economics analysis. The three EU ETS allowance price forecasts for 2030 are based on ICIS (2022) analysis and were provided by DESNZ.*

Note: *A full list of results across all policy scenarios is available in Annex B.*

The analysis looks at other possible policy scenarios:

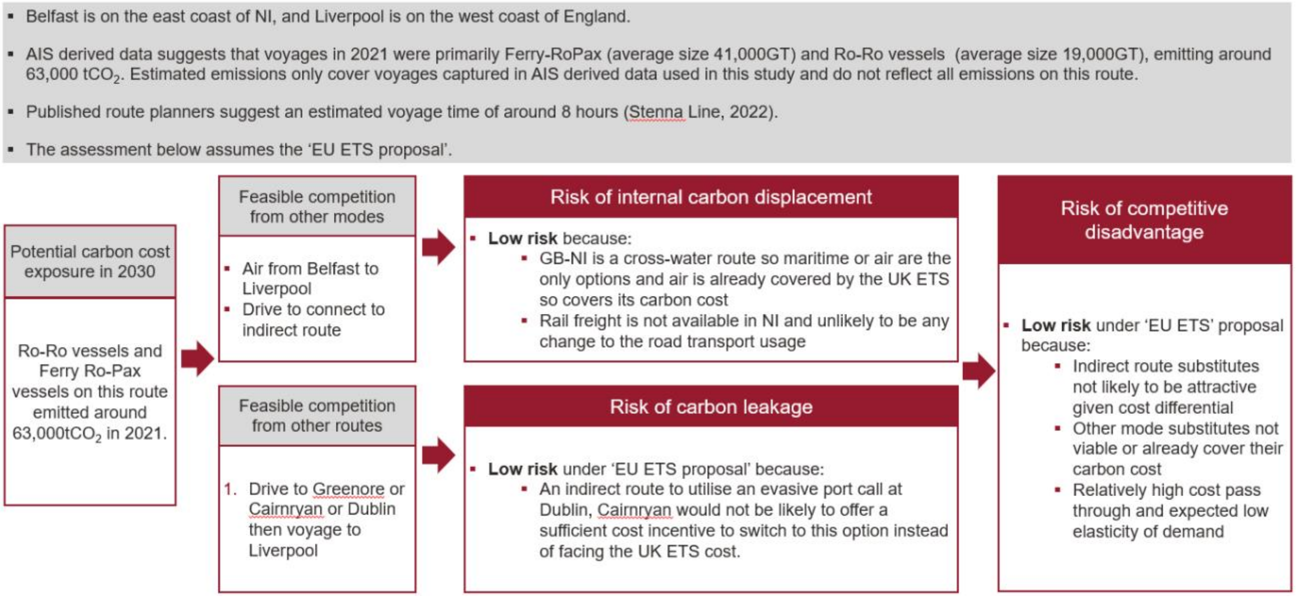
- If 100% of international maritime emissions were to be covered by the EU ETS, then the reduction in UK domestic shipping demand from including domestic shipping in the UK ETS would be lower than in the base case (across both vessel types and all EU ETS price scenarios looked at). This is because there would be a much narrower difference in voyage costs between direct GB-NI routes and indirect routes, making the substitution to those routes far less likely.
- Were road transport to be included in a separate EU ETS, then it would also pay its external costs of carbon, meaning that alternative transport modes involving road for moving cargo are less attractive than in the base case. Therefore reductions in domestic shipping demand from including UK domestic shipping in the UK ETS would likely be lower than in the base case.
- If maritime emissions were not covered in the EU ETS, then the reduction in UK domestic shipping demand from including domestic shipping in the UK ETS would be greater than in the base case for both vessel types, because indirect shipping routes could become substantially cheaper in comparison.

In the longer-term, these vessels may be able to switch their fuel to low-carbon options or abate in other ways such as air lubrication and wind assistance. Were this to be possible, then the carbon cost exposure would be less pronounced, leading to lower reductions in UK domestic shipping demand. However, it is beyond the scope of this report to look into the drivers and enablers of these longer-term investments.

8.2.5 Key Findings

Taking the qualitative assessment and illustrative quantitative assessment together, a summary of the risks of carbon leakage, internal carbon displacement and competitive disadvantage is provided below for this case study.

Figure 17 Overview of Key Findings



- Belfast is on the east coast of NI, and Liverpool is on the west coast of England.
- AIS derived data suggests that voyages in 2021 were primarily Ferry-RoPax (average size 41,000GT) and Ro-Ro vessels (average size 19,000GT), emitting around 63,000 tCO_2. Estimated emissions only cover voyages captured in AIS derived data used in this study and do not reflect all emissions on this route.
- Published route planners suggest an estimated voyage time of around 8 hours (Stenna Line, 2022).
- The assessment below assumes the 'EU ETS proposal'.

Potential carbon cost exposure in 2030

Ro-Ro vessels and Ferry Ro-Pax vessels on this route emitted around 63,000tCO_2 in 2021.

Feasible competition from other modes

- Air from Belfast to Liverpool
- Drive to connect to indirect route

Feasible competition from other routes

1. Drive to Greenore or Cairnryan or Dublin then voyage to Liverpool

Risk of internal carbon displacement

- **Low risk** because:
  - GB-NI is a cross-water route so maritime or air are the only options and air is already covered by the UK ETS so covers its carbon cost
  - Rail freight is not available in NI and unlikely to be any change to the road transport usage

Risk of carbon leakage

- **Low risk** under 'EU ETS proposal' because:
  - An indirect route to utilise an evasive port call at Dublin, Cairnryan would not be likely to offer a sufficient cost incentive to switch to this option instead of facing the UK ETS cost.

Risk of competitive disadvantage

- **Low risk** under 'EU ETS' proposal because:
  - Indirect route substitutes not likely to be attractive given cost differential
  - Other mode substitutes not viable or already cover their carbon cost
  - Relatively high cost pass through and expected low elasticity of demand

Source: *Frontier Economics - the estimated emissions only cover voyages captured in the AIS derived data used in this study and do not reflect all emissions on this route*

Carbon leakage

Overall, the potential risk of carbon leakage is considered low if the 'EU ETS proposal' were in place.

Based on the data available, it appears unlikely that operators would engage in evasive port calls. This is because there are no nearby ports in ROI that are close to Belfast. Further, several of the identified indirect routes would require the establishment of a new service to run from NI to ROI and/or from ROI and GB. For customers, several theoretically feasible options for alternative indirect routes via ROI and/or GB were identified. Practical challenges minimise the risk of these options due to the time penalty for customers (which may be key for Ro-Ro and Ferry-RoPax customers, given their time sensitivity) and the operational demands for operators.[60]

The indicative quantitative analysis suggests that if the 'EU ETS proposal' were in place, the potential decline in UK domestic shipping from switching to indirect routes is low. Carbon prices would need to reach £180/tCO_2 for there to be even a 10% reduction in demand for Ferry-RoPax and £169/tCO_2 for the equivalent reduction in Ro-Ro vessels. A significantly higher carbon price would be needed for the reduction in demand to reach 15% or 20%. These values could be even higher when based on analysis which uses alternative assumptions. This should be compared to the £98/tCO_2 allowance price the UK ETS reached in August 2022 (Ember, 2022). If road is included in a separate EU ETS, it becomes even less likely that customers switch to indirect routes (some of which include non-electrified road transport). Furthermore, it should be noted that these estimated UK ETS allowance

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[60] For example, there may be contractual constraints to establishing a new route, and it may be unclear if there is sustainable and sufficient demand for the new route to be viable.

prices are purely hypothetical estimates and that they do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

Internal carbon displacement

Overall the potential risk of internal carbon displacement is low. Based on the data available, some of the theoretically feasible indirect routes involve a switch to non-electrified road travel (which is not covered by the UK ETS or EU ETS) for at least part of the journey. For routes 1 and 3, non-electrified vehicles need to drive through NI to reach an ROI port (which then sails to Liverpool). For route 2, which lands at a different GB port (Cairnryan), this requires customers to drive to reach their final destination (Liverpool) through GB. The (non-electrified) road component of each of these routes is not covered by the UK ETS or EU ETS, however the likelihood of internal carbon displacement is still low. This is because it mirrors that of carbon leakage in being directly related to the EU ETS coverage. If the 'EU ETS proposal' were in place, switching to indirect routes is expected to be low and therefore the risk of internal carbon displacement is also low. For the alternative route using aviation, the potential risk of internal carbon displacement is low as aviation is part of the UK ETS.

Competitive disadvantage[61]

Overall, there is a low risk of competitive disadvantage if the 'EU ETS proposal' were in place. This is because demand elasticity is expected to be low for both vessel types and there is only a low risk of carbon leakage and internal carbon displacement (as outlined in the sections above).

8.3 Case study 3: Belfast to Southampton

8.3.1 Route overview

The final case study analysed is Belfast (NI) to Southampton (GB). Figure 18 shows a map of the route, where Belfast is on the east coast of NI and Southampton is on the south coast of England. As shown in Table 20, for voyages captured in the AIS derived data used in this study, Belfast to Southampton voyages were almost entirely cruise ships in 2021, emitting a total of 15,000tCO_2 based on UMAS analysis of AIS data and accounting for 98% of total CO_2 emissions on that route in that year.[62]

For this case study, for voyages captured in the AIS derived data used in this study, total CO_2 is significantly higher on this route in 2021 compared to previous years because of a large increase in the number of domestic cruises due to the COVID-19 pandemic (McGillivray, 2021) (see Table 37 for 2019 route summary statistics). The average cruise ship size on this route was around 160,000GT, which is significantly above the proposed UK ETS threshold of 5,000GT under our definition of the

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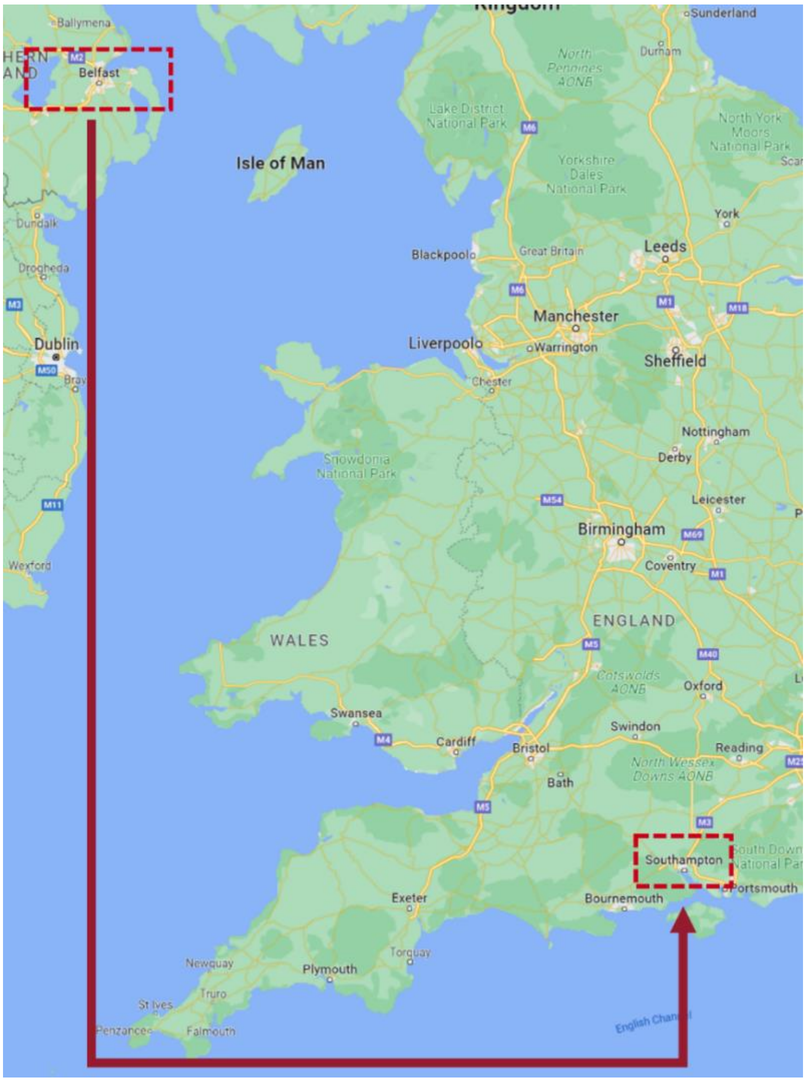
[61] The assessed risk of competitive disadvantage relates to UK domestic maritime operators that operate on the direct route before and after domestic maritime shipping is included in the UK ETS

[62] The Southampton to Belfast route in 2021 had a similar composition of ship types.

'UK ETS proposal'. According to UMAS analysis of AIS data, the median journey time for cruise ships on this route is 38 hours.

Figure 18 Belfast to Southampton route map



Source: Google Maps

Table 20 Belfast to Southampton route summary statistics for voyages captured in AIS derived data (2021)

Ship Type	Total CO_2 emitted (t)	Average emissions intensity (tCO_2/nm)	Median distance travelled (nm)	Median voyage duration (hours)	Average ship size (GT)
Cruise	**15,000**	**1.02**	**547**	**38**	**160,000**
Chemical tanker	130	0.24	544	57	24,000

Ship Type	Total CO_2 emitted (t)	Average emissions intensity (tCO_2/nm)	Median distance travelled (nm)	Median voyage duration (hours)	Average ship size (GT)
Container	120	0.13	491	40	4,000
General cargo	110	0.19	566	47	23,000

Source: *AIS derived data used in this study. The estimates only cover voyages captured in the AIS derived data used in this study and do not reflect all voyages on this route.*

Note: *The vessel type in bold is over the 5% of total emissions materiality threshold.*

To understand how typical the types of vessels on this route are relative to the types of vessels the two ports handle across all routes, evidence is triangulated across a range of sources. UMAS analysis of the AIS data has been validated by reviewing other sources of data (such as timetables) to confirm that these two ports can handle many different types of vessels. For cruises, there is no journey planner information available as itineraries vary widely for the different cruises that travel between Belfast and Southampton (cruisecritic, 2022).

Belfast Port[63] is capable of handling Ferry-RoPax, liquid, dry and break bulk, cruise and offshore vessels (Belfast Harbour, 2022). This corroborates with UMAS analysis of AIS data as well as official statistics, which show that Belfast Port handled 294 tankers, 3,699 Ro-Ro, 276 container, 1,211 dry cargo and 73 passenger[64] vessel arrivals in 2021 (DfT, 2022b). From the AIS derived data, the top five destinations departing from Belfast Port were: Liverpool, Heysham, Greenock, Avonmouth and Dublin.

Southampton Port[65] is capable of handling Ro-Ro, containers, dry bulk, liquid bulk and offshore vessels (Associated British Ports, 2022). This corroborates with UMAS analysis of AIS data as well as official statistics, which shows that Southampton Port handled 1,330 tankers, 3 Ro-Ro, 758 container, 1,348 dry cargo and 417 passenger[64] vessel arrivals in 2021 (DfT, 2022b). From the AIS derived data, the top origin ports arriving at Southampton were: Portland (UK), Shoreham, Portsmouth and Cowes.

Across all voyages at these two ports, Belfast mainly handles Ro-Ro and dry cargo, with Southampton handling tankers and dry cargo in terms of the number of vessels serviced.

8.3.2 Competing options to the direct UK domestic maritime route

Next, potential indirect maritime routes via different ports and modes of transport are identified. Figure 19 includes a map with alternative ports that could be used to travel to Southampton. To assess whether these ports can accommodate cruise vessels, official government data, port websites and

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[63] Belfast Port combines “Belfast” and “Newtonabbey” from the AIS derived dataset together. This is to ensure as close alignment as possible with the port definitions used by DfT.

[64] Passenger vessels refer to passenger and cruise vessels. Ferry-RoPax vessels are classified under the “Ro-Ro” category.

[65] Southampton Port combines “Southampton”, “Fawley”, “Hamble”, “Itchen”, “Eling”, and “Marchwood” from the AIS derived dataset together. This is to ensure as close alignment as possible with the port definitions used by DfT.

the AIS derived data were examined. The results of this assessment are outlined in Table 21. While Rosslare and Holyhead have been identified as theoretically feasible alternative ports that can handle cruise ships, Cairnryan has been considered as a theoretically feasible alternative to accommodate a potential modal shift from cruise to Ferry-RoPax.[66]

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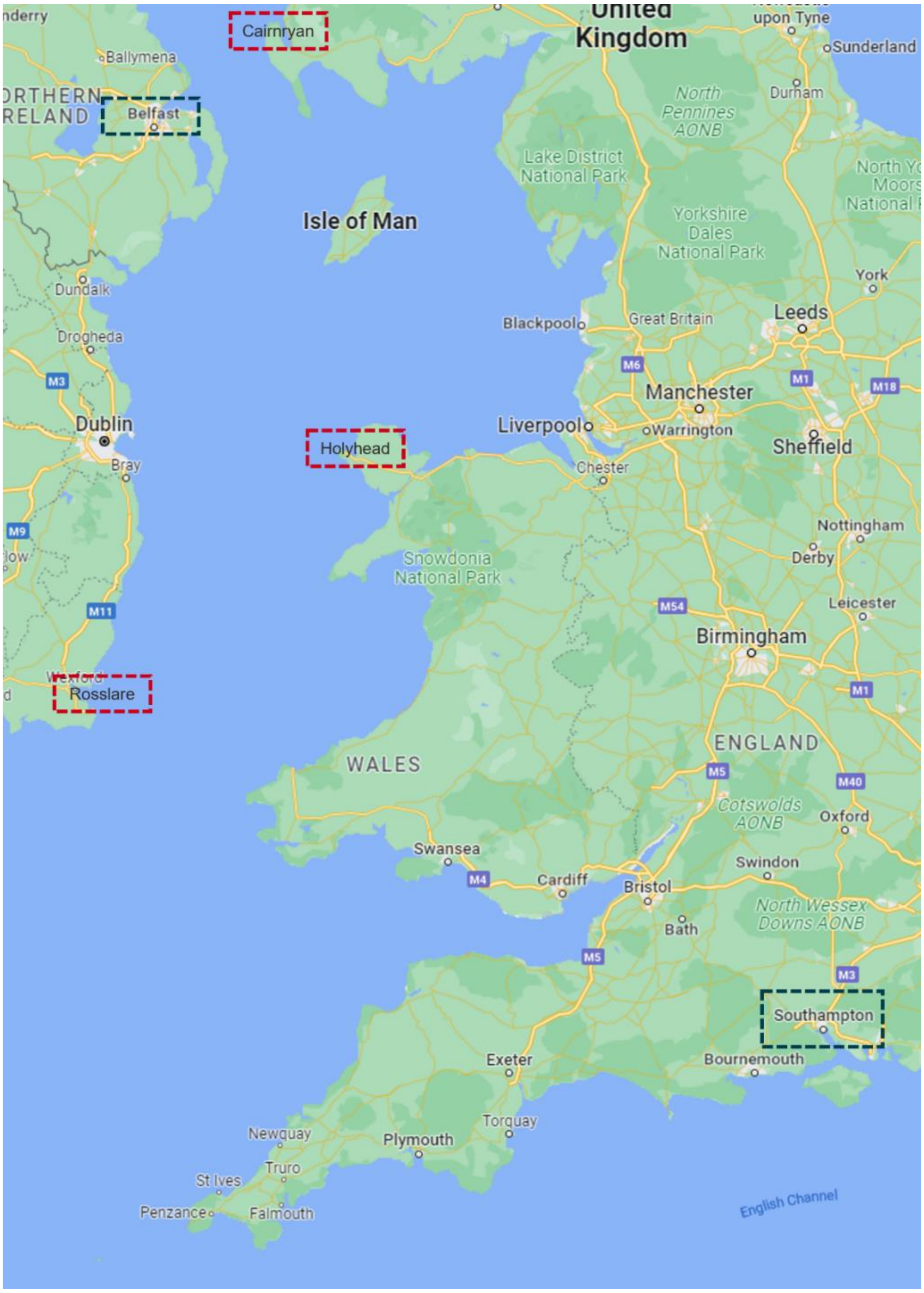
[66] By saying switching to Ferry-RoPax is a *possible* alternative, this is not to say that it is a *feasible* alternative, as this section is merely looking into possible indirect routes. The discussion of the feasibility of routes is later in this section.

Figure 19 Options for alternative ports to Southampton



Source: Google Maps

Table 21 Options for alternative ports to Southampton

Ports	Country	UMAS analysis of AIS Data	Port Websites	Official Statistics
Rosslare	Republic of Ireland	This port did not handle cruise vessels in 2021.	This port handles Ro-Ro, RoPax, offshore, dry bulk and general cargo. (Rosslare Europort, 2022a). It also has cruise terminal facilities (Rosslare Europort, 2022b).	Not included in a dataset of cruise ship handling ports suggesting no significant activity at this port (Central Statistics Office, 2022).
Cairnryan	Great Britain	This port did not handle cruise vessels in 2021 (only Ferry-RoPax).	This port handles Ro-Ro, Ferry-RoPax and General Cargo (Port of Larne, 2022) (MarineTraffic, 2022d).	This port handled 2,090 Ro-Ro and 2 dry cargo vessel arrivals in 2021 (DfT, 2022b).
Holyhead	Great Britain	This port handled cruise vessels in 2021.	This port handles Ro-Ro, Ro-Pax, cruise, tankers, bulk, fishing and military support vessels (Holyhead Port Authority, 2022).	This port handled 46 tankers, 2,845 Ro-Ro and 9 passenger vessel arrivals in 2021 (DfT, 2022b).

Having identified potential alternative ports, a total of four options for theoretically feasible indirect routes were identified and assessed. A summary of the results is outlined in Table 22, split into operator and customer responses. Further details on each of these indirect routes are outlined in Annex B .

Table 22 Summary of indirect routes from Belfast to Southampton

Route Type	Route	Time Estimate*	Feasible alternative route?
Direct	Belfast to Southampton	Total: 38hr journey time	N/A
Indirect (Operator response)	(1) Belfast to Rosslare to Southampton (all maritime)	Belfast to Rosslare to Southampton (no time estimate available for the additional stop at Rosslare, although it is unlikely to be significant relative to the entire journey)	Potentially feasible: As Rosslare is capable of accommodating cruise vessels, this could be a potential evasive port call as this would render all emissions on the journey as 'international' and outside of the UK ETS.
	(2) Belfast to Holyhead (maritime) to Southampton (rail/road)	Belfast to Holyhead (no time estimate available for cruise ships) Holyhead to Southampton via road or rail (c5 hrs)	Unlikely to be feasible: Customers take cruises for the experience of being on the cruise-liner and would have no need to go to Southampton if the cruise ship did not start/end there and instead started/ended at Holyhead. The end-to-end

Route Type	Route	Time Estimate*	Feasible alternative route?
			journey would be affected, depending on where they live.
Indirect (Customer response)	(3) Belfast to Cairnryan (maritime) to Southampton (rail/road)	Belfast to Cairnryan via Ferry-RoPax (2 hr 22 min) Cairnryan to Southampton via road (7 hr 47 min) or rail + bus (10hr 7 min) **Total: 10 hr 9 min**	Unlikely to be feasible: While switching from a cruise to Ferry-RoPax and then driving to Southampton is possible, customers take cruises for the experience and not to deliberately include Southampton within their journey. So, this is not likely.
	(4) Belfast to Southampton (air)	**Total: 1 hr 40 min** (plus check in and baggage time)	Unlikely to be feasible: Customers take cruises for the experience of being on the cruise-liner and visiting new locations and would have no need to go to Southampton if the cruise ship did not start/end there. Aviation to Southampton is therefore not likely.

Source: *Various – see Annex B for details*

Note: **Time estimates are based on port-to-port travel and do not include the extra time required for stopping and unloading (including any customs checks where relevant). The total journey time for customers will depend on the ultimate origin and destination of the cargo and/or passengers.*

From a practical perspective – not accounting for relative costs – only indirect route 1 was found to be potentially feasible. This would involve the operator undertaking an evasive port call at Rosslare in ROI to avoid paying the UK carbon price. Indirect routes 2, 3 and 4 were found to be unlikely to be feasible. This is because customers take cruises for the experience of being on the cruise-liner and visiting new locations, meaning the modal shift required for these three indirect routes renders them unlikely.

8.3.3 Qualitative assessment

Having assessed that the Belfast to Southampton journey has one theoretically feasible option for an alternative indirect route via ROI, the next step is the qualitative assessment of the risks of carbon leakage, internal carbon displacement and competitive disadvantage, as was undertaken for case studies 1 and 2. Table 23 is a repeat of the relevant elements of the vessel table in Chapter 7 and then the results of our assessment is in Table 24.

Table 23 Qualitative assessment of risk factors based on vessel archetype

Vessel archetype:	Cruise
Carbon cost exposure	Cruise vessels are relatively emissions intensive with the main abatement option involving a shift to alternative fuels. There is also a greater likelihood that customers are sensitive to issues related to pollution (compared to cargo for example), creating greater incentive to use lower carbon fuels.
Likelihood of cost pass-through	Cruise prices are typically driven less by their costs, as a large proportion of revenue comes from onboard sales. Cruise ships operate in a moderately competitive industry. This reduces the likelihood of cost pass-through.
Likelihood of a shift to substitute options	As this is passenger based, it is easier for cruise ships to change the ports they stop at (and so a greater chance of evasive port calls) or to not stop at a port but anchor off instead nearby. Modal shifts are unlikely since customers take cruises for the experience of being on the cruise-liner.
Potential degree of customer response	Cruise ships are a luxury good and so are more driven by quality than price, especially as cruise passengers tend to be relatively price inelastic.[67] If additional port calls lead to a reduction in quality, then there may be a customer response. Alternative modes for passengers include flying or using Ferry-RoPax and road to drive to their destination.

Source: Frontier Economics, based on review of evidence. See Section 7 for further details of sources.

Table 24 Qualitative assessment of the risk of carbon leakage, internal carbon displacement and competitive disadvantage

Vessel archetype:	Cruise
Risk of carbon leakage	**Low: if the 'EU ETS proposal' were in place** Although there is a theoretically feasible alternative option for an evasive port call in ROI (Rosslare), this is not likely to occur if the 'EU ETS' proposal were in place. This is because the cost advantage of an evasive port call to avoid the UK ETS is minimised if operators were still subject to a carbon price, as in the 'EU ETS proposal'. The risk is lower still if IMO introduces ambitious climate policy. If international maritime journeys into the ROI are not covered within the EU ETS, then the risk of carbon leakage could be high.
Risk of internal carbon displacement	**Low: modal shifts are unlikely since customers take cruises for the experience of being on a cruise-liner**

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[67] This is based on expert industry-specific knowledge gathered as part of writing this report.

	While there are several theoretically feasible alternative routes that customers could take that could lead to a risk of internal carbon displacement (e.g. using road or non-electrified rail in GB which are not included in the UK ETS), customers take cruises for the experience of being on the cruise-liner and would have no need to go to Southampton if the cruise ship did not start/end there. If passengers choose to fly directly from Belfast to Southampton, there is a lower risk of internal carbon displacement as aviation is included in the UK ETS.
Risk of competitive disadvantage	**Low: if the 'EU ETS' proposal were in place** Competing options to the direct UK domestic maritime route are not able to offer a more competitive alternative if they are covered within the EU ETS. If these options are not covered by the EU ETS, then the risk would be medium, since demand for cruises is inelastic and cruise operators compete on service rather than price.

Source: Frontier Economics

8.3.4 Indicative quantitative assessment

To complement the qualitative analysis above, we consider the potential order of magnitude of carbon prices within the UK ETS that could be associated with a particular scale of effect on shipping demand, using the same indicative 'switching analysis' as in the previous case studies.

The base case is the 'EU ETS proposal', which is Scenario 3 of the policy scenarios outlined in Section 4.2.6. This indicative analysis suggests that on the basis of the assumptions made, for there to be a 10% reduction in demand on this shipping route, the UK ETS price would need to be £189/tCO_2. For a 15% reduction in demand it would need to be £262/tCO_2 and for a 20% reduction in demand it would need to reach £335/tCO_2. As mentioned previously, there are inevitable uncertainties in this analysis and hence varying some of the assumptions (such as the responsiveness of demand, fuel prices and fuel share of voyage costs) reveals that UK ETS carbon prices would need to be higher still for these changes in demand to be observed. Furthermore, it should be noted that these estimated UK ETS allowance prices are purely hypothetical estimates and that they do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

This is shown in Table 25, which also presents results from applying alternative assumptions from those used in the base case (assuming the carbon prices are fixed across alternative policy scenarios and sensitivities, as previously explained in Section 4.2.6). The analysis suggests the following:

- a higher EU ETS price makes it less likely that the UK demand reduces because there is less incentive to switch to routes covered by the EU ETS;
- if fuel is a smaller proportion of voyage costs – 30% rather than 50% – this leads to a lower reduction in UK shipping demand because the carbon cost is equivalent to an increase in fossil fuel cost and so because this is a lower proportion of voyage costs, overall costs change by a lower amount and so does demand; and
- if price elasticity of demand is lower – -0.1 instead of -0.19 – then the reductions in UK domestic shipping demand are lower because customers are less responsive to the price change.

The estimated UK ETS prices shown in the table below represent the estimated UK allowance prices that would hypothetically be required in order for there to be 10%, 15% and 20% reductions in demand on the case study route under the base case (Scenario 3). Therefore, it should be noted that the estimated UK ETS allowance prices shown in the table below are purely hypothetical and do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

Table 25 Indicative switching analysis for cruise vessels in the Belfast to Southampton case study

Scenario	Sensitivity	Change in UK domestic Ro-Ro demand on Belfast to Southampton route for the following hypothetical estimated UK ETS prices:		
		£189/tCO$_2$	£262/tCO$_2$	£335/tCO$_2$
3	Base Case	-10%	-15%	-20%
2	High EU ETS price	-9%	-14%	-18%
4	Low EU ETS price	-11%	-17%	-22%
3	Fuel is 30% of voyage costs	-6%	-10%	-13%
3	Quartile 3 elasticity (-0.1)	-5%	-8%	-11%

Source: Frontier Economics analysis. The three EU ETS allowance price forecasts for 2030 are based on ICIS (2022) analysis and were provided by DESNZ.

Note: A full list of results across all policy scenarios is available in Annex B.

The analysis looks at other possible policy scenarios:

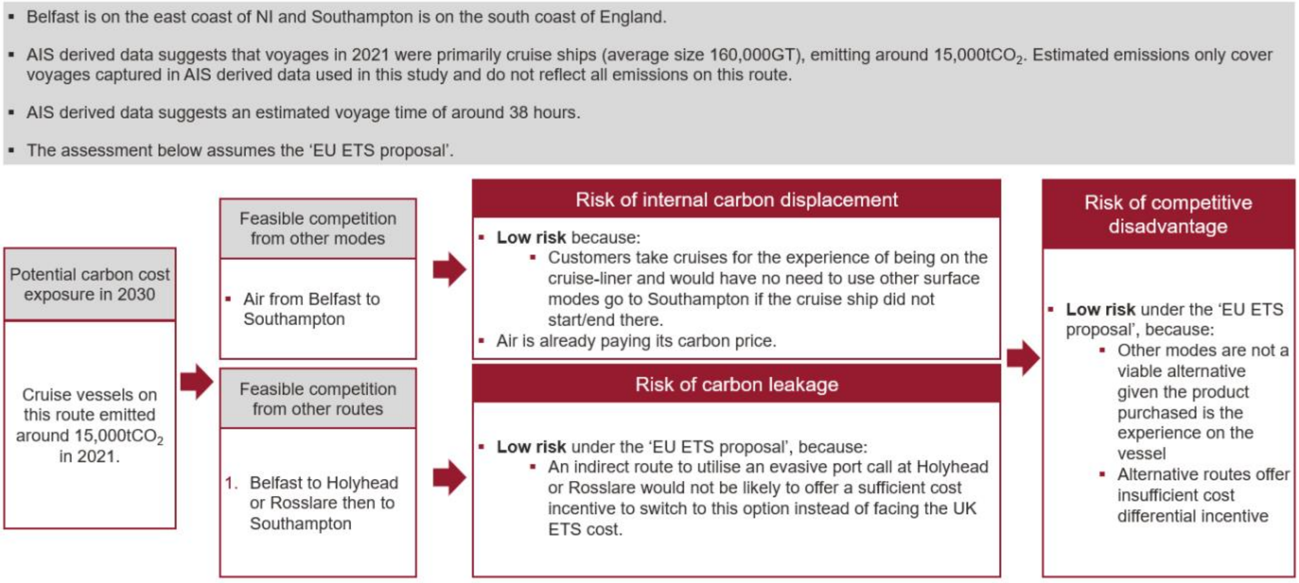
- If 100% of international maritime emissions were to be covered by the EU ETS then the reduction in UK domestic shipping demand from including domestic shipping in the UK ETS would be lower than in the base case (across all EU ETS price scenarios looked at). This is because there would be a much narrower difference in voyage costs between direct GB-NI routes and indirect routes.
- Were road transport to be included in a separate EU ETS then it would also pay its external costs of carbon, meaning that alternative transport modes involving road for moving cargo are less attractive than in the base case. Therefore reductions in domestic shipping demand from including UK domestic shipping in the UK ETS would likely be lower than in the base case.
- If maritime emissions were not covered in the EU ETS, then the reduction in UK domestic shipping demand from including domestic shipping in the UK ETS would be greater than in the base case, because indirect shipping routes could become substantially cheaper in comparison.

In the longer-term, these vessels may be able to switch their fuel to low-carbon options or abate in other ways such as air lubrication and wind assistance. Were this to be possible, then the carbon cost exposure would be less pronounced, leading to lower reductions in UK domestic shipping demand. However it is beyond the scope of this report to look into the drivers and enablers of these longer-term investments.

8.3.5 Key Findings

Taking the qualitative assessment and illustrative quantitative assessment together, a summary of the risks of carbon leakage, internal carbon displacement and competitive disadvantage is provided below for this case study.

Figure 20 Overview of Key Findings



- Belfast is on the east coast of NI and Southampton is on the south coast of England.
- AIS derived data suggests that voyages in 2021 were primarily cruise ships (average size 160,000GT), emitting around 15,000tCO_2. Estimated emissions only cover voyages captured in AIS derived data used in this study and do not reflect all emissions on this route.
- AIS derived data suggests an estimated voyage time of around 38 hours.
- The assessment below assumes the 'EU ETS proposal'.

Potential carbon cost exposure in 2030

Cruise vessels on this route emitted around 15,000tCO_2 in 2021.

Feasible competition from other modes

- Air from Belfast to Southampton

Feasible competition from other routes

1. Belfast to Holyhead or Rosslare then to Southampton

Risk of internal carbon displacement

- **Low risk** because:
  - Customers take cruises for the experience of being on the cruise-liner and would have no need to use other surface modes go to Southampton if the cruise ship did not start/end there.
- Air is already paying its carbon price.

Risk of carbon leakage

- **Low risk** under the 'EU ETS proposal', because:
  - An indirect route to utilise an evasive port call at Holyhead or Rosslare would not be likely to offer a sufficient cost incentive to switch to this option instead of facing the UK ETS cost.

Risk of competitive disadvantage

- **Low risk** under the 'EU ETS proposal', because:
  - Other modes are not a viable alternative given the product purchased is the experience on the vessel
  - Alternative routes offer insufficient cost differential incentive

Source: *Frontier Economics – the estimated emissions only cover voyages captured in the AIS derived data used in this study and do not reflect all emissions on this route.*

Carbon leakage

Overall, the potential risk of carbon leakage is considered low if the 'EU ETS proposal' were in place.

Based on the data available, it appears theoretically feasible that operators could undertake an evasive port call at Rosslare in ROI to avoid paying the UK carbon price. This is so the emissions on this journey would be considered international and therefore outside of the UK ETS. While there are several other theoretically feasible indirect routes (that also involve modal shifts), cruise customers are less likely to take these as they are relatively price inelastic and seek the experience of being on-board a cruise ship.

The indicative quantitative analysis suggests that if the 'EU ETS proposal' were in place, the potential decline in UK domestic shipping from switching to indirect routes is low. Carbon prices would need to reach £189/tCO_2 for there to be even a 10% reduction in demand and significantly higher for the reduction in demand to reach 15% or 20%. These values could be higher still, based on analysis which uses alternative assumptions. This should be compared to the £98/tCO_2 allowance price the UK ETS reached in August 2022 (Ember, 2022). If road is included in a separate EU ETS, it becomes even less likely that customers switch to indirect routes (some of which include non-electrified road transport). Furthermore, it should be noted that these estimated UK ETS allowance prices are purely hypothetical estimates and that they do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

Internal carbon displacement

Overall, the potential risk of internal carbon displacement is low. This is because cruise passengers are unlikely to switch their mode of transport as they seek the experience of being on-board a cruise ship and have no need to travel to Southampton if the cruise ship did not start/end there. For this reason, switching to either car or air travel is unlikely and in any case air travel is included in the UK ETS, so would entail a low risk of internal carbon displacement.

Competitive disadvantage[68]

Overall, there is a low risk of competitive disadvantage if the ‘EU ETS proposal’ were in place. This is because demand elasticity for cruise passengers is expected to be low as cruise operators compete primarily on quality of service rather than price. There is only a low risk of evasive port calls leading to carbon leakage, though if additional port calls reduced the quality of service, then this could impact competitiveness. The risk of internal carbon displacement is also low (as outlined above).

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[68] The assessed risk of competitive disadvantage relates to UK domestic maritime operators that operate on the direct route before and after domestic maritime shipping is included in the UK ETS

9 Summary of findings

This study has used the best available data and evidence to explore the risk of carbon leakage, internal carbon displacement and competitive disadvantage if UK domestic maritime were to be included in the UK Emissions Trading Scheme (ETS). It focuses on three particular routes between GB and NI that were identified as meriting focused analysis because of the prevalence of fossil-fuel based maritime activity and the potential for substitutes to be chosen by operators and/or customers on those routes. Although the details of how UK domestic maritime (such as the scale of vessels to be included, for example) could be included in the UK ETS are being considered, this analysis has been taken forward on the basis of the lead option identified in the Government's consultation (variations around this are considered in the narrative).

The main findings of the analysis are:

1. The carbon cost exposure on the three GB-NI routes on which this analysis focuses (Belfast to Liverpool; Heysham to Warrenpoint; and Southampton to Belfast) is likely to provide a strong incentive to accelerate decarbonisation, therefore addressing one of the key barriers to decarbonisation (Frontier et al., 2019).[69]
2. The risk of carbon leakage is considered to be low across all three GB-NI routes analysed if the 'EU ETS proposal' were in place. Including shipping in the EU ETS reduces the cost differential between the GB-NI route and other potential substitute options that would, in theory and if chosen, aim to limit exposure to the UK ETS. This risk would be even lower if the International Maritime Organization (IMO) pursues an ambitious decarbonisation policy framework for international shipping in the future. The risk of carbon leakage could therefore be higher if the 'EU ETS proposal' were not in place.
3. The risk of internal carbon displacement (which would involve shifting to modes of transport other than UK domestic maritime) is considered to be low across all three GB-NI routes analysed. This is primarily because of the limited opportunity for such shifts given the need to cross water between GB and NI.
4. The risk of competitive disadvantage is considered to be low across the three GB-NI routes considered if the 'EU ETS proposal' were in place. As with carbon leakage, this is because the cost differential with competing journey options is lower if both the UK and EU have carbon pricing mechanisms in place. The risk would therefore be higher if the 'EU ETS proposal' were not in place.
5. The assessment of risk would be different if international maritime emissions were not included in the EU ETS, as would be the case under the 'EU ETS proposal'. In such a case, the risk of carbon leakage could be high across all three case study GB-NI routes, due to the incentive to avoid the UK ETS by switching to an indirect route via the Republic of Ireland. Furthermore, there could be differential competitiveness effects associated with the 'UK ETS proposal' depending

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[69] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

on the size of operators, given the potential barriers to decarbonisation for small operators (Frontier et al., 2019)[70] and across different vessel types.

6. Indicative switching analysis suggests that a very high UK ETS allowance price[71] (far in excess of the current UK ETS allowance price) would be likely to be needed for a material reduction in UK domestic maritime demand to be observed. Although there are substantial uncertainties in the analysis, even under cautious assumptions a high allowance price would be likely to be needed. This suggests a significant change in UK domestic maritime traffic would not be likely following its inclusion in the UK ETS as per the 'UK ETS proposal'.

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[70] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/815671/identification-market-failures-other-barriers-of-commercial-deployment-of-emission-reduction-options.pdf

[71] For the purpose of this report, 'carbon price', 'allowance price' and 'ETS price' are used interchangeably. All terms refer to the amount an operator would need to pay per tonne of carbon dioxide equivalent that they emit. The same terminology is used whether discussing the UK ETS or the EU ETS.

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Annex A – Quality assurance

This annex provides detail on the quality assurance processes that have been implemented for this study. This covers both the data and modelling work. The quality assurance has been carried out in a proportionate and appropriate way. Every feasible effort has been taken to review and quality assure the inputs and results and to minimise the risk of errors. Proportionality principles have required quality assurance to be undertaken pragmatically and systematically, with greater priority and attention placed on those aspects of the modelling that have the greatest consequence for the results and findings.

A.1 Quality assurance process

Assurance process for inputs

As outlined in Chapter 4, the AIS derived data is subject to certain limitations, with the base voyage identification methodology optimised for longer voyages for global shipping routes. To validate the GB-NI case study routes, a detailed and resource intensive process was undertaken to provide a deep dive analysis. This involved developing a new voyage identification method described in Section 4 (in addition to the approach used in the 4th IMO GHG report). This was then compared with published statistics on port activity, timetables, EU MRV (where possible) and the original AIS derived dataset.

Based on this deep dive, it was determined that under some circumstances, the number of voyages could be understated. This voyage identification issue was found to occur predominantly for short journeys (<6hrs) with short port-turnaround times. For the three chosen GB-NI cases study journeys, when compared against available published activity data, only the Heysham-Warrenpoint journey required an adjustment to the total number of voyages. The rest of the statistics were found to be sufficiently accurate. Therefore, it was not necessary to explicitly account for this within the other two case study analyses.

Assurance process for analysis

The Stata software package was used to analyse the AIS derived data. This informed two main aspects of the analysis: firstly, it was used to determine the routes that would merit further analysis as GB-NI case studies, given the identification criteria described in the main report. Secondly, it was used to provide descriptive statistics about the maritime sector in the UK. The switching analysis associated with the GB-NI case study routes was carried out in Excel. Both pieces of analysis have undergone a full quality assurance process, carried out by an experienced modeller who had not been involved in the design or development of the analysis. The details of each part of the quality assurance process are described below.

Stata analysis for descriptive statistics and to determine case study routes

This quality assurance involved a line-by-line re-run of the Stata code. This re-run checked that:

- the code was running correctly without errors;
- the new datasets were being saved correctly at each stage, with the correct versions of the datasets being used at each of the different stages;
- the logic behind the code was appropriate and fit for purpose;
- the data was cleaned correctly - including the dropping of duplicate observations or editing of incorrect observations, so as not to influence the results;
- the data was manipulated correctly – including the calculation of new statistics;
- the outputs used in reported tables matched the results of the analysis;
- the code was efficient; and
- the code was clear to the reader.

This quality assurance process was carried out independently by a modeller who was not involved in the original design or development of the analysis. The results of this QA were then brought back to the wider project team to discuss. Where relevant, these discussions led to the project team updating the code and outputs accordingly until all issues that had been flagged were resolved.

Excel switching analysis

The quality assurance process involved a test of all calculations throughout the data, calculations and output sheets. These tests were recorded in a separate ‘quality assurance’ sheet in the model. These calculation checks included:

- making sure formulae were correct and used correct input cells;
- checking formulae had been applied correctly throughout relevant columns;
- spot-checking output values of certain formulae (e.g. index-match) with their input values;
- manually changing input cells to make sure output cells updated accordingly and in the correct direction;
- ensuring the logic and methodology of calculations – especially in processes of multiple steps – made sense through internal discussions and applications of economic theory; and
- linked cells updated appropriately.

The quality assurance process was carried out independently by a modeller who was not involved in the original design or development of the analysis. The results of this QA were then brought back to the wider project team to discuss. Where relevant these discussions led to the project team updating the calculations until all issues that had been flagged were resolved and the quality assurance lead was satisfied in the quality of the analysis.

Assurance process for assumptions for the switching analysis

The switching analysis is intended to be indicative only, with the aim of providing policy makers with an estimated order of magnitude of carbon price that could be associated with given scales of reduction in demand for UK domestic maritime traffic. The values of 10%, 15% and 20% were explored in this analysis as the scale of demand effects – these were selected to be illustrations for the purposes of this analysis. Assumptions used for this analysis are based on best available published literature, including evidence of the elasticities of demand (for which a sensitivity range has also been included); the proportion of operating costs accounted for by fuel (a consensus view across several sources has been taken and applied as an average, with sensitivity analysis also applied); and EU ETS allowance price forecasts (for which values are based on ICIS (2022) analysis). This approach has been validated by our academic expert advisor.

Assurance process for reporting

This report was drafted collaboratively by Frontier Economics with input and guidance from UMAS. All sections have been thoroughly reviewed by the Frontier project manager and project director. Frontier's head of public policy has also provided input on the report structure. A final proofread has also been carried out.

This report builds on an interim results deliverable which was submitted to the client. Feedback on that deliverable has been reflected in this output. In addition, written feedback on earlier drafts of this report from the client has also been incorporated into the final version.

A.2 Quality assurance statement

Reasonableness of the analysis / scope of challenge

This analysis has focused on three GB-NI case studies. These case studies were identified using transparent criteria and agreed with the client prior to analysis being carried out. The case study-specific results may not apply to other routes.

Multiple sources of published data have been used to arrive at this study's conclusions. International Maritime Organization (IMO) regulations require AIS transceivers to be fitted onboard all ships in excess of 300 gross tonnage (GT) that are engaged in international voyages, cargo ships in excess of 500GT even if not engaged in international voyages and all passenger ships irrespective of size. Although this means the AIS data does not cover all maritime vessels and is therefore subject to limitations, the data is fit for purpose because it is primarily small vessels that are not covered, and these would be below the proposed threshold for inclusion in the UK ETS under our definition of the 'UK ETS proposal'. Although the derived AIS data can only provide a partial view of total emissions from UK domestic shipping, the data was discussed with our academic expert and cross validation checks were undertaken to provide confidence that the data was appropriate for this analysis. Specifically, DfT publish port level statistics on volume of goods transported by direction. This is useful for some routes where the analysis identifies Ro-Ro activity. This cross-check indicated that the derived AIS data was consistent with the published DfT information. A comparison was also undertaken on other routes using published ferry schedules to check order of magnitude of voyage counts. Again the AIS derived data was consistent with that other public information. Finally, a comparison of emissions (by vessel type) captured in the derived AIS data to emissions included in the EU MRV data was carried out. It is difficult to draw any conclusions from comparing these datasets due to the impact of COVID-19 on both datasets. Overall, there is broad alignment across the majority of vessel types. For some vessels there are significant differences. These differences could potentially be explained by interannual variability, but without further information it is not possible to be conclusive.

The data used constitutes the best available information to address the research questions of this piece of work. The appropriateness of the dataset of shipping activity has been validated as fit for purpose for this analysis, recognising that a full inventory of shipping emissions was not needed. Rather, it provides the granular route-specific data (such as emissions, emissions intensity, vessel types) that was essential for this analysis – such detail is not available in other published data.

The results of previous peer reviewed published studies have fed directly into the modelling. Sensitivity testing has been undertaken to explore the impact of varying key parameters. Where relevant, the results of this sensitivity testing have been reported in the main body of the report.

The switching analysis undertaken is intended to be illustrative in nature rather than precise or definitive. This reduces the scope for challenge. However, as noted throughout the report the results are sensitive to a range of assumptions and parameter values. Proportionate effort has been invested in gathering evidence to inform each of these assumptions.

Given the checks described above, the AIS-derived dataset is deemed as fit for purpose in identifying UK-UK routes which manifest the factors suggesting the risk of carbon leakage, internal carbon displacement and competitive disadvantage and therefore, merit further case study analysis.

Risk of error / robustness of the analysis

This study has required the use of models to produce the required input data and to analyse that information to identify case study routes and carry out the switching analysis. It has been noted throughout that the switching analysis provides a high-level indicative estimate of the potential estimated magnitude of change in UK ETS allowance price that could be associated with a given level of change in UK domestic maritime demand. This is subject to considerable uncertainty and the precision of the results should therefore be interpreted accordingly.

The analysis of data incorporates standard modelling techniques. All individuals undertaking the data analysis were trained to Masters level in economics and have extensive experience carrying out detailed quantitative analysis. In addition, in-depth QA significantly reduces the risk of error.

Uncertainty

UK domestic maritime is a sector on which there is little published academic evidence of the elasticities of demand, business models, operating costs or route-level emissions data. This study has sought to address these gaps by using the fit-for-purpose geo-spatial data on vessel activity and triangulating data sources. There remain inevitable uncertainties in the analysis which have been transparently highlighted.

The switching analysis and the resulting UK ETS allowance prices estimated to be associated with given level of impact on UK domestic maritime demand are subject to high levels of uncertainty. To carry out this analysis, several assumptions had to be made including the proportion of voyage costs accounted for by fuel and carbon policy decisions in the UK and EU. To account for this uncertainty, multiple scenarios have been examined individually and sensitivity testing has been carried out.

The primary analysis for this study remains qualitative, the findings of which have been peer reviewed by our academic expert advisor who is an internationally recognised maritime expert.

Annex B Additional case study analysis

B.1 Case study 1: Heysham to Warrenpoint

The direct maritime route for case study 1 is from Heysham to Warrenpoint. According to the AIS derived data verified using other published sources, this route is primarily used by Ro-Ro vessels. The following provides a detailed breakdown of the potential indirect routes that could be taken by operators and/or customers if UK domestic maritime shipping is included in the UK ETS and an assessment of their feasibility. We also detail the full switching analysis results at the end of this section.

Indirect route 1

As shown in Figure 21, operators could respond by undertaking an evasive port call at Greenore (in ROI). This is to avoid paying the UK ETS carbon price, as this would be classified as an international journey (if international maritime voyages are not part of the EU ETS). Customers could then either keep their cargo (loaded in lorries) on the same vessel and travel to Warrenpoint or unload onto another vessel and travel to Warrenpoint. Based on the evidence in Table 26, it appears Greenore has accommodated Ro-Ro (and Ferry-RoPax) vessels in the past. This suggests undertaking an evasive port call may be feasible.

Figure 21 Map of indirect route 1

Source: Google Maps

Table 26 Evidence for feasibility assessment for indirect route 1

Vessel type:	**Ro-Ro**
AIS Derived Data	Heysham to Greenore (2021): data suggests there were Ro-Ro voyages in 2019 (but not 2021) Greenore to Warrenpoint (2021): data suggests there were Ferry-RoPax voyages
Greenore Port Data	**AIS derived data (2021)** This port handled Ferry-RoPax and Ro-Ro vessels in 2021 **Port website:** This port handles non-containerised cargo such as bulk and general cargo (Greenore Port, 2022). **Official statistics:** Not included in dataset of Ro-Ro and container handling ports (Central Statistics Office, 2022).
Journey Planners	Heysham to Greenore: no services published online Greenore to Warrenpoint: no services published online.

Source: Various

Indirect route 2

Customers may respond to higher prices associated with the UK ETS (assuming cost pass-through) by taking alternative routes. Figure 22 shows one indirect route that involves travelling from Heysham to Greenore and then on to Greencastle. This requires customers to keep their cargo (loaded in lorries) on the same vessel and travel to Greencastle (via ship) or to unload onto another vessel and travel to Greencastle (also via ship). Customers may do this because these voyages would be classified as international journeys and not be subject to the UK ETS carbon price. These routes may therefore have a price advantage. Based on the evidence in Table 27, while Greenore appears to be capable of accommodating Ro-Ro and the sailing time between Greenore and Greencastle is quite short (20 minutes), no Ro-Ro voyages currently exist. For this reason, this route is considered less likely to be feasible for Ro-Ro.[72] For Ferry-RoPax, there is a service currently operating between Greenore and Greencastle. This means the route is potentially feasible for this vessel type.

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[72] For example, there may be contractual constraints to establishing a new route, and it may be unclear if there is sustainable and sufficient demand for the new route to be viable.

Figure 22 Map of indirect route 2

Source: Google Maps

Table 27 Evidence for feasibility assessment for indirect route 2

	Ro-Ro
AIS Derived Data	Heysham to Greenore (2021): data suggests there were Ro-Ro voyages in 2019 (but not 2021) Greenore to Greencastle (2021): data suggests there were Ferry-RoPax voyages
Greenore Port Data	**AIS derived data (2021)** This port handled Ferry-RoPax and Ro-Ro vessels in 2021 **Port website:** This port handles non-containerised cargo such as bulk and general cargo (Greenore Port, 2022). **Official statistics:** Not included in dataset of Ro-Ro and container handling ports (Central Statistics Office, 2022).
Greencastle Port Data	**AIS derived data (2021)** This port handled Ferry-RoPax and Ro-Ro vessels in 2021 **Port website:** This port handles fishing, trawler and passenger vessels (MarineTraffic, 2022c).

	Official statistics: Not included in dataset of Ro-Ro and container handling ports (Northern Ireland Statistics and Research Agency, 2022).
Journey Planners	Heysham to Greenore: no Ro-Ro services published online Greenore and Greencastle: There is a Ferry-RoPax service (which does not transport trucks) sailing once an hour (20-minute sailing time). It operates from Feb to Oct (Carlingford Lough Ferry, 2022).

Source: Various

Indirect route 3

Alternatively, customers could travel via ship from Heysham to Greenore (with operators performing an evasive port call as per indirect route 1) and then drive to the final destination via road towards Newry (see Figure 23). Based on the evidence in Table 28, as Greenore is capable of accommodating Ro-Ro and the road trip via Newry is short (26 minutes plus loading/unloading time), this is classified as a potentially feasible alternative indirect route.

Figure 23 Map of indirect route 3

Source: Google Maps

Table 28 Evidence for feasibility assessment for indirect route 3

	Ro-Ro
AIS Derived Data	Heysham to Greenore (2021): data suggests there were Ro-Ro voyages in 2019 (but not 2021) Greenore to Warrenpoint (2021): data suggests there were Ferry-RoPax voyages
Greenore Port Data	**AIS derived data (2021)** This port handled Ferry-RoPax and Ro-Ro vessels in 2021 **Port website:** This port handles non-containerised cargo such as bulk and general cargo (Greenore Port, 2022). **Official statistics:** Not included in dataset of Ro-Ro and container handling ports (Central Statistics Office, 2022).
Journey Planners	Heysham to Greenore: no services published online Greenore to Newry: 26-minute drive, plus unloading time (Google, 2022b)

Source: Various

Indirect route 4

A fourth alternative that customers could take involves travelling from Heysham to Dublin (via maritime) and then onto Warrenpoint via maritime, road or rail (see Figure 24). Table 29 shows that there are currently Ro-Ro services running between Heysham and Dublin. The first leg of this journey is therefore feasible. For the second leg, there are currently no maritime services between Dublin and Warrenpoint, so this is unlikely to be feasible (and could take a material amount of time). There are also no rail freight operators in NI, so rail is not a feasible option either. While the drive from Dublin to Warrenpoint is feasible (given the cargo is already loaded onto lorries), the increase in total journey time of 25% is relatively material. For Ro-Ro and Ferry-RoPax cargo, which is time sensitive, this may be significant. This route is therefore considered as only potentially feasible.

Figure 24 Map of indirect route 4

Source: Google Maps

Table 29 Evidence for feasibility assessment for indirect route 4

	Ro-Ro
AIS Derived Data	Heysham to Dublin (2021): data suggests there were Ro-Ro voyages Dublin to Warrenpoint (2021): data suggests there were Ro-Ro voyages in 2019 (but not in 2021)
Dublin Port Data	**AIS derived data (2021)** This port handled Ferry-RoPax and Ro-Ro vessels in 2021 **Port website:** This port handles Ro-Ro, RoPax, container, bulk solid, bulk liquid and cruise vessels (Dublin Port Company, 2022). **Official statistics:** Included in dataset of Ro-Ro and container handling ports (Central Statistics Office, 2022).
Journey Planners	Heysham to Dublin: 1 Ro-Ro service daily, 8.5 hrs sailing time (Seatruck, 2022) Dublin to Warrenpoint (maritime): no services online Dublin to Newry (road): 1hr 33 minutes by road from Dublin to Newry (Google, 2022a). Dublin to Warrenpoint (rail): There are no rail freight operations in NI (Department for Infrastructure (NI) & Department of Transport (NI), All Island Strategic Rail Review, 2021)

Source: Various

Full results of indicative switching analysis

The estimated UK ETS prices shown in the table below represent the estimated UK allowance prices that would hypothetically be required in order for there to be 10%, 15% and 20% reductions in demand on the case study route under the base case (Scenario 3). Therefore, it should be noted that the estimated UK ETS allowance prices shown in the table below are purely hypothetical and do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

Table 30 Full indicative switching analysis results for Ro-Ro vessels in the Heysham to Warrenpoint case study

Scenario	Sensitivity	Change in UK domestic Ro-Ro demand on Heysham to Warrenpoint route for the following hypothetical estimated UK ETS prices:		
		£173/tCO_2	£238/tCO_2	£302/tCO_2
1	Today (0% in EU ETS)	-16%	-22%	-28%
2	High EU ETS price	-9%	-13%	-18%
3	**Base case**	**-10%**	**-15%**	**-20%**
4	Low EU ETS price	-12%	-17%	-22%
5	High EU ETS price and 100% of international maritime emissions in EU ETS	-4%	-8%	-11%
6	Central EU ETS price 100% of international maritime emissions in EU ETS	-6%	-10%	-14%
7	Low EU ETS price and 100% of international maritime emissions in EU ETS	-8%	-13%	-17%
8	High EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS	These scenarios are described qualitatively in Chapter 8 of the main report		
9	Central EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS			

Scenario	Sensitivity	Change in UK domestic Ro-Ro demand on Heysham to Warrenpoint route for the following hypothetical estimated UK ETS prices:		
		£173/tCO_2	£238/tCO_2	£302/tCO_2
10	Low EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS			
3	Fuel is 30% of voyage costs	-6%	-10%	-13%
3	Quartile 1 elasticity (-0.9) *(Extreme scenario presented for the purposes of illustration only)*	-47%	-71%	-95%
3	Quartile 3 elasticity (-0.1)	-5%	-8%	-11%

Source: *Frontier Economics analysis. The three EU ETS allowance price forecasts for 2030 are based on ICIS (2022) analysis and were provided by DESNZ.*

Note: *The base case is in bold.*

B.2 Case study 2: Belfast to Liverpool

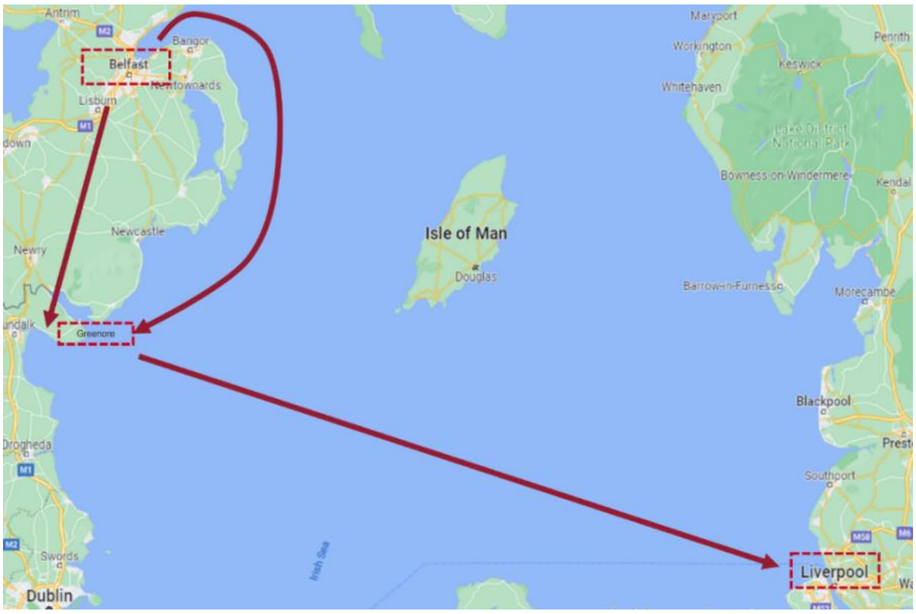
The direct maritime route for case study 2 is from Belfast to Liverpool. According to the AIS derived data verified using other published sources, this route is predominantly used by Ferry-RoPax and Ro-Ro vessels. The following provides a detailed breakdown of the potential indirect routes (summarised in Table 15) that could be taken by operators and/or customers if UK domestic maritime shipping is included in the UK ETS and an assessment of their feasibility. Overall for this route, there are limited options for operators to engage in evasive port calls to avoid paying the UK ETS carbon price. This is either because there are not currently active routes for these vessel types, or because it would add a significant amount to journey time. As such, all indirect routes show the potential responses of customers switching to alternative routes/modes. We also detail the full switching analysis results at the end of this section.

Indirect route 1

Customers may respond to higher prices associated with the UK ETS (assuming cost pass-through) by taking alternative routes. As shown in Figure 25, customers could respond by travelling from Belfast to Greenore in ROI via maritime or road (travelling by rail is not feasible since there is no rail freight in NI). Once at Greenore, customers could then board another vessel and travel to Liverpool via maritime. They may do this as maritime journeys from Greenore (ROI) would be classed as international and not subject to the UK ETS (and so may have a price advantage).

Based on the evidence in Table 31, it appears Greenore has accommodated Ferry-RoPax and Ro-Ro vessels in the past. However, there are no Ferry-RoPax or Ro-Ro services between Belfast and Greenore, or between Greenore and Liverpool. If the travel time between Greenore and Liverpool were similar to Belfast to Liverpool and Ro-Ro and Ferry-RoPax operators set up this new route, then this could be a feasible indirect route. This is because the extra time incurred travelling via road (from Belfast to Greenore) is relatively minimal.

Figure 25 Map of indirect route 1



Source: Google Maps

Table 31 Evidence for feasibility assessment for indirect route 1

Vessel Type:	Ro-Ro	Ferry-RoPax
AIS Derived Data	**Belfast – Greenore:** No Ro-Ro voyages **Greenore – Liverpool:** No Ro-Ro voyages	**Belfast – Greenore:** No Ferry-RoPax voyages **Greenore – Liverpool:** No Ferry-RoPax voyages
Greenore Port Data	**AIS derived data (2021)** This port handled Ferry-RoPax and Ro-Ro vessels in 2021 **Port website:** This port handles non-containerised cargo such as bulk and general cargo (Greenore Port, 2022) **Official statistics:** Not included in dataset of Ro-Ro and container handling ports (Central Statistics Office, 2022).	
Journey Planners	**Belfast – Greenore:** No Ro-Ro services online	**Belfast – Liverpool:**

	1 hour 9 min (Google, 2022g) drive. No rail freight in NI. **Greenore – Liverpool:** No Ro-Ro services online	Maritime distance: 193 nautical miles (Ports.com, 2022) **Belfast – Greenore:** 1 hour 9 min (Google, 2022g) drive. Passengers: no rail connections to Greenore. Freight: No rail freight in NI. Maritime distance: 102 nautical miles (Ports.com, 2022) **Greenore – Liverpool:** No RoPax services online Maritime distance: 119 nautical miles (Ports.com, 2022)

Source: Various

Indirect route 2

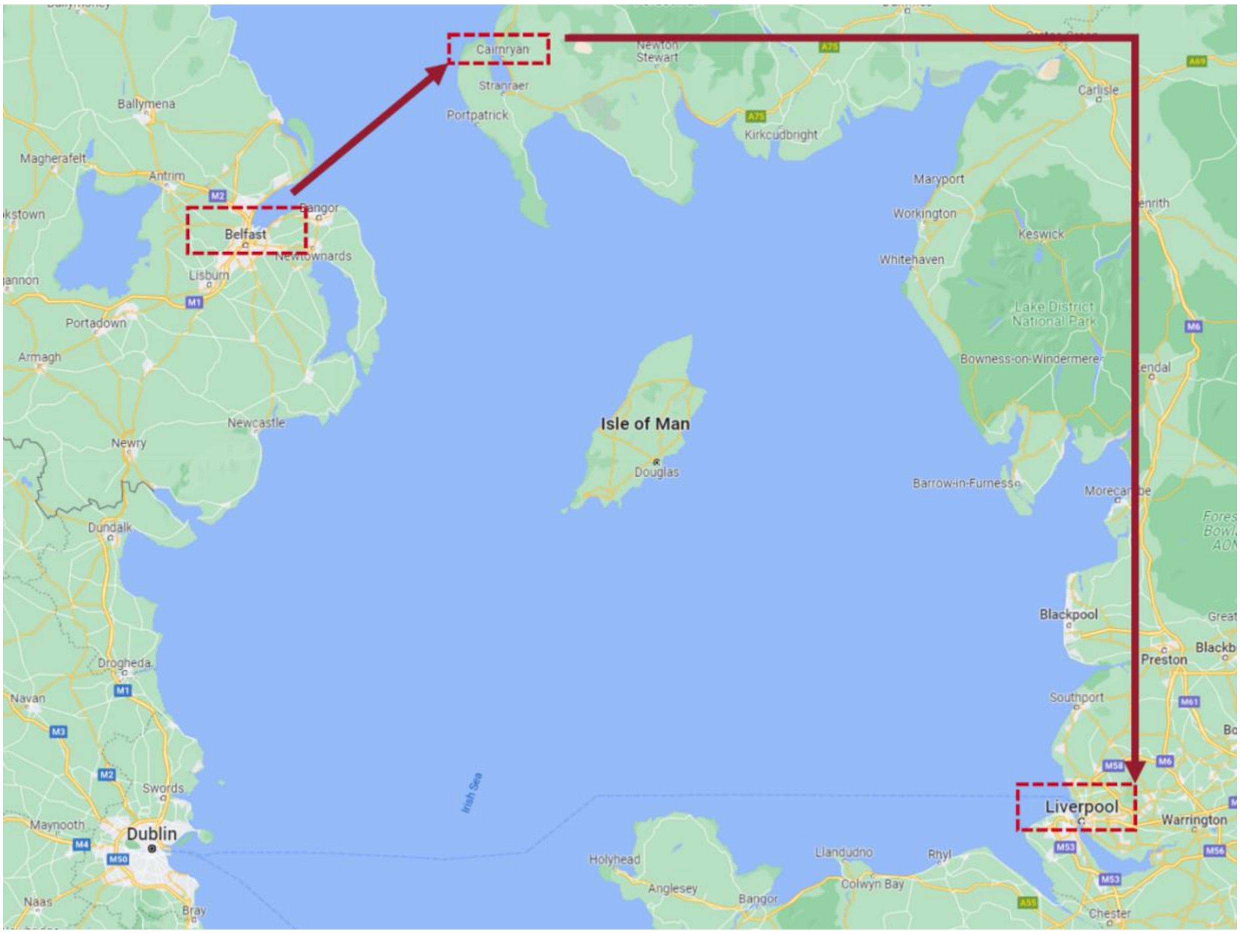
Figure 26 shows another indirect route that customers could take. This involves travelling from Belfast to Cairnryan (via ship) and then on to Liverpool (via road or rail). Customers may do this because the maritime voyage is significantly shorter than the direct Belfast-Liverpool maritime voyage, meaning it may have a lower exposure to the UK ETS carbon price (resulting in a relative price advantage).

Based on the evidence in Table 32, there is currently an established Ferry-RoPax service between Belfast and Cairnryan. The total travel time from Belfast to Liverpool on this indirect route (including travelling from Cairnryan to Liverpool via road) is 7 hours. This is similar to the direct route (8 hours), meaning this could be a feasible indirect route.

For Ro-Ro, while there is no established Ro-Ro route between Belfast and Cairnryan, the port is capable of handling Ro-Ro vessels. If operators set up a new Ro-Ro service, then this could also be a feasible route.

Travel via rail (for both passengers and freight) from Cairnryan to Liverpool does not however appear feasible. This route is therefore only considered feasible for Ferry-RoPax and Ro-Ro customers if they drive from Cairnryan to Liverpool.

Figure 26 Map of indirect route 2



Source: Google Maps

Table 32 Evidence for feasibility assessment for indirect route 2

Vessel Type:	Ro-Ro	Ferry-RoPax
AIS Derived Data	**Belfast – Cairnryan:** No Ro-Ro voyages	**Belfast – Cairnryan:** No Ferry-RoPax voyages
Cairnryan Port Data	**AIS derived data (2021)** This port handled Ferry-RoPax vessels in 2021 **Port website:** This port handles Ro-Ro, Ferry-RoPax and General Cargo (Port of Larne, 2022) (MarineTraffic, 2022d). **Official statistics:** This port handled 2,090 Ro-Ro and 2 dry cargo vessel arrivals in 2021 (DfT, 2022b).	

Journey Planners	**Belfast – Cairnryan:** No Ro-Ro services online **Cairnryan – Liverpool:** 4-hour 32 min drive (Google, 2022e) Cairnryan is not a key port in rail freight and not part of UK's key freight corridors (Network Rail, 2021). Freight will have to go north via road through Ayr or Glasgow before heading down to Liverpool via rail (MDS Transmodal, 2020).	**Belfast – Cairnryan:** 2 hours 22 min Ferry-RoPax, 6 round trips daily (Stena Line, 2022a) (£30 on foot, £119 on car) **Cairnryan – Liverpool:** Passengers and freight: 4 hours 32 min drive (Google, 2022e) No existing direct rail connections. Rail and bus: 6 hours 13 min (Bus to Inglis Way, then Rail from Girvan to Liverpool in 4 journeys) (Google, 2022e)

Source: Various

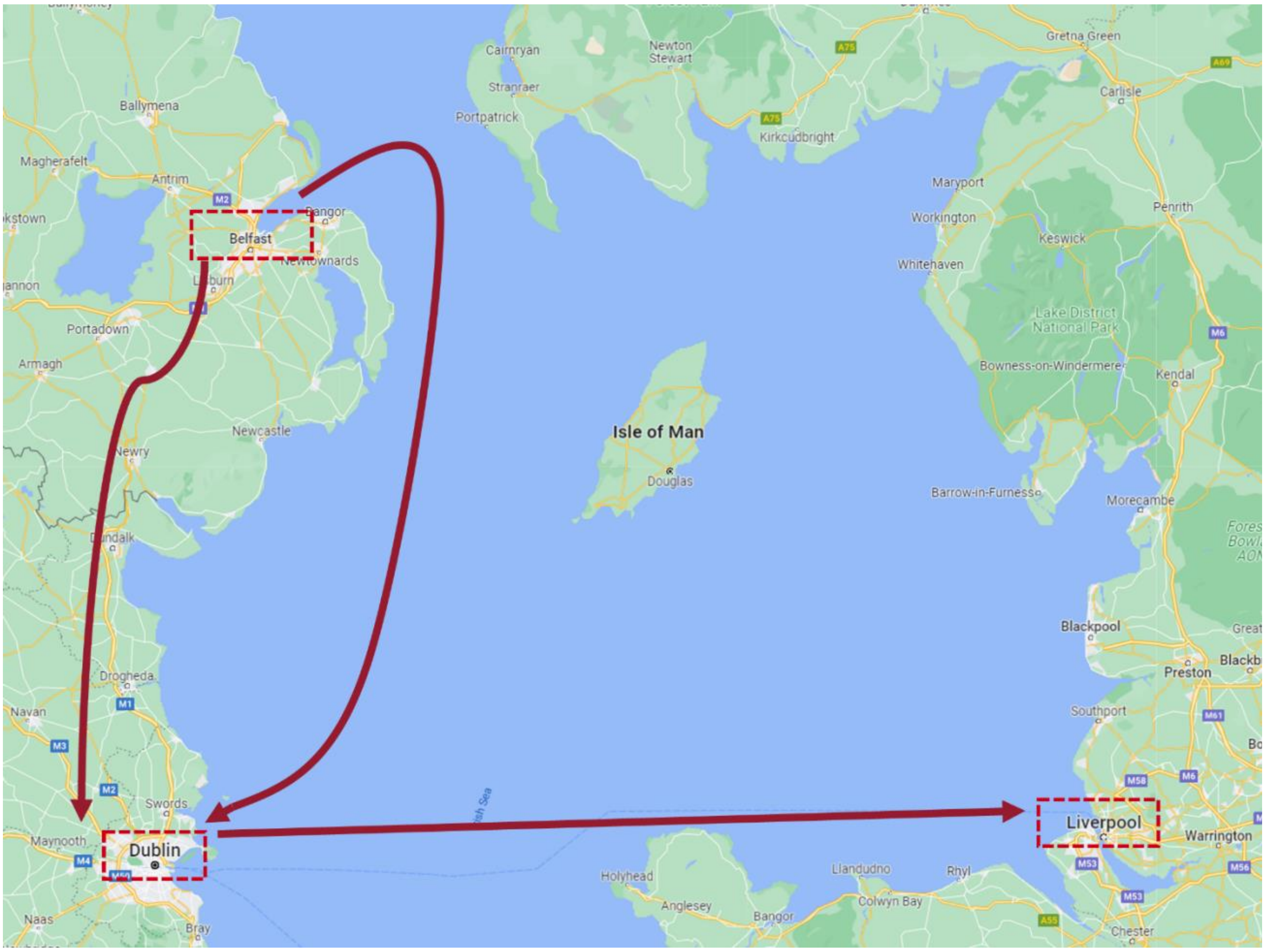
Indirect route 3

Another indirect route customers could take involves two parts. First, it involves travelling via ship, road, or rail from Belfast to Dublin. The second part involves travelling to Liverpool via ship. This is detailed in Figure 27.

For Ferry-RoPax vessels, travelling from Belfast to Dublin via rail is feasible for passengers, but not freight (see Table 33). Travelling via ship is also possible, although there are no services currently operating. Travelling via road is also possible. While there is an established Dublin to Liverpool Ferry-RoPax service that takes a similar amount of time as Belfast to Liverpool (8 hrs), the additional time to drive or take the train from Belfast to Dublin of 2hrs represents a potentially material increase in total journey time of >20%.

For Ro-Ro vessels, although there are no Ro-Ro services currently operating from Belfast to Dublin, or from Dublin to Liverpool, Dublin is a feasible port as it is capable of accommodating Ro-Ro. Travelling from Belfast to Dublin via rail is not possible for Ro-Ro customers, as there is no rail freight in NI. However, travelling via road is possible. If a Ro-Ro service from Dublin to Liverpool were established and this took a similar amount of time as the direct Belfast to Liverpool route, then travelling via road from Belfast to Dublin and taking a maritime Ro-Ro service would lead to a total travel time of 10hrs (a relatively material increase in total journey time of >20%).

Figure 27 Map of indirect route 3



Source: Google Maps

Table 33 Evidence for feasibility assessment for indirect route 3

Vessel type:	Ro-Ro	Ferry-RoPax
AIS Derived Data	**Belfast – Dublin:** Ro-Ro voyages in 2021 **Dublin – Liverpool:** Ro-Ro voyages in 2021	**Belfast – Dublin:** Ferry-RoPax voyages in 2021 **Dublin – Liverpool:** Ferry-RoPax voyages in 2021
Dublin Port Data	**AIS derived data (2021)** This port handled Ferry-RoPax and Ro-Ro vessels in 2021 **Port website:** This port handles Ro-Ro, Ferry-RoPax, container, bulk solid, bulk liquid and cruise vessels (Dublin Port Company, 2022).	

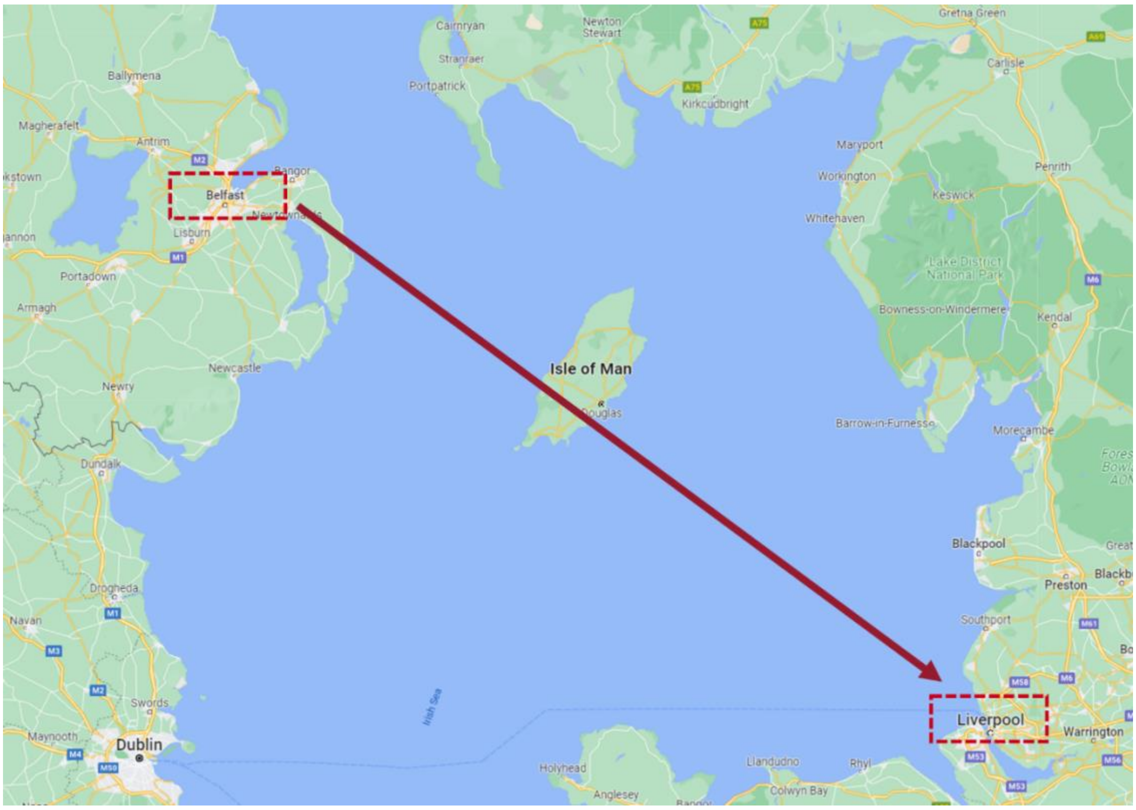
	Official statistics: Included in dataset of Ro-Ro and container handling ports (Central Statistics Office, 2022).	
Journey Planners	**Belfast – Dublin:** No Ro-Ro services online 2-hour drive (Google, 2022f) No rail freight in NI **Dublin – Liverpool:** No Ro-Ro services online	**Belfast – Dublin:** No RoPax services online 2-hour drive (Google, 2022f) Passengers: 2-hour 5 min by rail (train tickets £41) (Rail.Ninja, 2022) **Dublin – Liverpool:** 8 hours by Ferry-RoPax (P&O Ferries, 2022)

Source: Various

Indirect route 4

A fourth alternative that customers could take involves a modal shift and travelling from Belfast to Liverpool via air (Figure 28). Based on the evidence in Table 34, this is a feasible route for passengers who do not need to travel with their vehicle. For freight customers, this could also be feasible depending on the type of freight being transported, such as high value light-weight items. However, given that aviation is already in the UK ETS, this is unlikely to be a cheaper route in practice.

Figure 28 Map of indirect route 4



Source: Google Maps

Table 34 Evidence for feasibility assessment for indirect route 4

Vessel type:	Ro-Ro	Ferry-RoPax
Journey Planners	**Air freight:** Bespoke quotes and services available from different service providers, such as time-critical air cargo chartering (Air Charter Service, 2022)	**Travel by air** (Google, 2022i)**:** £30-40 Duration - 50 min 2-5 flights daily **Compared to travel by ferry** (Stena Line, 2022b)**:** £37 on foot, £129 with vehicle Duration - 8 hours 1-2 round trips daily

Source: Various

Full results of indicative switching analysis

The estimated UK ETS prices shown in the tables below represent the estimated UK allowance prices that would hypothetically be required in order for there to be 10%, 15% and 20% reductions in demand on the case study route under the base case (Scenario 3). Therefore, it should be noted that the estimated UK ETS allowance prices shown in the tables below are purely hypothetical and do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

Table 35 Full indicative switching analysis results for Ferry-RoPax vessels in the Belfast to Liverpool case study

Scenario	Sensitivity	Change in UK domestic Ferry-RoPax demand on Belfast to Liverpool route for the following hypothetical estimated UK ETS prices:		
		£180/tCO_2	£249/tCO_2	£317/tCO_2
1	Today (0% in EU ETS)	-16%	-22%	-28%
2	High EU ETS price	-9%	-13%	-18%
3	**Base case**	**-10%**	**-15%**	**-20%**
4	Low EU ETS price	-12%	-17%	-22%
5	High EU ETS price and 100% of international maritime emissions in EU ETS	-4%	-8%	-12%
6	Central EU ETS price 100% of international maritime emissions in EU ETS	-6%	-10%	-14%
7	Low EU ETS price and 100% of international maritime emissions in EU ETS	-8%	-13%	-18%
8	High EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS	These scenarios are described qualitatively in Chapter 8 of the main report		
9	Central EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS			
10	Low EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS			
3	Fuel is 30% of voyage costs	-6%	-10%	-13%

Scenario	Sensitivity	Change in UK domestic Ferry-RoPax demand on Belfast to Liverpool route for the following hypothetical estimated UK ETS prices:		
		£180/tCO₂	£249/tCO₂	£317/tCO₂
3	Quartile 1 elasticity (-0.9) *(Extreme scenario presented for the purposes of illustration only)*	-47%	-71%	-95%
3	Quartile 3 elasticity (-0.1)	-5%	-8%	-11%

Source: *Frontier Economics analysis. The three EU ETS allowance price forecasts for 2030 are based on ICIS (2022) analysis and were provided by DESNZ.*

Note: *The base case is in bold*

Table 36 Full indicative switching analysis results for Ro-Ro vessels in the Belfast to Liverpool case study

Scenario	Sensitivity	Change in UK domestic Ro-Ro demand on Belfast to Liverpool route for the following hypothetical estimated UK ETS prices:		
		£169/tCO₂	£232/tCO₂	£295/tCO₂
1	Today (0% in EU ETS)	-16%	-23%	-29%
2	High EU ETS price	-9%	-13%	-18%
3	**Base case**	**-10%**	**-15%**	**-20%**
4	Low EU ETS price	-12%	-17%	-22%
5	High EU ETS price and 100% of international maritime emissions in EU ETS	-3%	-7%	-11%
6	Central EU ETS price 100% of international maritime emissions in EU ETS	-6%	-10%	-14%
7	Low EU ETS price and 100% of international maritime emissions in EU ETS	-8%	-13%	-17%
8	High EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS	These scenarios are described qualitatively in Chapter 8 of the main report		

Scenario	Sensitivity	Change in UK domestic Ferry-RoPax demand on Belfast to Liverpool route for the following hypothetical estimated UK ETS prices:		
		£169/tCO_2	£232/tCO_2	£295/tCO_2
9	Central EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS			
10	Low EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS			
3	Fuel is 30% of voyage costs	-6%	-10%	-13%
3	Quartile 1 elasticity (-0.9) *(Extreme scenario presented for the purposes of illustration only)*	-47%	-71%	-95%
3	Quartile 3 elasticity (-0.1)	-5%	-8%	-11%

Source: Frontier Economics analysis. The three EU ETS allowance price forecasts for 2030 are based on ICIS (2022) analysis and were provided by DESNZ.

Note: The base case is in bold

B.3 Case study 3: Belfast to Southampton

The original direct maritime route for case study 3 is from Belfast to Southampton. This route is composed of mainly cruise vessels. The following provides a detailed breakdown of the potential indirect routes (summarised in Table 22) that could be taken by operators and/or customers if UK domestic maritime shipping is included in the UK ETS. We also detail the full switching analysis results at the end of this section.

In 2021, the COVID-19 pandemic meant that international cruises were likely substituted for domestic cruises (McGillivray, 2021). In order to understand what a representative year may look like, for voyages captured in AIS derived data used in this study, summary statistics for this route in 2019 were also analysed and presented in Table 37. Compared to 2021, for voyages captured in the AIS derived data, cruise ships in 2019 still formed the bulk of emissions on this route. However, for voyages captured in the AIS derived data, total CO_2 emitted is significantly less. This is due to far fewer cruises taking place between Belfast and Southampton in 2019 than in 2021.

Table 37 Belfast to Southampton route summary statistics for voyages captured in AIS derived data (2019)

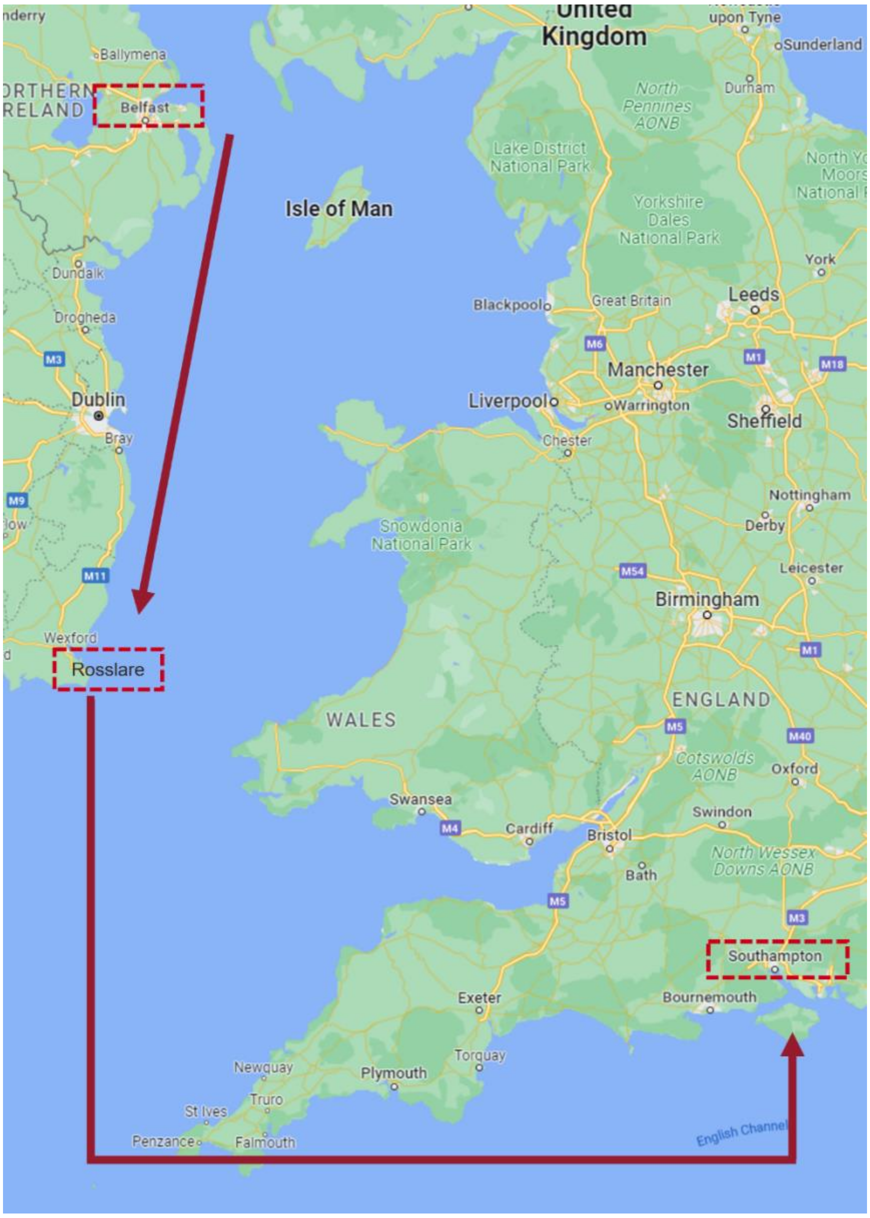
Ship Type	Total CO_2 emitted (t)	Average emissions intensity (tCO_2/nm)	Median distance travelled (nm)	Median voyage duration (hours)	Average ship size (GT)
Cruise	1,600	1.02	526	33	103,000
Liquefied gas tanker	370	0.30	618	153	4,250
Bulk carrier	130	0.25	536	88	33,000
General cargo	40	0.08	488	48	3,000

Source: AIS derived data used in this study. The estimates only cover voyages captured in the AIS derived data used in this study and do not reflect all voyages on this route.

Indirect route 1

As shown in Figure 29, operators could respond by undertaking an evasive port call at Rosslare (in ROI), then continuing onwards to Southampton. This is to avoid paying the UK ETS carbon price, as this would be classified as an international journey. Based on the evidence in Table 38, Rosslare is able to accommodate cruise vessels. For this reason, this could be a potential indirect route.

Figure 29 Map of indirect route 1



Source: Google Maps

Table 38 Evidence for feasibility assessment for indirect route 1

Vessel type:	**Cruise**
AIS Derived Data	Belfast to Rosslare: data suggests there were no cruise voyages Rosslare to Southampton: data suggests there were no cruise voyages
Rosslare Port Data	**AIS derived data (2021)** This port did not handle cruise vessels in 2021 **Port website:** This port handles Ro-Ro, Ferry-RoPax, offshore, dry bulk and general cargo vessels (Rosslare Europort, 2022a). It also has cruise terminal facilities (Rosslare Europort, 2022b). **Official statistics:** Not included in dataset of cruise ship handling ports[73] (Central Statistics Office, 2022).
Journey Planners	No journey planner data on this route Belfast to Rosslare maritime distance: 243nm (Ports.com, 2022) Rosslare to Southampton maritime distance: 367nm (Ports.com, 2022)

Source: Various

Indirect route 2

Alternatively, cruise operators could shorten their route by travelling from Belfast to Holyhead (via ship) to reduce the carbon costs incurred. Customers could then choose to travel via road or rail to Southampton. This is shown in Figure 30. Based on the evidence in Table 39, Holyhead appears to be capable of accommodating cruise ships. While this indirect route is feasible, customers take cruises for the experience of being on the cruise-liner and would have no need to go to Southampton if the cruise ship did not start/end there and instead started/ended at Holyhead. Thus, this route is considered unlikely to be feasible.

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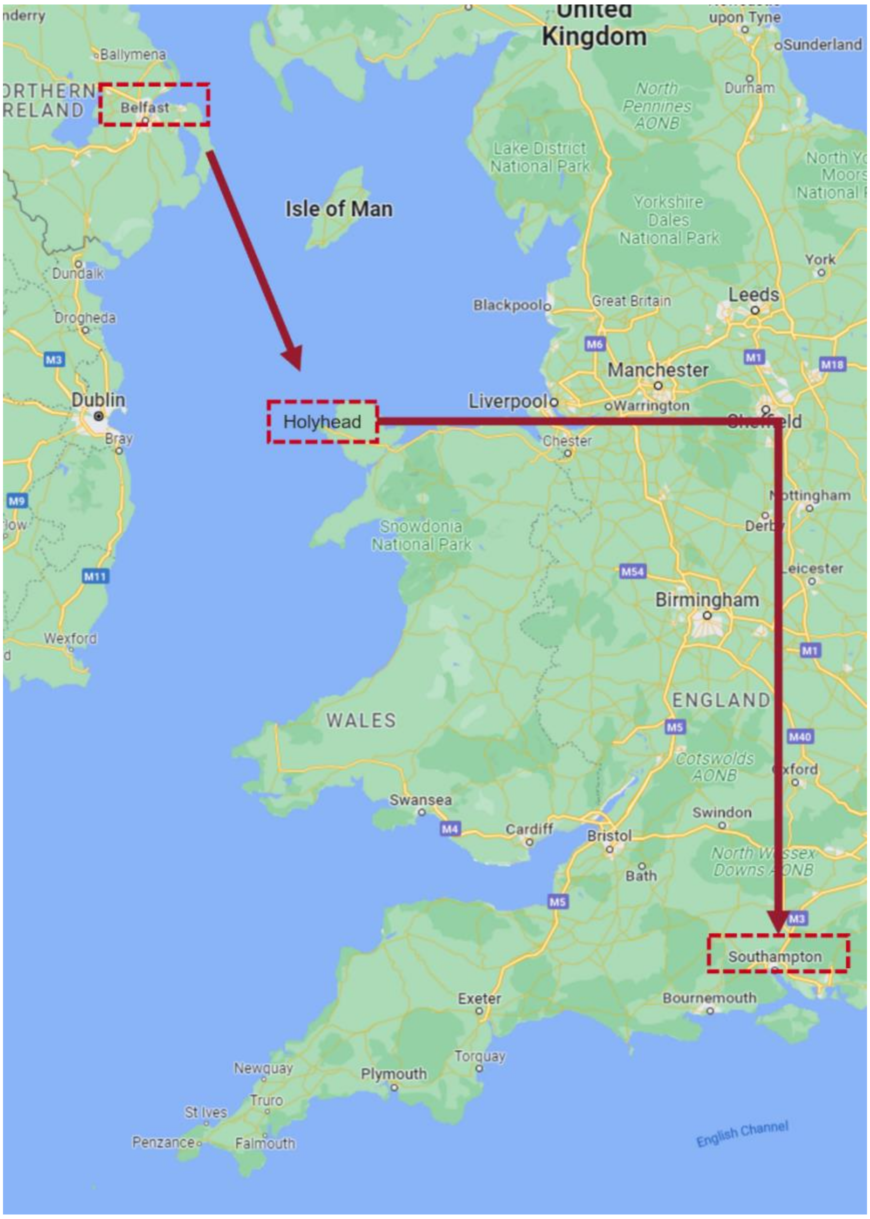
[73] This dataset is only updated till 2019 for cruise ships.

Figure 30 Map of indirect route 2



Source: Google Maps

Table 39 Evidence for feasibility assessment for indirect route 2

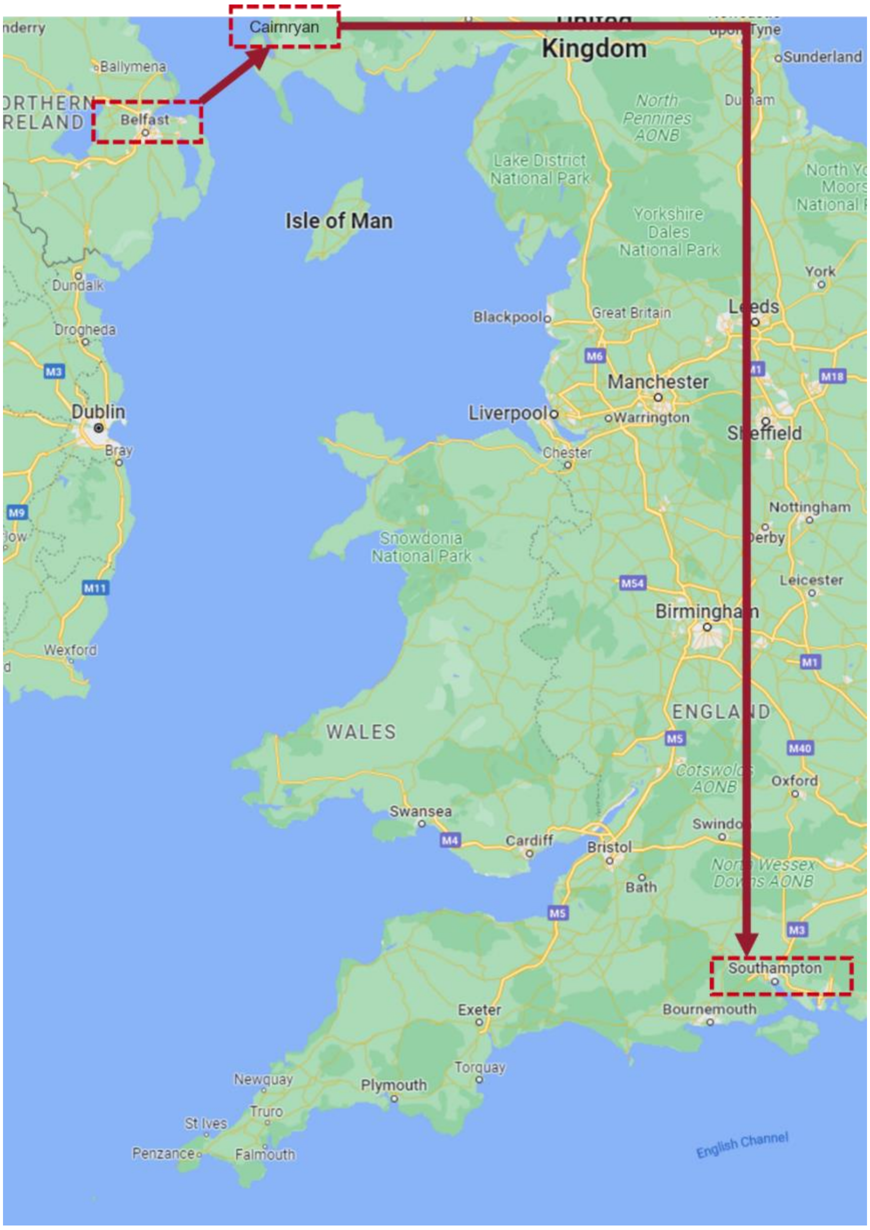
Vessel type:	**Cruise**
AIS Derived Data	Belfast to Holyhead (2021): data suggests there were cruise voyages in 2021
Holyhead Port Data	**AIS derived data (2021)** This port handled cruise vessels in 2021 **Port website:** This port handles Ro-Ro, Ferry-RoPax, cruise, tankers, bulk, fishing and military support vessels (Holyhead Port Authority, 2022). **Official statistics:** This port handled 46 tankers, 2,845 Ro-Ro and 9 passenger vessel arrivals in 2021 (DfT, 2022b).
Journey Planners	Holyhead to Southampton: 5h 11min via road (Google, 2022h) Holyhead to Southampton: 5h 32min via rail (3 rail journeys from Holyhead – Euston – Waterloo –Southampton Central) (Google, 2022h)

Source: Various

Indirect route 3

Alternatively, customers could travel via ship from Belfast to Cairnryan, then travel to Southampton via rail or road (Figure 31). While Cairnryan did not handle cruises in 2021 (Table 40), customers could choose to take a Ferry-RoPax from Belfast to Cairnryan and then drive or take a train down to Southampton. While this is possible, customers take cruises for the experience and not to deliberately include Southampton within their journey, so this is not a potentially feasible indirect route.

Figure 31 Map of indirect route 3



Source: Google Maps

Table 40 Evidence for feasibility assessment for indirect route 3

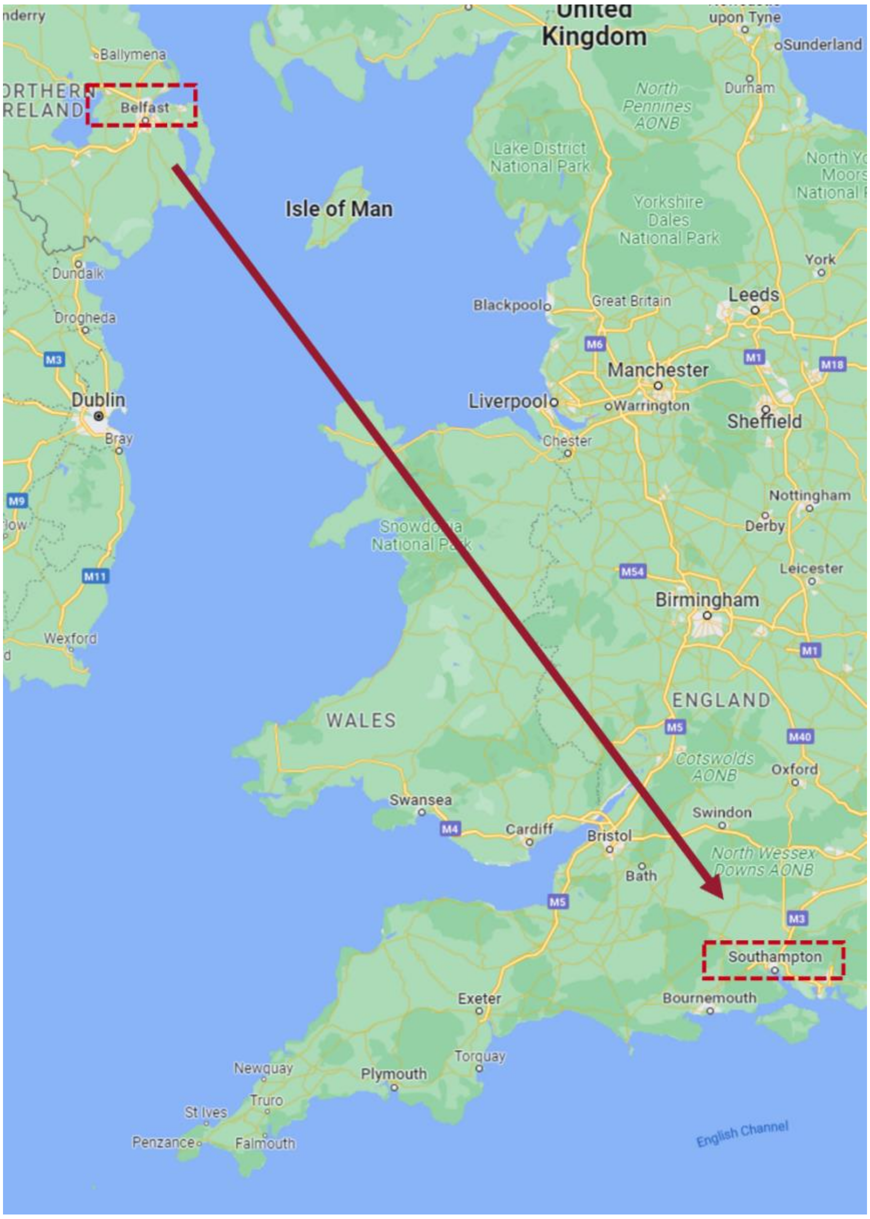
Vessel type:	**Cruise**
AIS Derived Data	Belfast to Cairnryan: data suggests there were no cruise voyages between Belfast and Cairnryan
Cairnryan Port Data	**AIS derived data (2021)** This port did not handle cruise vessels in 2021 **Port website:** This port handles Ro-Ro, Ferry-RoPax and General Cargo (Port of Larne, 2022) (MarineTraffic, 2022d). **Official statistics:** This port handled 2,090 Ro-Ro and 2 dry cargo vessel arrivals in 2021 (DfT, 2022b).
Journey Planners	Belfast to Cairnryan: 2-hour 22 min Ferry-RoPax, 6 round trips daily (Stena Line, 2022a) (£30 on foot, £119 including a car) Cairnryan to Southampton: 7h 40min via road (Google, 2022d) Cairnryan to Southampton: 10h 7min via rail and bus (2 bus journeys to Dumfries followed by 4 rail journeys to Southampton) (Google, 2022d)

Source: Various

Indirect route 4

A fourth alternative indirect route that customers could take involves travelling from Belfast to Southampton via air (Figure 32). According to journey planners, this would take 1hr 40mins and there are 2 flights daily (Google, 2022c). However, customers take cruises for the experience of being on the cruise-liner and visiting new locations and would have no need to go to Southampton if the cruise ship did not start/end there. A modal switch to aviation in order to travel to Southampton is therefore not likely.

Figure 32 Map of indirect route 4



Source: Google Maps

Full results of indicative switching analysis

The estimated UK ETS prices shown in the table below represent the estimated UK allowance prices that would hypothetically be required in order for there to be 10%, 15% and 20% reductions in demand on the case study route under the base case (Scenario 3). Therefore, it should be noted that the estimated UK ETS allowance prices shown in the table below are purely hypothetical and do not represent forecasts or projections of the future UK ETS prices that will be experienced in practice.

Table 41 Full indicative switching analysis results for cruise vessels in the Belfast to Southampton case study

Scenario	Sensitivity	Change in UK domestic cruise demand on Belfast to Southampton route for the following hypothetical estimated UK ETS prices:		
		£189/tCO$_2$	£262/tCO$_2$	£335/tCO$_2$
1	Today (0% in EU ETS)	-15%	-21%	-27%
2	High EU ETS price	-9%	-14%	-18%
3	**Base case**	**-10%**	**-15%**	**-20%**
4	Low EU ETS price	-11%	-17%	-22%
5	High EU ETS price and 100% of international maritime emissions in EU ETS	-4%	-8%	-12%
6	Central EU ETS price 100% of international maritime emissions in EU ETS	-6%	-10%	-15%
7	Low EU ETS price and 100% of international maritime emissions in EU ETS	-8%	-13%	-18%
8	High EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS	These scenarios are described qualitatively in Chapter 8 of the main report		
9	Central EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS			
10	Low EU ETS price, 50% of international maritime emissions in EU ETS and road in separate EU ETS			
3	Fuel is 30% of voyage costs	-6%	-10%	-13%
3	Quartile 1 elasticity (-0.9). ***Extreme scenario presented***	-47%	-71%	-95%

Scenario	Sensitivity	Change in UK domestic cruise demand on Belfast to Southampton route for the following hypothetical estimated UK ETS prices:		
		£189/tCO_2	£262/tCO_2	£335/tCO_2
	for the purposes of illustration only			
3	Quartile 3 elasticity (-0.1)	-5%	-8%	-11%

Source: *Frontier Economics analysis. The three EU ETS allowance price forecasts for 2030 are based on ICIS (2022) analysis and were provided by DESNZ.*

Note: *The base case is in bold*

B.4 Impact on operating costs under different carbon prices

In the main body we state the carbon cost exposure of the different case studies. This is expressed as the percentage increase in voyage costs from a carbon price that is equal to the forecasted EU ETS price. We have used three scenarios of the EU ETS price and present a range of carbon cost exposure depending on whether fuel accounts for 30% or 50% of voyage costs. As is the case for the other estimates included in the report, these estimates are subject to uncertainty and are sensitive to the assumptions made and data sources used in this analysis.

Table 42 Carbon cost exposure

Carbon price scenario	Low	Central	High
Carbon price (£/tCO_2), 2021 prices	£61	£87	£112
Estimated indicative increase in voyage costs from the carbon price:			
Heysham – Warrenpoint (Ro-Ro)	18-30%	26-43%	33-56%
Belfast – Liverpool (Ferry-RoPax)	17-28%	24-40%	31-52%
Belfast – Liverpool (Ro-Ro)	19-31%	27-45%	35-58%
Belfast – Southampton (Cruise)	16-26%	22-37%	29-48%

Source: *Frontier Economics. The assumed carbon prices are based on the ICIS EU ETS price forecasts for 2030, converted to pound sterling. The estimates shown in this table assume, based on academic literature, that fuel costs are 30-50% of voyage costs on average.*

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