OPTIONS FOR EXTENDING THE NORTH SEA SHIPPING EMISSIONS CONTROL AREA

A Report for the Department for Transport

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This is a slightly updated version of a report that was produced in 2019. The cost-benefit analysis in the report was completed in 2019. It therefore reflects the evidence that was available, and the appraisal guidance that was in place, at the time the analysis was completed. The policy options assessed in the report are purely illustrative and do not represent current Government policy.

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1 EXECUTIVE SUMMARY

The shipping industry is critical for the UK's trade in goods. Around 95% of British imports and exports in goods are moved by sea, including 25% of the UK's energy supply and almost half of the country's food supplies (DfT, 2019a[1]). The UK port sector is the second largest in the European Union, handling around 5% of the world's total maritime freight transport at some point in its journey (DfT, 2019a).

To undertake this scale of activity, ships require a substantial volume of fuel. The current reliance on fossil fuels, however, has consequences for the environment and health due to the associated emissions. These include nitrogen oxides (NOx), sulphur dioxide (SO_2), particulate matter ($PM_{2.5}$ & PM_{10}), volatile organic compounds (VOCs) and ammonia (NH_3). In 2020, UK domestic shipping alone accounted for 12% of the UK's total domestic NOx emissions, 2% of the UK's total domestic primary $PM_{2.5}$ emissions and 4% of the UK's total domestic SO_2 emissions.[2]

Globally, air pollution from shipping is regulated by the International Maritime Organization (IMO) through the International Convention for the Prevention of Pollution from Ships (MARPOL). Annex VI of MARPOL entered into force in 2005, with, among other things, the aim of minimising airborne emissions from ships. There are currently limited additional regulations or policies in the UK specifically to incentivise reductions of emissions to air from shipping.

The main international limits on emissions to air of pollutants from shipping are through the North Sea emissions control area (ECA) in which a sulphur cap of 0.1% was introduced in 2015 (a ten-fold reduction from the 1% limit introduced in 2010); and in 2008, Member States at the IMO agreed to a 0.5% sulphur limit for global shipping outside ECAs from 2020.[3] There are also global limits on the NOx emissions from shipping, which affects ships as a function of their build year. Ships operating in the ECA will also be required to meet more stringent limits on NOx emissions (Tier III), if they are built after 2021.

This report considers what the potential impacts, costs and benefits could be of extending the North Sea ECA beyond its current geographical limits in order to further reduce emissions to air of pollutants from shipping. Three illustrative extension options are considered with a view to informing policy makers about the option most likely to be worth exploring in more detail.

The three options are:

- Policy Option 1: Extending the North Sea ECA to include all major ports in England not covered by the current ECA from 1st January 2021;

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[1] DfT (2019a) Maritime 2050 Navigating the Future. Available at: https://www.gov.uk/government/publications/maritime-2050-navigating-the-future

[2] Department for Transport statistics. ENV0301: Air pollutant emissions by transport mode: United Kingdom. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1112230/env0301.ods

[3] The 2020 date was subject to an IMO led review on fuel availability and was confirmed in 2016.

- Policy Option 2: Extending the North Sea ECA to include all of the UK territorial waters from 1st January 2021; and
- Policy Option 3: Extending the North Sea ECA to include the Irish Sea and down to the English Channel (including the Isle of Ouessant but not going South to the Biscay Bay) from 1st January 2026.

In line with best practice cost-benefit analysis, and as advocated in the Green Book (HMT, 2018[4]), the options have all been assessed against the outcomes that would be likely in the absence of the interventions. This is called the 'business as usual' case.

It should be noted that the options differ in terms of both the spatial scale of their coverage, and the time period over which they are assumed to be in operation. For these reasons, the business as usual case is specific to each option and only the impacts on ships operating within the spatial areas of the respective ECA extensions of each policy option are considered.

The actions that ship owners and operators are permitted to take within the analysis to comply with the emissions regulations imposed within the new ECAs are as follows.

Compliance with the ECA sulphur limit:

- If ships are using fuel oil and do not already have a sulphur scrubber fitted, under the business as usual case, including if they are expected to be using 0.5% compliant low sulphur fuel oil, then when operating in the extended ECA they are expected to switch to Marine Diesel Oil (MDO) to comply with the 0.1% limit. This has the impact of increasing the operating costs to the relevant ship owners and operators. For ships not using fuel oil (e.g. using MDO or liquefied natural gas (LNG)), these ships will already be in compliance and therefore they are assumed to continue to use the same fuel when operating in the extended ECA. If the ship is specified in the business as usual scenario as already having a sulphur scrubber fitted, then the ship is assumed to continue to use high sulphur fuel when operating in the extended ECA, with the scrubber used to reach the compliance limit.

Compliance with the ECA NOx limit:

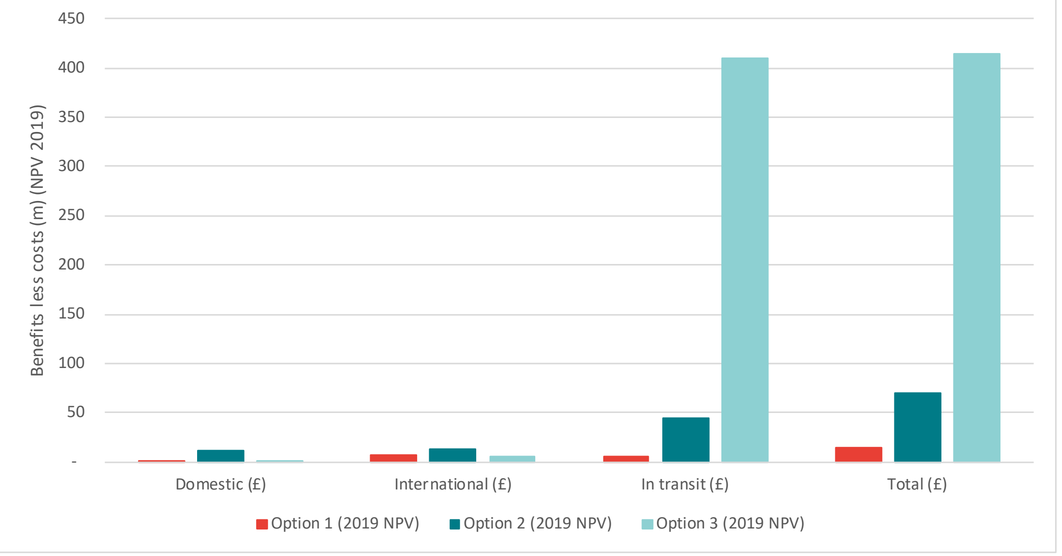
- Compliance is only required for newbuild ships that are required to meet the Tier III NOx limit (e.g. ships built after 2021). It is assumed, given expectations of interoperability between coasts of the UK, that ships that need to be Tier III compliant will already have a Selective Catalytic Reduction system (or equivalent Tier III compliant machinery) fitted under the business as usual case. They will therefore just be required to operate it in the extended ECA.

Of the three extension options considered, Option 3 is estimated to deliver the largest Net Present Value (NPV) to the UK (defined as the excess of benefits over costs, discounted) of all options in absolute terms: around £414.7 million over the

[4] HM Treasury (2018) The Green Book: Central Government Guidance on Appraisal and Evaluation. Available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf

10-year period (discounted to 2019, in 2017 prices). Option 2 is estimated to have an NPV to the UK of around £70.2 million, and Option 1 – which covers the smallest spatial area – is estimated to have an NPV to the UK of around £14.3 million. The key results are shown in Figure 1.

Figure 1 Net present values of the three ECA policy options



Source: Frontier analysis of UMAS GloTraM modelling

Note: Values are shown over the ten-year period of the policy discounted to 2019 in 2017 prices.

The key figures are shown in Figure 2.

Figure 2 Net present values of the three ECA extension policy options, discounted to 2019 (2017 prices)

	UK domestic (£m)	UK international (£m)	In-transit (£m)	Total (£m)
Option 1	1.7	6.6	6.0	14.3
Option 2	12.1	13.7	44.5	70.2
Option 3	0.1	5.1	409.4	414.7

Source: Frontier analysis of UMAS GloTraM modelling

Note: Figures are rounded. For UK domestic shipping, the costs and benefits included relate to changes in fuel, emissions to air of pollutants[5] and GHGs; for UK international shipping, these are as per domestic but excluding the monetary value of changes in GHGs (because they do not contribute to UK carbon budgets); and for in-transit shipping, only the benefits of lower emissions to air of pollutants are included (i.e. no monetary values of the changes in GHGs or fuel are included).

Other key observations from the analysis are:

First, under options 1 and 2, UK domestic shipping (ships which both begin and end their voyage at a UK port) accounts for 12% and 17% respectively of the overall NPVs, whereas for option 3, the equivalent share of UK domestic shipping is just 0.03%. UK international shipping (ships which serve the UK for imports or

[5] Only changes in emissions to air of pollutants within a certain distance of the UK are valued. See the technical annex report for an explanation of the approach taken and the justification for this.

exports) account for 45.8% and 19.5% of total NPV for options 1 and 2 respectively, whereas for option 3 the equivalent share is just 1.2%. Finally, in-transit shipping (ships that pass through the ECA but do not call at a UK port) accounts for 42.2% for option 1, 63.3% for option 2 and 98.7% for option 3. Therefore, this shows that the benefits of the ECA from regulating in-transit shipping are a key driver of the net benefit of each option, particularly option 3. This is because for the purposes of this analysis, as the focus is on the costs and benefits to the UK, the benefits to the UK of reduced emissions to air of pollutants from in-transit shipping are included, but the costs of the ECA extension to in-transit ships are not treated as costs to the UK, and nor are any increases in greenhouse gas emissions from those ships.

Second, the absolute scale of costs to UK domestic shipping (both fuel costs and increases in GHG emissions) from the policy options is much lower in option 1 (around £39.7 million in discounted present value terms[6], 2017 prices) compared to option 2 (around £366.6 million in discounted present value terms[7] and option 3 (around £352.8 million in discounted present value terms[8], 2017 prices).

Third, in all options, emissions to air of pollutants from shipping would be expected to be lower than under the business as usual scenario. However, emissions of SO_2 and $PM_{2.5}$ could in some cases initially decline but then rise again over the ten year period of the policy under consideration due to the expected growth in shipping transport demand.

Fourth, there is an apparent trade-off such that when air pollution is targeted through the ECA extension, this has the effect under all options of increasing greenhouse gas emissions from UK domestic shipping, which is an issue in the context of UK carbon budgets. This is because more vessels that utilise HFO with a scrubber will enter the fleets to comply with the sulphur requirements in and outside of the ECA which, in turn, will increase the GHG emissions due to an intensified usage of a scrubber. Therefore, **complementary policy would be needed to provide appropriate incentives to reduce greenhouse gas emissions, while also remaining compliant with air pollution regulations**.

Fifth, the costs of the ECA extensions to UK domestic and international shipping are likely to fall more heavily on some ship types than others. For option 1, 94% of the change in fuel costs is expected to be incurred by four ship types: RoRo, oil tankers, RoRo & passengers and 'other'[9]. For option 2, the same four ship types plus container ships account for 93% of the change in fuel costs; with the same finding for option 3. This reflects the prevalence of these ship types in the respective areas.

[6] Over the ten-year period of the policy, discounted to 2019

[7] Over the ten-year period of the policy, discounted to 2019

[8] Over the ten-year period of the policy, discounted to 2019

[9] "Other" vessels comprise the non-modelled in GloTraM vessel types that include chemical tankers, general cargo vessels, liquefied gas tankers, other liquids tankers, refrigerated bulk carriers, vehicle carriers, yachts and miscellaneous – fishing vessels

2 INTRODUCTION

2.1 Emissions to air of pollutants from shipping

The shipping industry is critical for the UK's trade in goods. Around 95% of British imports and exports in goods are moved by sea, including 25% of the UK's energy supply and almost half of the country's food supplies (DfT, 2019a). The UK port sector is the second largest in the European Union, handling around 5% of the world's total maritime freight transport at some point in its journey (DfT, 2019a).

To undertake this scale of activity, ships require a substantial volume of fuel. The current reliance on fossil fuels, however, has consequences for the environment and health due to the associated emissions. These include nitrogen oxides (NOx), sulphur dioxide (SO_2), particulate matter ($PM_{2.5}$ & PM_{10}), volatile organic compounds (VOCs) and ammonia (NH_3). In 2020, UK domestic shipping alone accounted for 12% of the UK's total domestic NOx emissions, 2% of the UK's total domestic primary $PM_{2.5}$ emissions and 4% of the UK's total domestic SO_2 emissions.[10]

Emissions from UK international shipping, and voyages that are in transit through UK waters far outweigh the volume of emissions from UK domestic shipping. The table below demonstrates the relative scale of NOx emissions from domestic, international and in transit shipping activity. This is shown in Figure 3.

Figure 3 NOx emissions from UK shipping in 2016

	UK domestic shipping	UK international shipping	In transit through UK waters
NOx emissions in 2016 (thousand tonnes)	75	233	433

Source: Imperial College cited in "Maritime 2050: Navigating the Future" (Department for Transport, 2019)
Note: Some emissions are outside the area of the National Atmospheric Emissions Inventory (NAEI)

As will be described in more detail below, shipping activity is projected to increase over time as the demand for imports and exports increases and population grows. Although efficiency improvements coupled with technological advances are likely to reduce emissions per unit of activity over time, the risk that growth in demand for shipping could counter efforts taken to mitigate emissions, is one reason further action could be required to minimise the environmental impacts of UK shipping emissions.

Globally, air pollution from shipping is regulated by the International Maritime Organization (IMO) through the International Convention for the Prevention of Pollution from Ships (MARPOL). Annex VI of MARPOL entered into force in 2005, with, among other things, the aim of minimising airborne emissions from ships. As described in more detail in the next section, there are currently limited regulations

[10] Department for Transport statistics. ENV0301: Air pollutant emissions by transport mode: United Kingdom. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1112230/env0301.ods

or policies in the UK specifically to incentivise reductions of emissions to air of pollutants from shipping. The main international limits on emissions to air of pollutants from shipping are through the North Sea emissions control area (ECA) in which a sulphur cap of 0.1% was introduced in 2015 (a ten-fold reduction from the 1% limit introduced in 2010); and in 2008 Member States at the IMO agreed to a 0.5% sulphur limit for global shipping outside ECAs from 2020.[11]

This report considers what the potential impacts, costs and benefits could be of extending the North Sea ECA beyond its current geographical limits to further reduce emissions to air of pollutants from shipping. Three extension options are considered, as described in section 3.2, with a view to informing policy makers about the option most likely to be worth exploring in more detail.

2.2 Air pollution and the Clean Air Strategy

Air pollution results from a wide range of activities such as transport, energy production, chemicals manufacture, domestic combustion and farming. It has harmful effects on human health and environmental ecosystems. Once released, air pollution is dispersed by the weather and can travel significant distances within and between countries (Defra, 2019).[12]

The impact of air pollution depends on how much is emitted, how harmful it is and how it interacts with other substances in the air. It also depends on where it is emitted and how sensitive the exposed population or environment is.

Given the risk to human health and the environment, the UK published its Clean Air Strategy (CAS) in 2019. This reaffirmed the national emission reduction commitments for overall UK emissions of five damaging air pollutants. These are:

- fine particulate matter ($PM_{2.5}$);
- ammonia (NH_3);
- nitrogen oxides (NO_x);
- sulphur dioxide (SO_2); and
- non-methane volatile organic compounds (NMVOCs).

Particulate matter is everything in the air that is not a gas. Particulates are classified according to size, either as PM10 (particles of ≤10μm (micrometres) diameter) or PM2.5 (particles of ≤2.5μm diameter particles which are 200 times smaller than a grain of sand). These are important because PM is formed of tiny particles that can get into the lungs and blood and be transported around the body, lodging in the heart, brain and other organs. PM therefore can have harmful impacts on human and animal health. The UK's aim is to reduce emissions of $PM_{2.5}$ against the 2005 baseline by 30% by 2020, and 46% by 2030 (Defra, 2019).

[11] The 2020 date was subject to an IMO led review on fuel availability and was confirmed in 2016.

[12] Defra (2019) Clean Air Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770715/clean-air-strategy-2019.pdf

Ammonia is a gas that is emitted into the atmosphere and then either deposited back onto land or converted to secondary PM through reactions in the atmosphere. Ammonia can cause significant long-term harm to sensitive habitats, depositing more nitrogen onto soils and plants, and into freshwaters, than they can cope with. Its contribution to PM can lead to the health impacts described above. The UK's aim is to reduce emissions of ammonia against the 2005 baseline by 8% by 2020 and 16% by 2030 (Defra, 2019).

Nitrogen oxides (NO_x) are a group of gases that are predominantly formed during the combustion of fossil fuels. The majority of NO_x emitted as a result of combustion is in the form of nitric oxide (NO). When NO reacts with other gases present in the air, it can form nitrogen dioxide (NO_2), which is harmful to health. It is also important in the formation of ozone. The UK's aim is to reduce emissions of nitrogen oxides against the 2005 baseline by 55% by 2020, increasing to 73% by 2030 (Defra, 2019).

Sulphur dioxide is a corrosive, acidic gas which is harmful to health and combines with water vapour in the atmosphere to produce acid rain. Emissions of SO_2 are primarily from combustion of solid and liquid fuels. The UK's aim is to reduce emissions of sulphur dioxide against the 2005 baseline by 59% by 2020, increasing to 88% by 2030 (Defra, 2019).

Non-methane volatile organic compounds (NMVOCs) are a very large group of organic compounds. The UK's aim is to reduce emissions of NMVOCs against the 2005 baseline by 32% by 2020, increasing to 39% by 2030.

Shipping is a contributor to many of these harmful air pollutants due to its current reliance on fossil fuels. Action is therefore needed to ensure the shipping sector plays its part in achieving the UK's aims for air pollutants.

2.3 Structure of this report

This report is structured as follows:

- Section 3 provides more detail on the policy background and policy options being considered in this report;
- Section 4 presents more detail on the business as usual case which describes what would be expected to happen absent further policy action to address emissions to air of pollutants from UK shipping;
- Section 5 presents analysis of the impacts, costs and benefits of the three policy options for extending the North Sea emission control area; and
- Section 6 offers some policy insights.

3 POLICY BACKGROUND

3.1 Policy context

Emissions to air of pollutants from shipping are regulated at both the IMO and EU levels. The IMO is the governing body for the MARPOL convention, which contains specific regulations for the control of sulphur emissions and NOx emissions (in Annex VI). EU Directives are used to set legislation at the EU level on air pollution and regulation of the sulphur content of certain liquid fuels.

The Directives are mostly currently aligned to the MARPOL convention and set policy at the EU level to be consistent with the IMO's international policy. Two exceptions to this consistency are in the sulphur Directive 2016/802. The first exception is that from 2010, any ship at berth in EU ports must use fuel at 0.1% sulphur chemical composition or less. The second exception is that passenger ships operating on regular services to or from any EU port must use fuel at 1.5% or less (in terms of sulphur chemical composition). The UK follows the EU legislation and will retain comparable provisions after EU exit.

Control of air pollutants i.e. emissions of SO_2 and NOx, in MARPOL is carried out through both regulation of global emissions, and regulation of emissions within defined geographical areas known as Emission Control Areas, ECAs. There is currently an ECA covering the Channel and the North Sea, and an ECA covering the Baltic Sea which impacts on UK air quality. Within these ECAs, regulations are applied to both pollutants of the following form:

- SO_2 emissions are controlled by requiring the sulphur content of fuels used within the ECA to be of sulphur (chemical) content of 0.1% or less. Higher sulphur content fuels can be used on the condition that a device is fitted that removes SO_2 emissions from the exhaust to the equivalent level of the compliant fuel; and,
- NOx emissions are controlled by requiring ships built after 1st January 2021 to be compliant with the highest regulated stringency (known as 'Tier III' compliance). There is no geographical variation to the stringency for ships built before this date.

For global regulation of these pollutants, the stringencies are lower than the limits in the ECAs. Currently, there is a sulphur chemical content limit on fuel of 3.5%, which applies anywhere outside of an ECA. This global limit will reduce to 0.5% on the 1st January 2020. In relation to NOx emissions, globally, ships must meet Tier II standards if built after 1st January 2011, or Tier I standards if they were built before.

The stringencies for the Tiers of NOx regulation, which have varying limits depending on the rated engine speed, are presented in Figure 4. In general, larger ships (especially those involved in international transport) use engines with lower rated engine speed and lower stringency on NOx emissions, whereas smaller ships use engines with higher rated engine speed and higher stringency.

Figure 4 MARPOL Annex VI NOx emission limits

Tier	Date	NOx limit g/kWh		
		N<130	130≤n<2000	n≥2000
Tier I	2000	17.0	$45\ n^{-0.2}$	9.8
Tier II (outside ECAs)	2011	14.4	$44\ n^{-0.23}$	7.7
Tier III (NOx ECAs)	2021 [13]	3.4	$9\ n^{-0.2}$	1.96

Source: https://www.dieselnet.com/standards/inter/imo.php

Notes : 'Date' refers to the date from which regulation applies to new build ships. For example, ships built after January 1st 2011 must comply with Tier II standards.

Figure 5 MARPOL Annex VI fuel sulphur limits

Date	Sulphur limit in fuel (%m/m) Global	
	SO_2 ECA	Global
2000	1.5%	4.5%
2010	1.0%	4.5%
2012	1.0%	3.5%
2015	0.1%	3.5%
2020	0.1%	0.5%

Source: https://www.dieselnet.com/standards/inter/imo.php

As shown in Figure 4, NOx emission regulation stringency inside an ECA is approximately 3 to 5 times tighter than outside the ECA for ships built after 2021.

As shown in Figure 5, for SO_2 emission regulation, allowable emission levels in the ECA from 2020 are going to be one-fifth of those allowed globally.

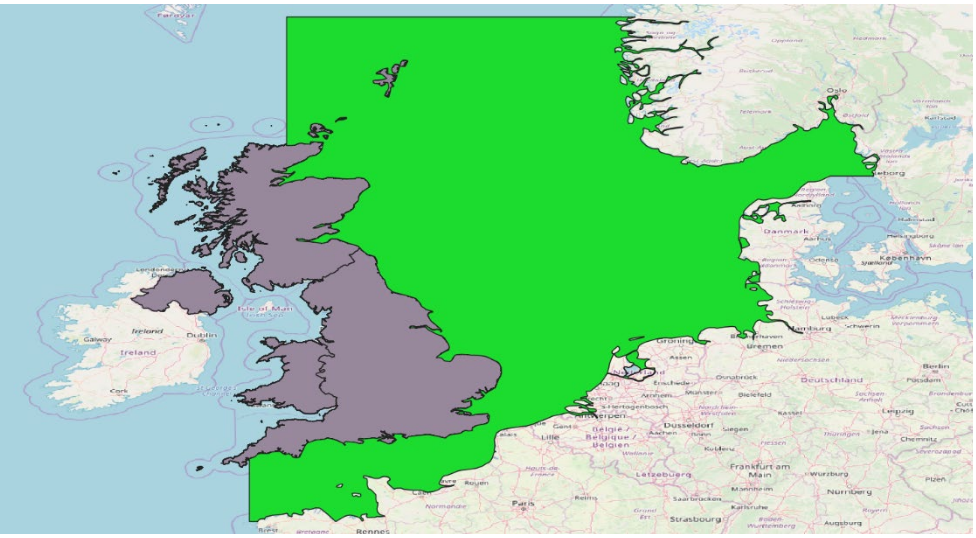
Under the EU Directive 2016/802, when in EU ports outside the ECA, the stringency applied is the same as that in the ECA on sulphur, but not for NOx where the stringency is the global limit.

The sea region included in the North Sea ECA is shown in Figure 6. It covers the East and South coast of the UK and the adjacent sea areas. There is no inclusion of the West coast of the UK or Northern Ireland. The UK is therefore in a position where there is a differential in stringency for the regulation of SO_2 and NOx, depending on the specifics of the location of the port. The potential implications of this differential in stringency by geography are as follows:

[13] Note that in the North American ECA, this date was 2016.

- There are likely to be different costs for ships operating in different parts of the UK;
- There could be the incentive for shipping to prefer to operate, where possible, in the less regulated West Coast ports and sea regions in preference to the East Coast;
- It creates a requirement for UK marine fuel supplies to contain a wide number of different fuels, currently 3.5%, 1.5% and 0.1% sulphur content compliant fuels to both domestic and international shipping (and from 2020: 0.5% and 0.1% sulphur content compliant fuels to both domestic and international shipping); and
- There are likely to be differences in the impacts of shipping on the air quality in similar cities just because they are in different parts of the country.

Figure 6 Current North Sea Emissions Control Area



Source: UMAS

Note: The green area represents current North Sea Emissions Control Area

The next section describes the policy options considered in this report in terms of extensions to the ECA.

3.2 Illustrative policy options

The illustrative policy options considered in this report relate to extending the North Sea ECA to include more of the UK coast. The channels through which these policy options would impact on emissions to air of SO_2 and NOx are that the policies would:

- Increase the amount of shipping that would need to be Tier III compliant from 2021 (with an expected increase in compliance costs for these ships);
- Increase the use of 0.1% sulphur limit fuel and therefore higher costs for operators using higher sulphur content fuels (e.g. most of international and transiting shipping and some domestic shipping); and

- Reduce levels of SO_2 and NO_x emissions when ships are operating at sea.

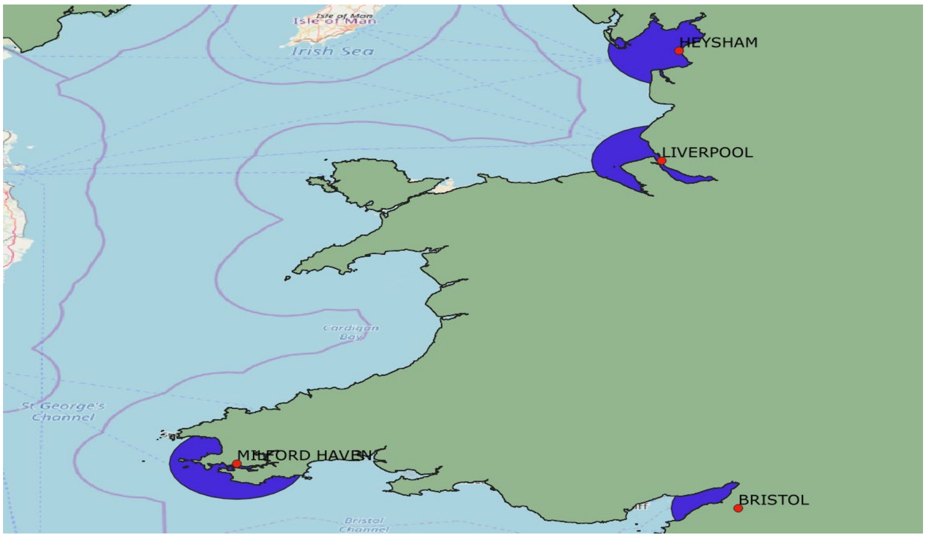
Three illustrative options are considered in this report for extending the North Sea ECA. These are below.

Option 1

This involves extending the North Sea ECA to include all major ports in England[14] not covered by the current ECA with a time period of interest from 1st January 2021 to 31st December 2030[15].

The map of the area is shown in Figure 7.

Figure 7 Emission Control Area extension option 1



Source: UMAS

Note: Policy Option 1 is assumed to apply to shipping activity within a 12 nm radius around each of the ports of interest. The ports of interest are Heysham, Liverpool, Milford Heaven and Bristol.

Option 2

This involves extending the North Sea ECA to include all of the UK territorial waters with a time period of interest of from 1 January 2021 to 31 December 2030.

The map of the area is shown in Figure 8.

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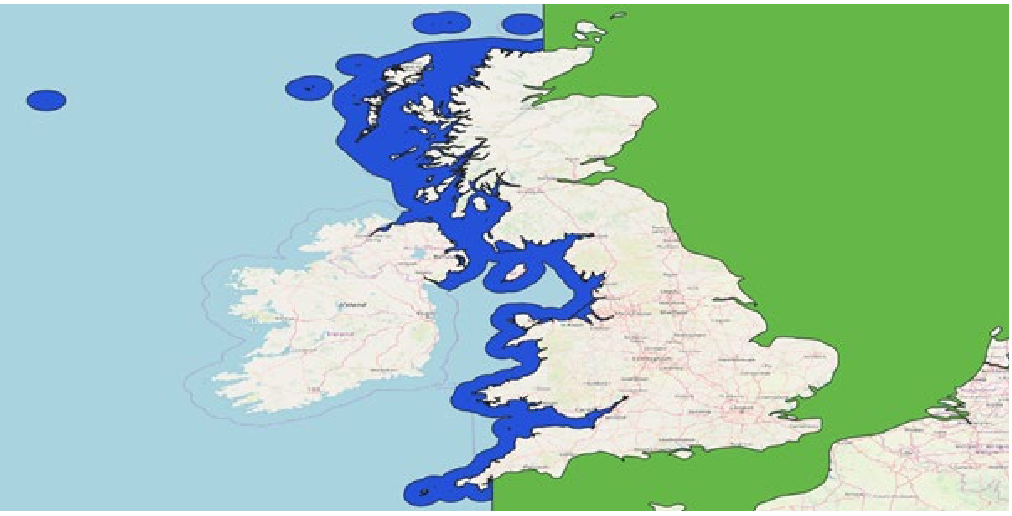
[14] Please note that this option was developed as a result of work from the Clean Air Strategy which only covered English ports plus Milford Haven in Wales as a reserved port function.

[15] The ports of interest considered under policy option 1 are Heysham, Liverpool, Milford Heaven and Bristol.

Figure 8 Emission Control Area extension option 2

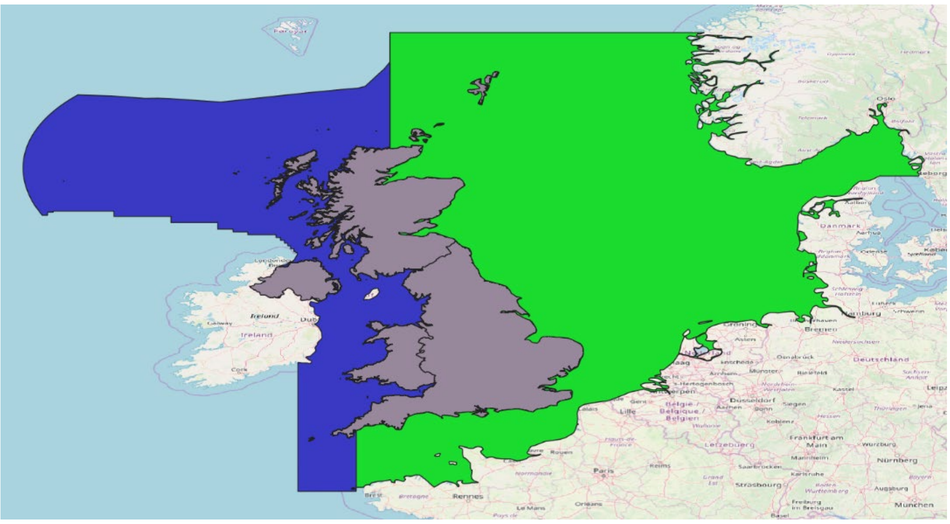


Source: UMAS

Option 3

This involves extending the North Sea ECA to include the Irish Sea and down to the English Channel (including the Isle of Ouessant but not going South to the Biscay Bay) with a time period of interest of 1st January 2026 to 31st December 2035. The map of the area is shown in Figure 9.

Figure 9 Emission Control Area extension option 3



Source: UMAS

Under each option, the extended ECA will have the same limits on SO_2 and NOx emissions as the current North Sea ECA over the relevant time period - these are presented in Figure 4 and Figure 5 (e.g. this will include the new limits on NOx emissions that will apply in the current North Sea ECA after 1 January 2021).

4 BUSINESS AS USUAL

4.1 Purpose of the business as usual scenario

To understand the impact of any policy change, it is important to first understand the likely situation in terms of shipping behaviour, emissions, operating costs and charter revenues in the absence of the policy change. This situation is called the Business as Usual (BAU). It sets the baseline against which the outcomes of the policy options can be compared.

The definition of the BAU and its underlying assumptions are therefore important. For the purposes of this analysis, the BAU scenario is defined with particular features, as below.

First, the ECA as shown in Figure 6 is in operation, controlling NOx and SO_2 emissions in line with the requirements of Figure 4 and Figure 5.

Second, the requirements of the existing regulation 21 of MARPOL Annex VI will be met. The regulation 21 of MARPOL Annex VI that entered into force in January 2013, requires the attained Energy Efficiency Design Index (EEDI)[16] of certain categories of new ships not to exceed the required EEDI[17] with the main objective of reducing international shipping's GHG emissions via improved ship design.

Third, port traffic demand is considered to grow in line with DfT's UK Port Freight Traffic Forecasts (DfT, 2019b)[18]. Key features of these forecasts, as described by DfT (2019b), are:

- Overall, port traffic is forecast to remain relatively flat in the short term, but grow in the long-term, with tonnage 39% higher in 2050 compared to 2016.
- The long-term growth in port traffic is driven by increases in unitised freight transport. In the short-term, this growth in unitised transport is offset by decreases in the other categories.
- Liquid bulk transport demand is forecast to decline over time. This is almost entirely due to falls in crude oil transport demand, in line with the declines which have been seen historically. It is likely that the projected decline in other liquid bulk transport demand is partly due to the shift from liquid bulk to tank containers for some shipments.
- General cargo is also forecast to decline over time, in line with the historic trend, which is also likely to be partly driven by increased containerisation of goods.

[16] The EEDI is an index that indicates the energy efficiency of a ship in terms of gCO_2 (generated) / tonne.mile (cargo carried); calculated for a specific reference ship operational condition. Source: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Air%20pollution/M2%20EE%20regulations%20and%20guidelines%20final.pdf

[17] For more information please refer to section 6.4.3 in Frontier, UMAS, CE Delft and E4tech: Reducing the UK Maritime Sector's Contribution to Climate Change and Air Pollution: Scenario Analysis: Take-up of Emissions Reduction Options and their Impacts on Emissions and Costs - Technical Annex

[18] Department for Transport (2019b) UK Port Freight Traffic: 2019 Forecasts https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/771852/port-freight-forecasts.pdf

- Dry bulk transport demand is forecast to have a relatively large decline in the short-term, driven primarily by demand for coal being projected to fall. However, in the long-term, dry bulk transport demand is forecast to increase, with other dry bulk, the largest category, continuing to increase as it has done historically.

Fourth, ship owners operate in a way which ensures they are in compliance with relevant regulations, while also profit maximising i.e. they respond to the market conditions in which they are operating. They are likely to make some investments in technologies that are able to save fuel (and associated operating costs), or to change their operating behaviour, where such actions would be consistent with profit maximisation.

The baseline fleet is taken to be as was observed in 2016 (using Automatic Identification System, AIS, data), and this evolves over time as new, more fuel-efficient ships enter the fleet to replace retired vessels. Ships also enter the fleet to ensure that the supply of shipping activity is sufficient to meet demand. Ship owners are assumed to invest in new technologies and retrofit them in response to either current regulatory requirements or profit maximisation objectives.

Fifth, the focus of the analysis of the impacts of ECA extension options is the ships that operate within each newly defined ECA. For this reason, in the analysis of each of the ECA extension options, the ships and voyages that are represented within the ‘business as usual’ reflect only a sub-set of those operating to, from or close to (in transit) the UK. In this sense, the business as usual has the same underlying assumptions in each case but focuses in on different fleets (those that are within each relevant ECA only). This is because the analysis assumes no impact of the ECA on other shipping activity (i.e. no diversion or changes to voyages).

Sixth, underlying assumptions relating to fuel prices, the drivers of ship owner behaviour (i.e. profit maximising), technologies taken up to reduce emissions under the business as usual, ship speeds etc. are all consistent with the assumptions used for the business as usual in the modelling analysis of Frontier et al. (2019).[19]

4.2 Technologies assumed to be taken up under the business as usual scenario

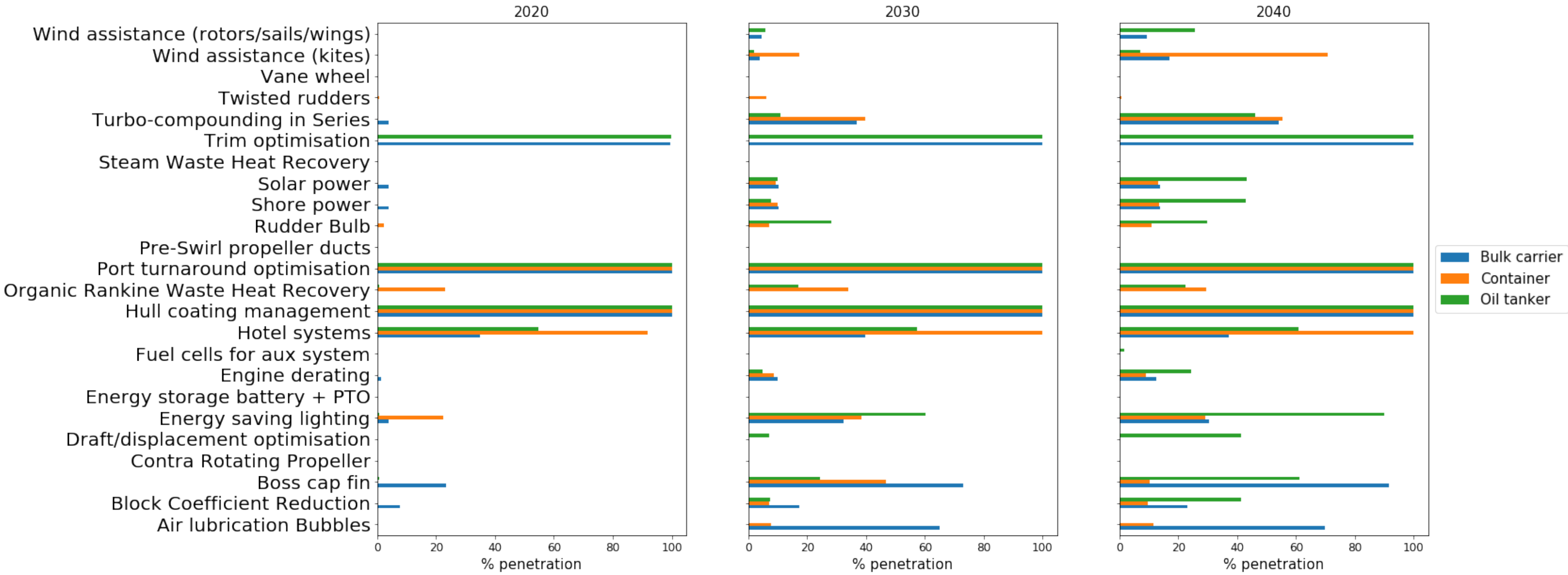
As noted above, ship owners and operators are assumed to take up different technologies, behaviours and fuels in line with meeting current regulations, and their profit maximising behaviour. This is because of the incentives provided by the desire to minimise operating costs, namely fuel costs, over time.

Figure 10 shows that in the early 2020s, the most prevalent emissions reduction options are port turn-around optimisation, trim optimisation, and hull coatings. As the years pass, the EEDI regulation increases in stringency and fleet coverage, and the fuel price rises, so there is even greater incentive for ship owners and operators to reduce their fuel operating costs by increasing their energy

[19] Frontier, UMAS, CE Delft and E4tech (2019): Reducing the UK Maritime Sector’s Contribution to Air Pollution and Climate Change: Scenario Analysis - Take-up of Emissions Reduction Options and their Impacts on Emissions and Costs

efficiency. Therefore, by around 2040, there are several energy efficiency options that are widely used – including those already largely adopted in the early 2020s, plus energy saving lighting, wind assistant technologies, turbo-compounding in series, air lubrication bubbles, and boss cap fins. By the 2040s, electrification begins to be evident through the gradual increase of shore power and solar power.

Figure 10 Uptake of energy efficiency devices by 2020, 2030 and 2040 under business as usual for UK shipping (domestic and international)



Source: UMAS modelling taken from the business as usual scenario (scenario A) which is described in detail in Frontier, UMAS, CE Delft and E4tech (2019): Reducing the UK Maritime Sector's Contribution to Air Pollution and Climate Change: Scenario Analysis - Take-up of Emissions Reduction Options and their Impacts on Emissions and Costs

Note: '% penetration' represents the percentage of the size and age categories for each ship type that is estimated to have taken up each of the options. These charts do not include options for using alternative fuels. Based on UMAS (GloTraM) modelling, the take-up of alternative fuels under business as usual includes LNG usage in a part of the bulk carrier and oil tanker fleets being a competitive and compliant option.

A number of remaining technologies exist that are not likely to be implemented under the BAU scenario over the time period considered. Options that are not taken up include energy storage battery, pre-swirl propeller ducts, steam waste heat recovery, contra rotating propellers and vane wheels. They are not taken up for a number of reasons – some are not considered cost-effective for the industry to implement; and some face market failures or other barriers that hinder their uptake.[20]

4.3 Profile of emissions under the business as usual scenario

To understand the impacts of extending the North Sea Emissions Control Area, of which three options are considered in this report, it is first important to understand the extent of shipping activity and the profile of emissions under the business as usual case i.e. before any extensions are implemented and assuming only the current North Sea emissions control area is in operation.

It should be noted that this section only reports shipping activity and emissions associated with ships that are operating in the areas identified for the ECA extensions only.

Firstly, given the period of coverage of the ECA extension policies (ten-year period of 2021 – 2030 for options 1 and 2; and 2026 – 2035 for option 3), the number of ships operating in the relevant extended ECA areas increases over time (in line with the DfT's UK port traffic forecasts[21]).[22]

The number of ships increases slightly over the course of the period in each of the relevant areas under BAU. The balance of UK domestic, UK international and in-transit ships is very different across the three ECA extension option areas. In particular:

- Option 1 has the largest share of international ships in the area with more than 55% of the ships accounted for by international voyages from or to the UK, more than 40% on domestic voyages and the remainder in-transit (not calling at the UK);
- Option 2 has relatively even distribution of voyage types where 38% are domestic; 34% international to or from the UK and 28% in-transit; and
- Option 3 has the highest total number of ships in the relevant area where domestic and UK international ships account for approximately one-quarter each, with in-transit ships accounting for around half.

Obviously, the ship types in operation are important in the context of emissions because ships vary substantially in terms of size, fuel requirements, fuel efficiency

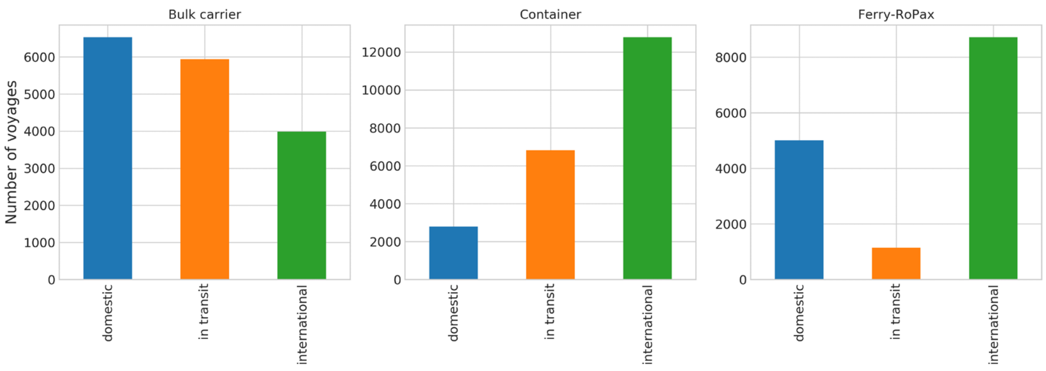
[20] Barriers to the uptake of options to reduce shipping emissions are explored in detail in Frontier, UMAS and E4tech (2019) Reducing the UK Maritime Sector's Contribution to Air Pollution and Climate Change: Identification of Market Failures and other Barriers to the Commercial Deployment of Emission Reduction Options

[21] Department for Transport (2019) UK Port Freight Traffic 2019 Forecasts available at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/771852/port-freight-forecasts.pdf

[22] Further detail on the number of ships can be found in the Technical Annexes accompanying this report.

and hence emissions. The number of voyages undertaken by three typical ship types are shown in Figure 11. This shows that ‘bulk carriers’ (which transport cargoes in bulk quantities) are assumed to undertake more domestic voyages than UK international or in-transit voyages; ‘container’ ships (which carry their cargo in truck-size containers) are assumed to undertake more international voyages and in-transit voyages than domestic; and ferries that are able to carry vehicles, cargo and passengers (referred to as Ferry RoPax) primarily undertake international voyages.

Figure 11 Annual number of voyages undertaken by the three most prevalent ship types in 2016



Source: UMAS modelling

Note: These figures do not relate to any particular ECA area – they show the voyages that are undertaken by each ship type to, from or within the UK waters.

Given the composition of vessels in the relevant ECA areas, the business as usual greenhouse gas emissions in each relevant geographical area are shown in Figure 12. The three gases that are together referred to as greenhouse gases and assessed in this analysis are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

This shows that, under business as usual, the absolute volume of emissions in the geographical area covered by Option 1 is lower than the emissions in the geographical areas covered by options 2 and 3. This is because of the smaller geographical area that is considered under Option 1.

Under business as usual, emissions are anticipated to rise in the geographical areas covered by options 1, 2 and 3 over the period assessed. The volume of emissions reflects the number of ships in each area. For example, in-transit emissions are higher in option 3 because there are more in-transit ships in that area than in the other areas.

In all cases, the fact that emissions rise over time implies that the growth in transport demand outstrips the rate of improvement in fuel efficiency arising from the fuel efficiency measures taken up under BAU, and the replacement of fleets with more efficient vessels over time.

The CH_4 trends are influenced by the LNG consumption which depends on the uptake of LNG ships. The GloTraM model simulates every 5 years which are in this case 2021, 2026, 2031 etc. The years in between are linearly interpolated making these modelled steps visible in the plots. It should be noted that that the difference in CH_4 trends between Option 2 and 3 is due to different timescale (x-axis). For Option 1, the kicks are not as visible due to lower number of LNG vessels operating under Option 1.

Figure 12 GHG emissions in the geographical areas covered by each of the ECA extension options under BAU

Source: UMAS modelling

Note: Emissions are associated with ships operating in the respective ECA extension areas only. The kicks on CH4 charts are emphasised by the modelling (every 5 years) and linear interpolation between the modelled points.

In terms of emissions to air of pollutants from shipping, the business as usual scenario emissions of sulphur emissions (SO_2); nitrogen oxides (NO_x) and fine particular matter ($PM_{2.5}$) in each relevant geographical area are shown in Figure 13.

The air pollution trends under BAU are mainly influenced by two factors: a growth of a transport demand over time and changes in the fleet composition (demand for newbuilds in each vessel type and an uptake of the energy efficient technologies).

There is also a noticeable trend indicating an increasing usage of HFO coupled with a scrubber within and outside of the ECA areas. When comparing the results for the geographical area covered by option 1 and option 2 with those for the geographical area covered by option 3, the relative demand for scrubbers for the fleet operating within the geographical area covered by option 1 and option 2 is slightly higher. Hence for vessels operating within the geographical area covered by option 1 and option 2, the demand for Marine Diesel Oil (MDO) and/or Low Sulphur Heavy Fuel Oil (LSHFO) fuels (a combination of MDO/LSHFO or solely MDO for when operating inside and outside of ECA) is slightly decreasing over time while the demand for HFO with a scrubber is increasing.

The increasing demand for the use of scrubbers does not significantly affect the SO_2 and NO_x trends – these initially decline for options 1 and 2 and then rise again, and for option 3 are increasing over the whole period. The increases are influenced by the increasing transport demand. However, given the modelling specifics of the $PM_{2.5}$ emissions, an impact on $PM_{2.5}$ emissions is observed when a scrubber is installed regardless of the ECA option being considered, therefore the $PM_{2.5}$ emissions in the geographical area covered by option 1 (and to a lesser extent for option 2) slightly decrease over time.

Having described the business as usual situation, the next Section explores the impacts of the three ECA extension policies.

Figure 13 Emissions to air of pollutants in ECA extension options under BAU

Source: UMAS modelling

Note: Emissions are associated with ships operating in the respective ECA extension areas only.

5 COST-BENEFIT ANALYSIS OF ECA EXTENSION POLICY OPTIONS

5.1 Introduction

This section presents the analysis of the costs and benefits of extending the North Sea ECA under the three illustrative options:

- Option 1: This involves extending the North Sea ECA to include all major ports in England[23] not covered by the ECA with a time period of interest from 1st January 2021 to 31st December 2030.
- Option 2: This involves extending the North Sea ECA to include all of UK territorial waters with a time period of interest of from 1st January 2021 to 31 December 2030.
- Option 3: This involves extending the North Sea ECA to include the Irish Sea and down to the English Channel (including the Isle of Ouessant but not going South to the Biscay Bay) with a time period of interest of 1st January 2026 to 31st December 2035.

Key assumptions are described first before presenting the results, including sensitivity tests.

5.2 Key assumptions

The methodology used to model the impacts of the ECA extension policy options is described in detail in the separate Technical Annex. A summary is presented here to provide the reader with a sufficient understanding of the approach such that the results can be appropriately interpreted.

The purpose of the analysis is to explore the impacts on emissions and costs associated with the three ECA extension options specified above. To estimate these impacts, modelling has been undertaken using the GloTraM modelling suite as this is able to model, with a geo-spatial level of specificity, the shipping activity that is projected over the period of the ECA extension policies and the associated impacts on shipping costs and emissions. Some of the key aspects of the analysis are below.

Scope of shipping activity included

The policy options are assumed to impact only on those ships and voyages that are within the ECA extension areas, whether undertaking domestic shipping activity, UK-related international shipping activity, or are in transit, passing through the ECA areas without calling at the UK.

[23] Please note that port activity is a devolved area and therefore this option can only cover English ports plus Milford Haven in Wales – which is also reserved.

Domestic shipping is considered to be shipping activity that begins and ends at a UK port. International shipping is defined as the fleet servicing UK international trade flows (imports and exports). This is identified from the specifics of the voyage: international shipping is shipping services provided by any ship arriving at a UK port immediately after leaving a non-UK port, or arriving at a non-UK port after leaving a UK port. The international shipping emissions within the ECA are the total of those voyages associated with both inbound to UK and outbound away from UK shipping activity. In-transit shipping is those voyages that pass through the ECA but do not call at a UK port.

Options available for compliance of ships with the ECA regulations

When the ECA extension options are implemented, all ships operating in that area, whether calling at a UK port or not, have to comply with the corresponding emissions regulations.[24] There are two pollutants which are controlled in the ECA and both are assumed in the modelling to be complied with using the following two strategies.

Compliance with the ECA sulphur limit[25]:

- If ships are using fuel oil and do not already have a sulphur scrubber fitted under the business as usual scenario, including if they are expected to be using 0.5% compliant low sulphur fuel oil, then when operating in the extended ECA they are expected to switch to MDO to be in compliance of the 0.1% limit. This has the impact of increasing the operating costs to the relevant ship owners and operators. For ships not using fuel oil (e.g. using MDO or LNG), these ships will already be in compliance and therefore they are assumed to continue on the same fuel when operating in the extended ECA. If the ship is specified in the business as usual scenario as already having a sulphur scrubber fitted, then the ship is assumed to continue to use high sulphur fuel when operating in the extended ECA, with the scrubber used to reach the compliance limit.

Compliance with the ECA NOx limit[26]:

- Compliance is only required for newbuild ships that are required to meet the Tier III NOx limit (e.g. ships built after 2021). It is assumed, given expectations of interoperability between coasts of the UK, that ships that need to be Tier III compliant will already have a Selective Catalytic Reduction system (or equivalent Tier III compliant machinery) fitted under the business as usual case. They will therefore just be required to operate it in the extended ECA.

In both cases, the change in behaviour that would be required for compliance can have the effect of increasing operating costs for the ship owner. This is because if the SCR is already fitted on the ship, switching it on when travelling through an ECA extension lowers the fuel efficiency of the vessel. Likewise, MDO is assumed

[24] As described in IMO MARPOL Annex VI and NOx Technical Code, http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx

[25] These different compliance options are discussed in IMO MEPC 70 INF.5, Assessment of fuel oil availability. The assumption that use of MDO is the default compliance choice for ships which do not already have a sulphur scrubber is also derived from MEPC 70 INF.5 which estimates that given the choice between a change of fuel type and use of a scrubber, the large majority of ships are likely to choose a change of fuel type (to a lower sulphur petroleum product).

[26] Wik, C. Niemi, S. (2016) Low emission engine technologies for future tier III legislations – options and case studies. Journal of Shipping and Trade. 1:3.

to be a more expensive fuel than the fuel oil used under BAU (if it wasn't, the ship owner would already have shifted to this fuel already).

An alternative to these assumptions would be the use of alternative means of compliance. For the sulphur limit, this could be the fitment of a SO_2 scrubber on the exhaust and continued use of a fuel with sulphur content above 0.1%. For the NOx limit this could also include alternative technology for example Exhaust Gas Recirculation (EGR), or for both the sulphur and NOx limit, it could be the use of alternative fuels like LNG. In the case of the scrubber, there is an additional capital cost and a small increase in GHG emissions, both are of similar magnitudes to those incurred through the assumption made on MDO. For the example of EGR, this is a competitor technology to SCR and therefore has similar cost implications and similarly creates a small increase in GHG emissions. For the case of LNG use instead of the assumed compliance choices, there would be more significant differences to emissions and costs (lower SO_2 emissions, lower CO_2 emissions but higher CH_4 emissions). The use of assumptions around MDO being the chosen compliance method is therefore conservative.

Costs to business

In light of the above two abatement options for compliance, cost impacts for businesses are on operational fuel costs only and not capital cost. This is because it is assumed that the fleet operating in the ECA extension area would be built to a specification that would also enable operation in the current ECA area (e.g. if a newbuild ship built after 2021 it would be fitted with a SCR). Another assumption is that the compliance route for satisfying the sulphur regulation is not to use hardware (e.g. exhaust gas cleaning equipment such as a scrubber), or switch to another alternative fuel (e.g. LNG, LPG or methanol). These would all incur some additional capital costs, which may be offset by the use of a lower cost fuel. The justification for the assumption that MDO is the most likely compliance method, is that there is currently no clarity about which of these competing compliance options is most attractive, and given that they are all substitutes for each other, are likely to be priced at similar levels. The MDO assumption is therefore a relevant proxy to the overall cost impacts of the alternative options, even if it is only represented solely as an impact on operational cost.[27]

Emissions to air of pollutants

The aim of the ECA is to reduce air pollutant emissions that are harmful to human health, and through deposition, can also cause harm to ecosystems and natural environments. Pollutants assessed in this analysis are emissions to air of NOx, SO_2 and $PM_{2.5}$.

For the purpose of this analysis, changes in these emissions are presented in tonnage terms and also are valued in monetary terms in line with Government Guidance and the Green Book. More specifically, emissions to air of pollutants are

[27] See the following for reference on assumptions: https://www.lr.org/en-gb/latest-news/emissions-guidance-issued-by-lloyds-register-compliance-and-performance-options/

valued in monetary terms using an approach based on Department for Environment, Food and Rural Affairs (Defra) guidance.

It is recognised that the location and timing of emissions are important because these factors, along with the populations exposed to those emissions, determine the value of the damage of each additional unit of emission.

Assessing these damages in detail requires use of dispersion models to estimate:

- how the estimated changes in emissions translate to changes in concentrations;
- the average relationship between emissions and exposure to concentrations, calculated as the population weighted mean concentration for a pollutant divided by the total annual emissions of that pollutant; and
- the changes in outcomes that result from the population weighted concentration changes estimated through dispersion modelling (outcomes include impacts on public health, the natural environment and the economy). This requires the application of concentration response functions.

Given the limited time available for this analysis, figures that Defra has published of damage cost estimates per tonne of emission[28] are used as a proxy for these detailed assessments. These valuations have been used in this analysis, as detailed in the Technical Annex.

Defra officials have confirmed that these damage costs can be used to value emissions from all types of shipping activity (e.g. domestic, international, and voyages transiting near to the UK). These damage costs account for the fact that some shipping emissions will be further from shore – i.e. the damage costs represent an average. However, these damage costs are estimated based on the emissions included in the National Atmospheric Emissions Inventory (NAEI). In particular, the analysis is based on the mapped NAEI emissions for shipping. In this instance, the 2013 NAEI. Therefore, Defra has advised that the damage costs should not be used to value any shipping emissions beyond the geographical area that the mapped NAEI emissions from shipping covers – emissions further away are not likely to incur the health and environmental costs to the UK that the damage costs represent. The approach to calculate benefits presented in this report does therefore not include emissions that are outside of the geographical area that the mapped NAEI emissions from shipping covers.

It should also be noted that there are likely to be impacts that the damage costs are not able to reflect. These could include, for example, the costs associated with emissions deposition on natural habitats. The valuations presented should therefore be considered as illustrative of the anticipated order of magnitude, rather than as accurate estimates.

[28] See https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/770576/air-quality-damage-cost-guidance.pdf

Greenhouse gases

It is also important to consider the changes in GHGs that result from the ECA extension policies because the UK has a legally binding target of net zero GHG emissions by 2050 . Changes to CO_2, CH_4 and N_2O are therefore considered.

Changes in GHGs have also been assessed in monetary terms using Government Guidance published by the Department for Business, Energy and Industrial Strategy[29]. This guidance provides a monetary value per tonne of GHG (CO_2, N_2O and CH_4 have been converted into a CO_2 equivalent value, as detailed in the technical annex).[30] This suggests, for example, that a tonne of CO_2e has a monetary value of £69/tCO_2e in 2021 rising to £116/tCO_2e in 2035 (2017 prices).

GHGs typically increase as a result of these policy options because, for example, SCR technology to remove emissions to air of pollutants lowers the fuel efficiency of the ship, relative to business as usual. Increases in GHGs are considered a cost.

In line with guidance from BEIS, only the costs of increases in GHG from domestic shipping are included in the cost-benefit analysis below (therefore the costs associated with increases in GHGs from international and in-transit shipping are excluded from the monetised cost-benefit analysis). This is because only domestic shipping emissions are included in the UK carbon budgets[31].

Estimating costs and benefits to the UK

In line with HM Treasury Green Book guidance (HMT, 2018), of relevance to inform UK government policy are the costs and benefits to the UK of any policy intervention. The international nature of shipping activity therefore requires that assumptions are made about which costs and benefits associated with an intervention are considered to be costs and benefits to the UK specifically.

In the context of this analysis, costs and benefits to the UK are considered to include the following:

- All costs and benefits to UK domestic shipping i.e. the monetary value of reduced emissions to air from pollutants; the changes in fuel costs and the costs associated with GHG increases;
- All benefits to UK international shipping (i.e. the monetary value of reduced emissions to air from pollutants) and the changes in fuel costs. The costs associated with increased GHGs are therefore excluded; and
- All benefits from in-transit shipping i.e. the monetary value of reduced emissions to air from pollutants on the basis that the UK would benefit from the lower air pollutants around its shores (only emissions changes within a certain

[29] BEIS (2018) "Valuation of energy use and greenhouse gas" https://webarchive.nationalarchives.gov.uk/20190105013225/https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/671205/Valuation_of_energy_use_and_greenhouse_gas_emissions_for_appraisal_2017.pdf. It is recognised that since this analysis was undertaken, more recent has been published as an update in 2019.

[30] As described in the annex, the non-traded value of GHGs has been used for this analysis because transport is not in the UK Emissions Trading System.

[31] This is correct at the time the analysis was undertaken in May 2019.

geographical distance from the UK are included, as noted above). None of the costs associated with increased fuel costs or increased GHGs are included.

This definition has been subject to sensitivity testing which is presented in section 5.5 and the separate report of Technical Annexes.

5.3 Impacts on emissions and costs for each option

5.3.1 Option 1

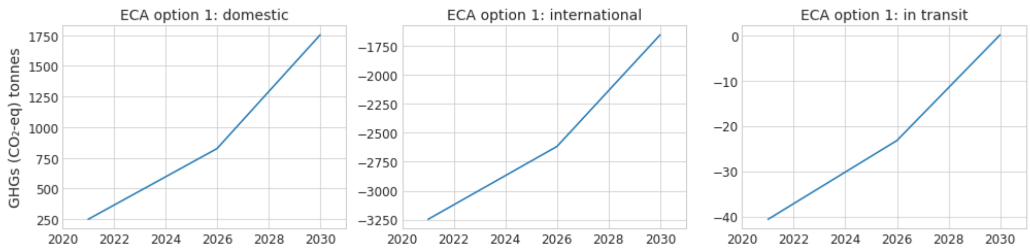
Option 1 involves extending the North Sea ECA to include all major ports in England[32] not covered by the current ECA with a time period of interest from 1st January 2021 to 31st December 2030.

The impacts on GHG emissions of this option when compared to the business as usual scenario are shown below – the charts show only the difference between the 'with policy' case and the BAU. This shows that the response to the policy option 1 is the increase of GHG emissions from domestic shipping and decrease of GHG emissions from international and in transit shipping.

Domestic shipping operating in the geographical area covered by option 1 is influenced by vessels that utilise HFO coupled with a scrubber in and outside of the ECA. Hence, when the ECA policy option 1 is considered in action, the GHG emissions will increase due to an intensified usage of a scrubber to comply with the ECA sulphur requirements.

International and "in transit" fleets operating in the geographical area covered by option 1 are more sensitive to vessels that burn LSHFO outside of the ECA and then switch to MDO when inside the ECA. This has a positive effect on GHG emissions when the ECA policy option 1 is in place because a lower amount of MDO fuel is needed to cover the operational energy demand inside the ECA than would have been needed of LSHFO (because MDO has a higher energy density than LSHFO). However, this positive effect is predicted to decrease over time as more vessels that utilise HFO with a scrubber will enter the fleets.

Figure 14 Impacts on annual emissions of option 1 relative to BAU (tonnes of CO_2e) over 2021 to 2030



Source: UMAS modelling

Note: Transport demand is assumed to increase over time - the kink in 2026 reflects the modelling approach to increase demand every 5-year period. Please see the Technical Annexes for more detail.

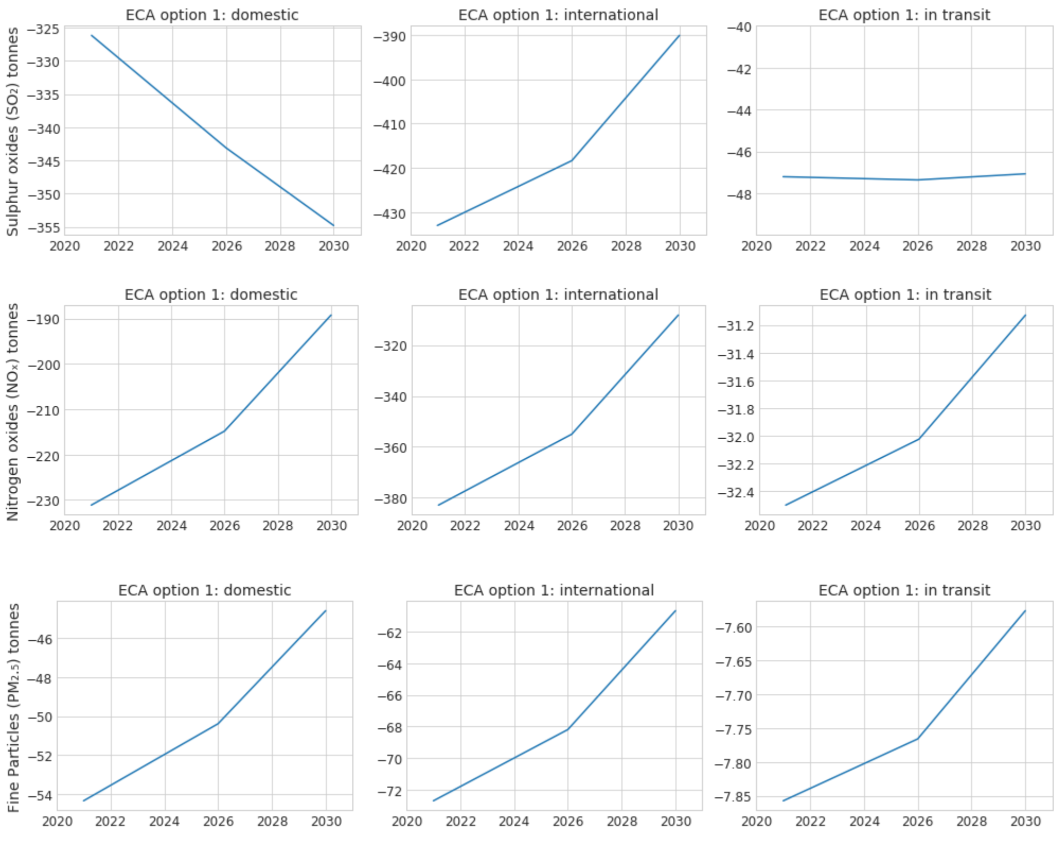
[32] Please note that port activity is a devolved area and therefore this option can only cover English ports plus Milford Haven in Wales – which is also reserved.

Figure 15 shows the impacts on emissions to air of pollutants of option 1. As shown, emissions of SO_2, NOx and $PM_{2.5}$ are lower with option 1 than they would have otherwise been under the business as usual.

The positive effect of ECA policy option 1 on both NOx and $PM_{2.5}$ emissions is predicted to become less visible over time as more vessels that utilise HFO with a scrubber will enter the fleets.

The effect of ECA policy option 1 on SO_2 emissions is also positive for all fleets. For the UK domestic fleet, the savings will continue to increase over time due to increasing demand for vessels that utilise HFO with a scrubber. For the UK international fleet, the SO_2 emissions savings associated with the ECA policy option 1 will slightly decrease over time in reaction to more vessels already complying with the sulphur limits in and outside the ECA entering the international fleet.

Figure 15 Impacts on annual emissions to air of pollutants from shipping of option 1 relative to BAU (SO_2, NO_x and $PM_{2.5}$), 2021 to 2030

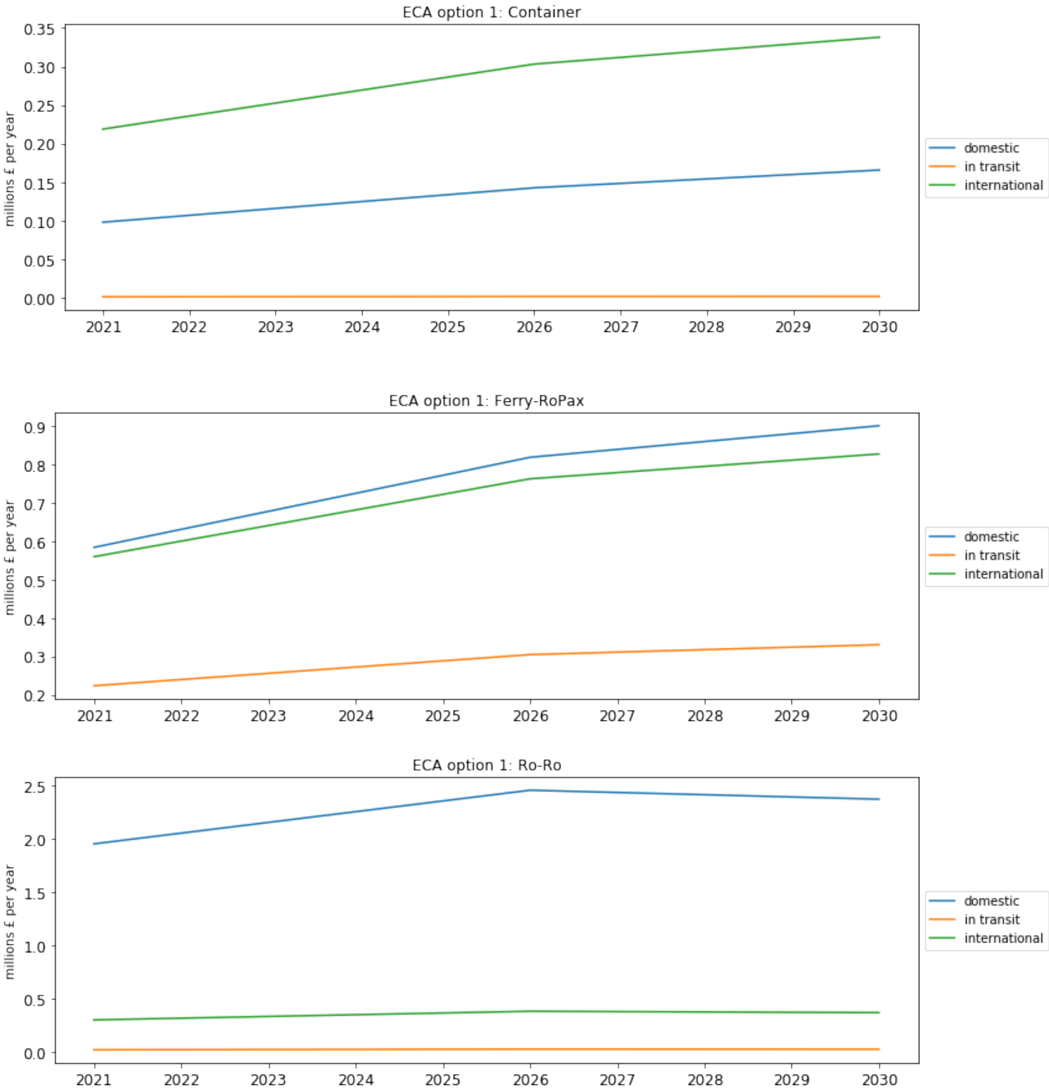


Source: UMAS modelling

Note: Transport demand is assumed to increase over time - the kink in 2026 reflects the modelling approach to increase demand every 5-year period. Please see Technical Annexes for more detail.

Option 1 is expected to impact on the fuel operating costs for each of UK domestic shipping, UK international shipping and in-transit shipping. The impacts on annual fuel operating costs are shown in Figure 16. The impacts are shown for three prevalent ship types: container ships, Ferry Ro-Pax and Ro-Ro. The charts show that option 1 impacts on in-transit transport fuel operating costs to a lesser extent than UK domestic and UK international shipping.

Figure 16 Impact on annual fuel operating costs of option 1 relative to BAU over 2021-2030 for container ships, Ferry Ro-Pax and Ro-Ro (£ undiscounted)



Source: UMAS modelling

Note: Costs for other ship types are in the Technical Annexes. Costs are in 2017 prices

Figure 16 shows the impact on Ro-Ro annual fuel operating costs are greater in magnitude than the other two prevalent ship types, and that for Ro-Ro it is UK domestic shipping that incurs higher annual fuel operating cost impacts (relative to BAU) for this ship type than UK international or in-transit transport.

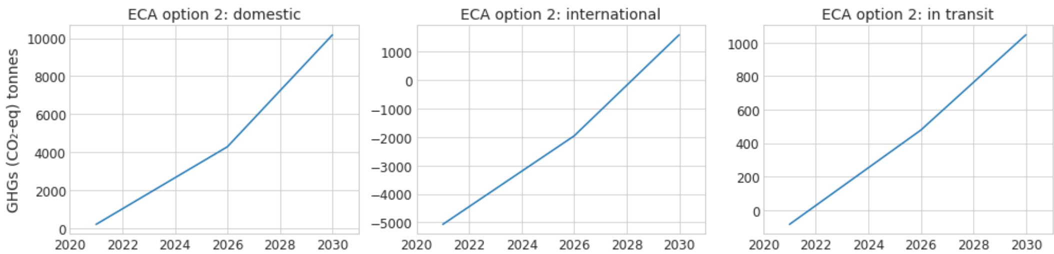
5.3.2 Option 2

Option 2 involves extending the North Sea ECA to include all of the UK territorial waters with a time period of interest of from 1st January 2021 to 31st December 2030 – this is the same time period as option 1.

The annual impacts on GHG emissions of this option when compared to the business as usual are shown below – the charts show only the difference between the 'with policy' case and the BAU. This shows that the *change* in GHGs associated with 'option 2' is to increase GHG emissions from UK domestic and in-transit shipping.

International shipping operating in the geographical area covered by option 2 is influenced by vessels that burn LSHFO outside the ECA and then switch to MDO when inside the ECA. This has a positive effect on GHG emissions up to about 2028. This is because a lower amount of MDO fuel is needed to cover the operational energy demand inside the ECA than would have been needed of LSHFO (because MDO has a higher energy density than LSHFO). However, the demand for vessels that utilise HFO with a scrubber will continue to rise resulting in increasing GHG emissions over time.

Figure 17 Impacts on annual emissions of option 2 relative to BAU (tonnes of CO_2e) over 2021 to 2030



Source: UMAS modelling

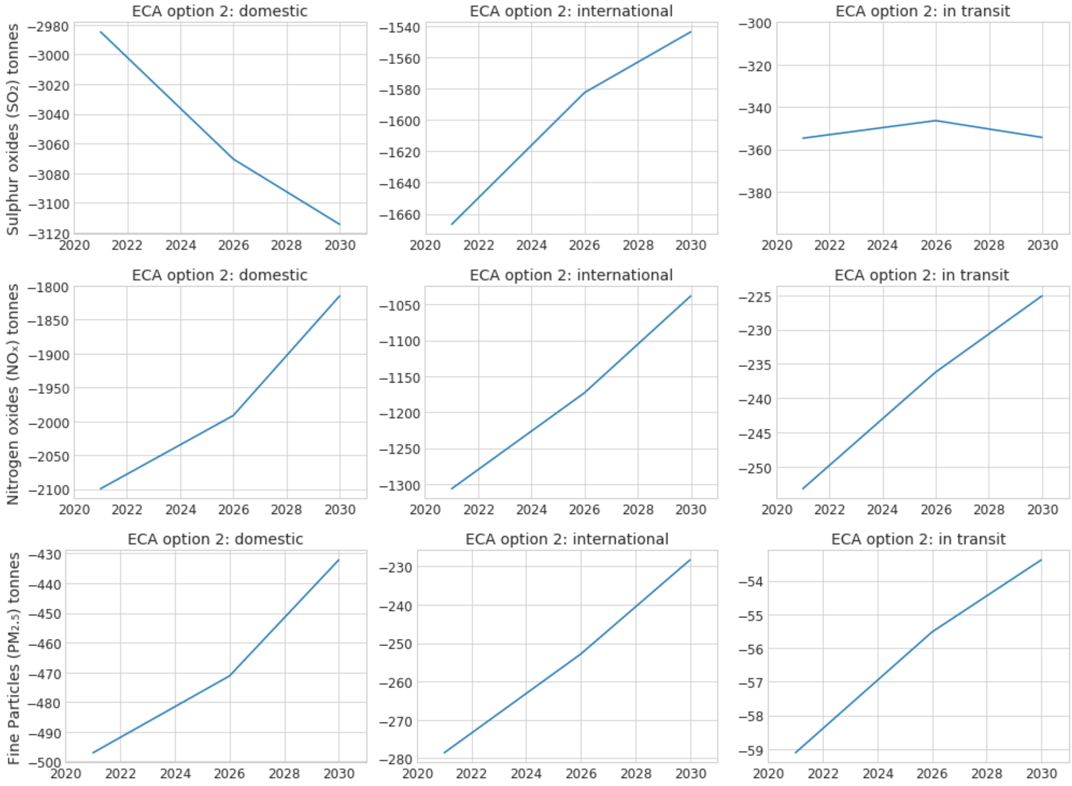
Note: Transport demand is assumed to increase over time - the kink in 2026 reflects the modelling approach to increase demand every 5-year period. Please see the Technical Annexes for more detail.

Figure 18 shows the impacts on emissions to air of pollutants from shipping under option 2. Similar to the impacts of option 1, as shown, emissions of SO_2, NOx and $PM_{2.5}$ are lower with option 2 than they would have otherwise been under the business as usual.

Similar to the impacts of the ECA extension policy option 1, the positive effect of the ECA policy option 2 on both NOx and $PM_{2.5}$ emissions is predicted to become less visible over time as more vessels that utilise HFO with a scrubber will enter the fleets.

The effect of the ECA policy option 2 on SO_2 emissions is also positive for all fleets. For the UK domestic fleet, the savings will continue to increase over time due to increasing demand for vessels that utilise HFO with a scrubber. For the UK international fleet, the SO_2 emissions savings associated with the ECA policy option 2 will slightly decrease over time in reaction to more vessels already complying with the sulphur limits in and outside of the ECA entering the international fleet.

Figure 18 Impacts on annual emissions to air of pollutants from shipping of option 2 relative to BAU (SO_2, NO_x and $PM_{2.5}$), 2021 - 2030



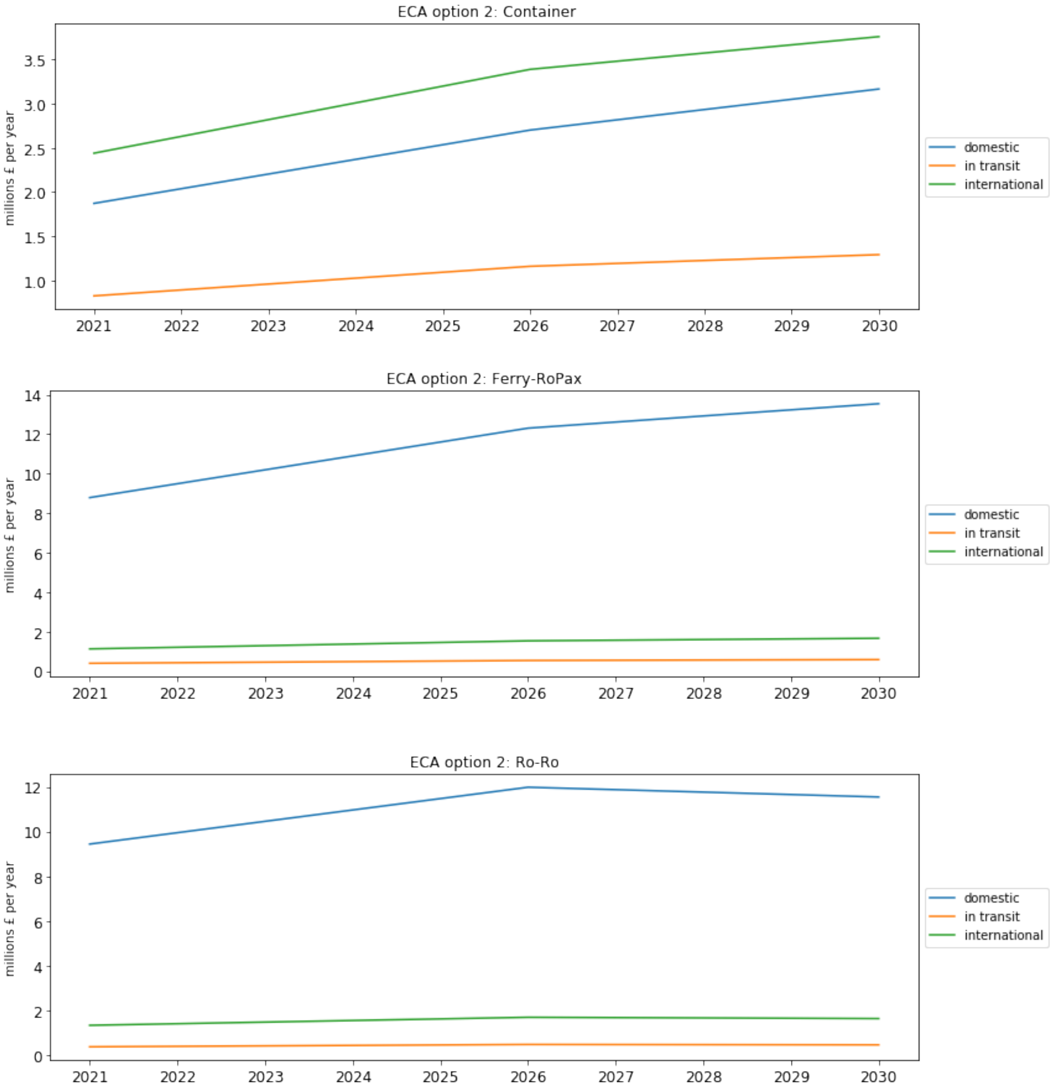
Source: UMAS modelling

Note: Transport demand is assumed to increase over time - the kink in 2026 reflects the modelling approach to increase demand every 5-year period. Please see Technical Annexes for more detail.)

As with option 1, under option 2, air pollutant emissions in all cases are unambiguously lower than they would have been under the BAU case. For NO_x and SO_2 emissions to air from UK international shipping, after the initial decline, the emissions begin to rise again over the period as shipping demand rises (though these emissions are still lower than they would have been under BAU). **This implies that the controls on marine air pollution could need to be tightened further in order to offset the increase in shipping demand over time**.

In terms of the impacts on annual fuel operating costs, these are shown in Figure 19 for three particular ship types which are found in the analysis to experience the largest increase in annual fuel operating costs as a result of option 2: Ferry Ro-Pax, Container and Ro-Ro.

Figure 19 Impact on annual fuel operating costs of option 2 relative to BAU over 2021-2030 for container ships, Ferry Ro-Pax and Ro-Ro (£ undiscounted)



Source: UMAS modelling

Note: Costs for other ship types are in the Technical Annexes. Costs are in 2017 prices

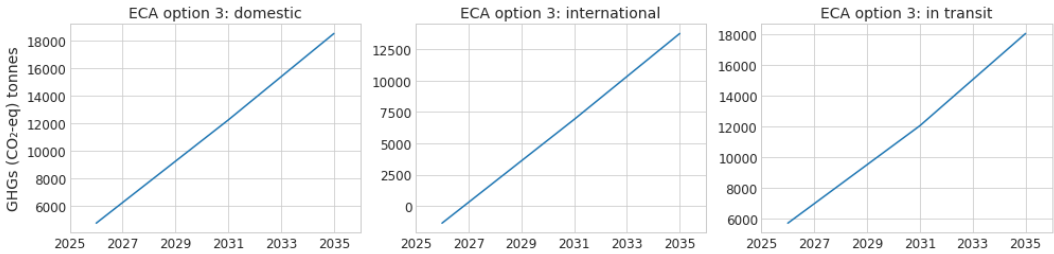
Figure 19 shows that again the impact on annual fuel operating costs relative to BAU for in-transit is low. For domestic Ferry Ro-Pax ships, the annual cost is relatively higher than for other ship types, with costs increasing by up to £14 million per year over the period. For container ships, costs continue to rise over time both for domestic and international, reaching close to £4 million per year for international shipping by 2030 and over £3 million per year for domestic. Similar to Ferry Ro-Pax, Ro-Ro ships are predominantly domestic shipping and these ships see costs rise by nearly £12 million per year.

5.3.3 Option 3

Option 3 covers a slightly later 10-year period as it involves extending the North Sea ECA to include the Irish Sea and down to the English Channel (including the Isle of Ouessant but not going South to the Biscay Bay) with a time period of interest of 1st January 2026 to 31st December 2035. This is the largest geographical area of the ECA extension options considered.

The impacts on annual emissions of GHGs relative to BAU of this policy option are shown in Figure 20. This shows annual GHG emissions are higher each year than they would have been under the BAU. This is due to an intensified usage of a scrubber to comply with ECA sulphur requirements.

Figure 20 Impacts on annual emissions of option 3 relative to BAU (tonnes of CO_2e) over 2026 to 2035



Source: UMAS modelling

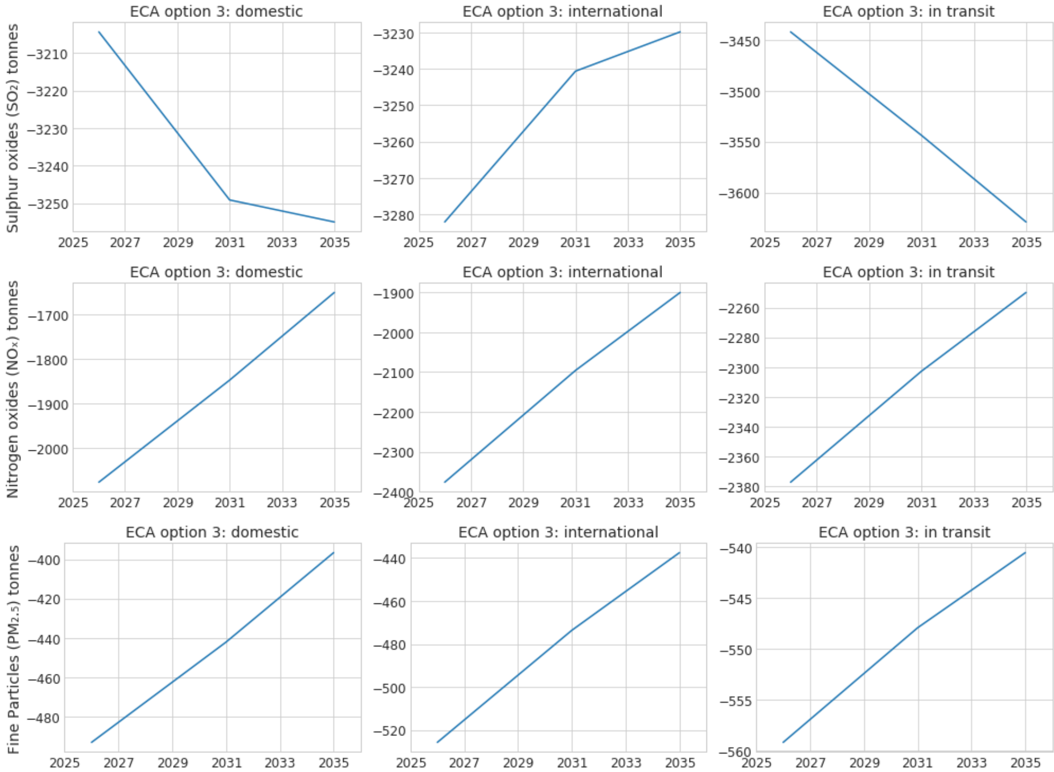
Note: Transport demand is assumed to increase over time - the kink in 2026 reflects the modelling approach to increase demand every 5-year period. Please see the Technical Annexes for more detail.

The annual impacts on air pollutants from shipping as a result of option 3 are shown in Figure 21. This shows that in all cases, air pollutant emissions are lower with option 3 than they would otherwise have been under the BAU case.

As with the other ECA extension options, the positive effect of the ECA policy option 3 on both NOx and $PM_{2.5}$ emissions is predicted to become less visible over time as more vessels that utilise HFO with a scrubber will enter the fleets.

The effect of the ECA policy option 3 on SO_2 emissions is also positive for all fleets. For the UK domestic and "in transit" shipping the savings will continue to increase over time due to increasing demand for vessels that utilise HFO with a scrubber. For the UK international shipping, the SO_2 emissions savings associated with the ECA policy option 3 will slightly decrease over time in reaction to more vessels already complying with the sulphur limits in and outside of the ECA entering the international fleet.

Figure 21 Impacts on annual emissions to air of pollutants from shipping of option 3 relative to BAU (SO_2, NO_x and $PM_{2.5}$), 2026 - 2035



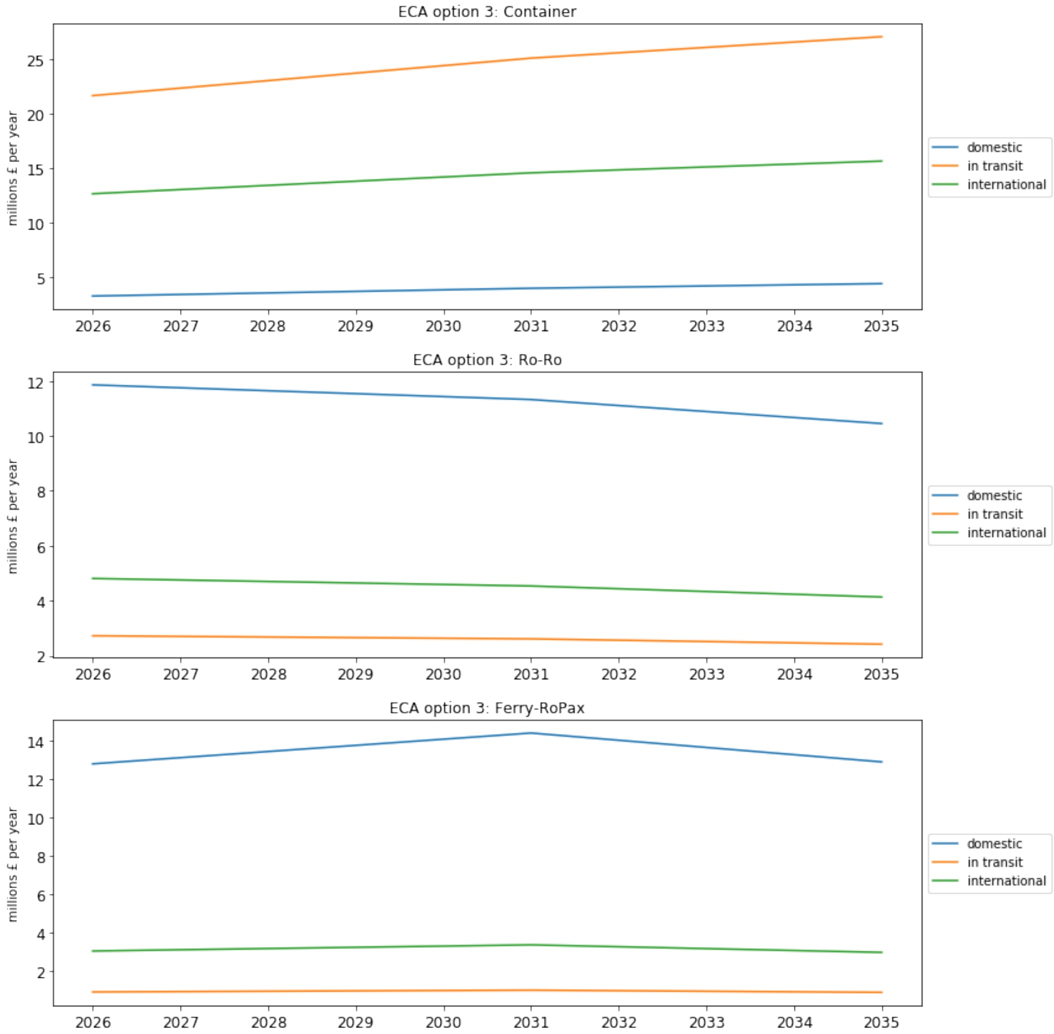
Source: *UMAS modelling*

Note: *Transport demand is assumed to increase over time - the kink in 2026 reflects the modelling approach to increase demand every 5-year period. Please see the Technical Annexes for more detail.*

The impacts on the annual fuel operating costs of option 3 are shown in Figure 22 for the three ship types that experience the most significant changes in these costs: Container, Ro-Ro and Ferry Ro-Pax. This shows that for containers ships, in transit voyages experience the greatest cost increases, of around £28 million per year by the end of the policy period in 2035, with international shipping voyages also experiencing cost increases of over £16 million per year by 2035. Costs are on an upward trend for both types of voyages over the period of the policy to 2035. Domestic shipping is less prevalent for this ship type, so the cost impacts are correspondingly lower.

For both Ro-Ro and Ferry Ro-Pax, UK domestic shipping is expected to experience larger annual fuel operating cost increases than UK international shipping or in transit voyages. This is because vessels of these types mostly operate domestically.

Figure 22 Impact on annual fuel operating costs of option 3 relative to BAU over 2026-2035 for container ships, Ro-Ro and Ferry Ro-Pax (£ undiscounted)



Source: UMAS modelling

Note: Costs for other ship types are in the Technical Annexes. Costs are in real 2017 prices

5.4 Comparing costs and benefits across the ECA extension options

This section provides a comparative analysis of the three policy options.

In line with the Green Book, costs and benefits over the period of the policy can be presented in 'present value' terms. This form of presentation allows monetary values to be placed on the annual costs (changes in annual fuel operating costs for the shipping industry, plus the change in annual GHG emissions) and the benefits (changes in emissions to air of pollutants from shipping). The sum of annual costs and benefits over the 10-year life of the policy are then 'discounted' to a sum over the ten-year appraisal period. Discounting accounts for the fact that costs and benefits in the future are given relatively less weight than costs and benefits realised in the nearer term.

The period of the policy intervention differs between options 1 and 2 (which both cover the period 1st January 2021 to 31st December 2030) and option 3 (which covers the period 1st January 2026 to 31st December 2035).

The cost benefit analysis therefore involves the following steps:

- Costs:
  - Take the impacts on annual fuel operating costs from the GloTraM modelling;
  - Take the impacts on annual GHG emissions from the GloTraM modelling. Convert to a monetary value using BEIS costs per tonne of CO_2e;
  - Convert to discounted sum of annual costs (both categories of costs above) over the ten-year period of the policy.
- Benefits:
  - Take the impacts on annual emissions to air of air pollutants (SO_2, NOx and PM2.5) from the GloTraM modelling. Convert to a monetary value using Defra values per tonne of each type of emissions;
  - Convert to discounted sum of annual benefits over the ten-year period of the policy.

To make each option directly comparable the NPVs of the options have been discounted to 2019 as show below.

To be in accordance with the Green Book, the central case of costs and benefits needs to reflect the costs and benefits to the UK only. For the purposes of this analysis this is considered to include the costs and benefits as shown in Figure 23.

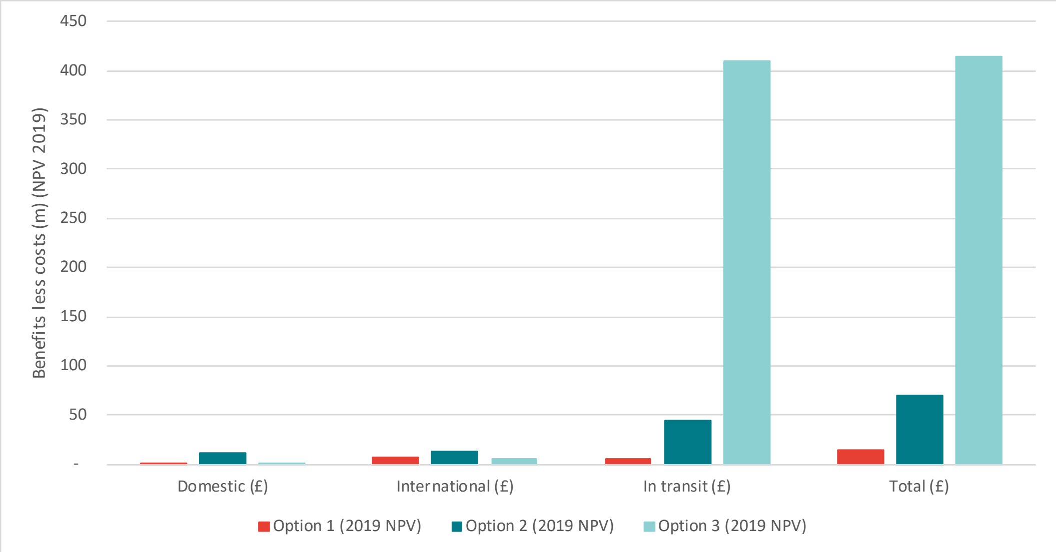
Figure 23 Costs and benefits included in the central analysis across ECA extension policy options

	Domestic	International	In-transit
Air quality benefits	✓	✓	✓
Fuel costs	✓	✓	
GHG costs	✓		

Note: Only the costs associated with the increase in GHG to UK domestic shipping are included (not for UK international or in-transit shipping) because only UK domestic shipping emissions are included in UK carbon budgets. This follows the advice of BEIS (provided April 2019).

The key results for the central case estimates of costs and benefits are shown in Figure 24.

Figure 24 UK net present values for the three policy options, discounted to 2019 (2017 prices)



Source: Frontier analysis

Note: NPV is defined as the discounted benefits minus discounted costs. The policies are implemented on the dates defined above.

Figure 24 shows that all three options have positive UK net present values indicating that overall, they deliver benefits in terms of air pollutant emission reductions that outweigh the costs to the shipping industry from the higher operating costs associated with compliance.

Overall, option 3 delivers the highest absolute UK net present value (i.e. monetary benefits to the UK exceed the monetary costs to the UK by the greatest absolute amount).

For option 3, benefits exceed costs to a greater extent for in-transit voyages far more than for domestic or international voyages. This is in part because the costs for those voyages are not considered a cost to the UK and have therefore not been included.

Detailed results for the costs and benefits are shown in Figure 25. This shows that option 3 is expected to deliver a net present value benefit of £414.7 million over the appraisal period (discounted to 2019). Option 2 delivers net present value benefits of around £70.2 million; with option 1 delivering a net present value benefit of around £14.3 million.

Figure 25 Net present values of the three ECA extension policy options, discounted to 2019 (2017 prices)

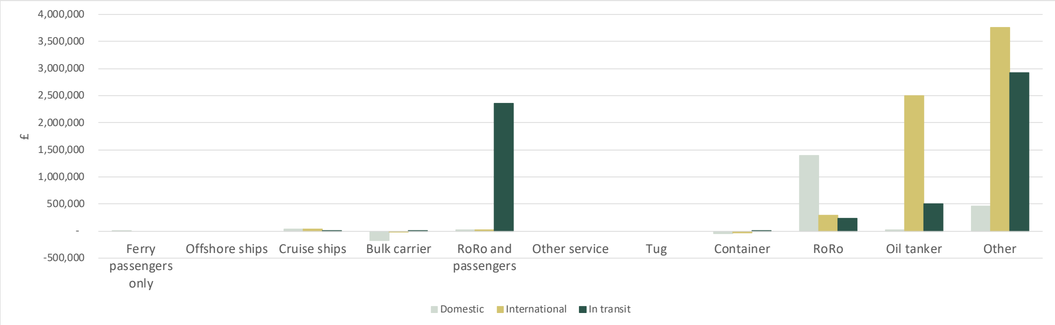
	UK domestic (£m)	UK international (£m)	In-transit (£m)	Total (£m)
Option 1	1.7	6.6	6.0	14.3
Option 2	12.1	13.7	44.5	70.2
Option 3	0.1	5.1	409.4	414.7

Source: Frontier analysis of UMAS GloTraM modelling

Note: Figures are rounded

When looking at the costs and benefits in more detail by ship type, for option 1, Figure 26 shows that although Ro-Ro and passenger ships, RoRo ships, oil tankers and ‘other’ experience the greatest absolute increases in annual fuel operating costs, these are outweighed by the benefits associated with lower emissions to air of pollutants (for in-transit shipping, changes in fuel and GHG emissions costs are not assumed to accrue to the UK, but the benefits of lowering emissions to air of pollutants do accrue to the UK).

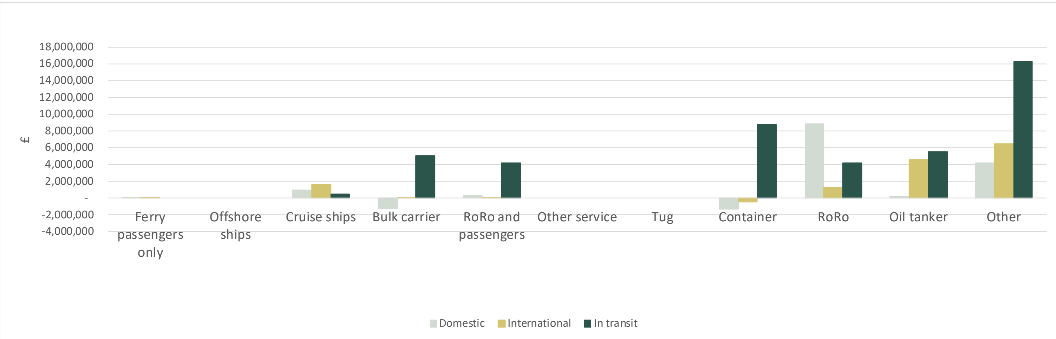
Figure 26 Net present values by ship type for option 1, discounted to 2019 (2017 prices)



Source: Frontier analysis of UMAS GloTraM modelling

For option 2, the distribution of ship types contributing to the overall net present value differs from option 1. The most significant contributors to the overall NPV are bulk carriers, RoRo and passenger ships, container ships, RoRo ships and oil tankers (plus ‘other’). For each of these ship types apart from RoRo, the key driver of the NPV is in-transit shipping. This is shown in Figure 27.

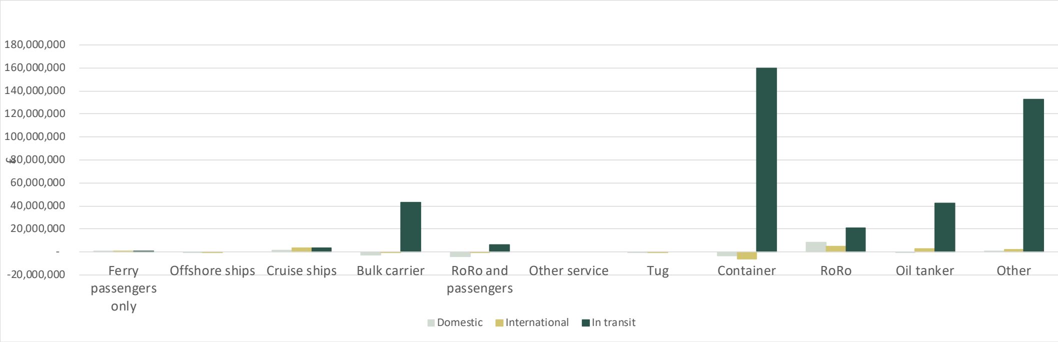
Figure 27 Net present values by ship type for option 2, discounted to 2019 (2017 prices)



Source: Frontier analysis of UMAS GloTraM modelling

For option 3, ships types for which benefits exceed the costs the most are primarily in-transit bulk carriers, containers, RoRo and oil tankers (and ‘other’). This is shown in Figure 28. Again, this is largely because in-transit fuel costs and GHG costs are not treated as costs to the UK but the benefits of reduced emissions to air of pollutants accrue to the UK.

Figure 28 Net present values by ship type for option 3, discounted to 2019 (2017 prices)



Source: Frontier analysis

5.5 Sensitivity analysis

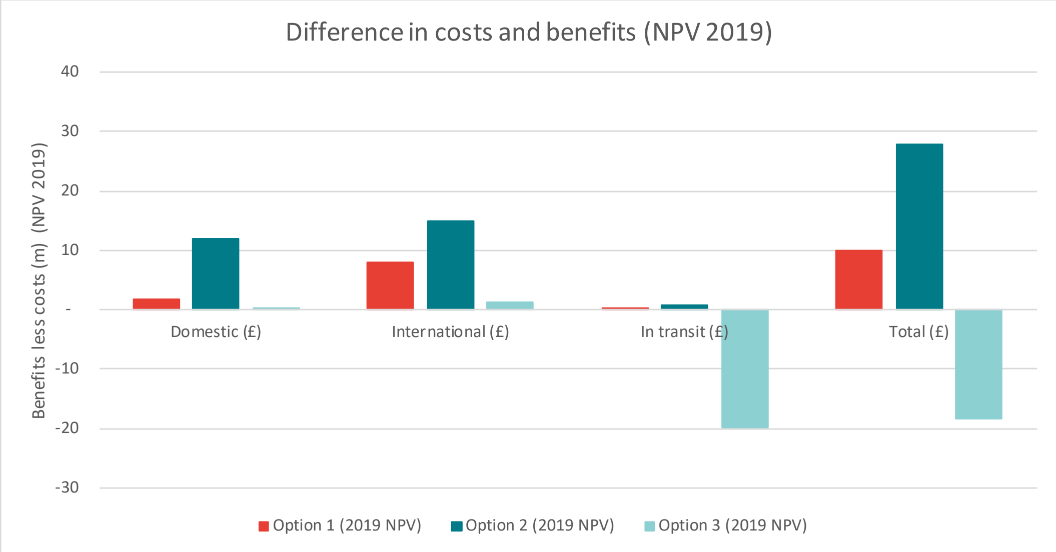
In order to understand how the results may differ under alternative configurations of the costs and benefits, two particular sensitivity tests are explored below (with more in the Technical Annexes). These relate to:

- The definition of 'costs and benefits to the UK'. Above, the costs and benefits to the UK were defined as indicated in Figure 23. Below, the following alternative sensitivity tests are explored:
  - The costs and benefits to the UK are defined as all costs (changes in annual fuel operating costs plus annual changes in GHGs) and benefits (changes in emissions to air of pollutants) for each of UK domestic, UK international and in-transit shipping; and
  - The costs and benefits to the UK are defined as per the central case, but all in-transit benefits are ignored;
- The year to which the costs and benefits are discounted. Above, the costs and benefits each year over the period of the intervention were discounted to 2019 to aid comparability. Below, the following alternative is explored:
  - Discount the values to the first day of the intervention (i.e. 1st January 2021 for options 1 and 2, and to 1st January 2026 for option 3).

5.5.1 Alternative definitions for the costs and benefits to the UK

Firstly, defining costs and benefits to the UK in terms of all costs and all benefits for each of UK domestic, UK international and in-transit shipping results in the costs and benefits as shown in Figure 29.

Figure 29 Net present values to the UK, including all costs and benefits for domestic, international and in-transit shipping (sensitivity analysis)



Source: Frontier analysis of UMAS GloTraM modelling
Note: Discounted to 2019, in 2017 prices

Relative to the case shown in Figure 24, the costs to ship owners and operators on in-transit voyages are now included, as are the costs and benefits associated with changes in GHG emissions from UK international and in-transit shipping. The inclusion of in-transit shipping has a material impact on option 3 in particular. For this sensitivity test, costs (including changes in fuel costs and changes in GHGs where they increase) outweigh the benefits of reduced emissions to air of pollutants by around £19.9 million. This reflects the fact that option 3 has a material impact on the costs of in-transit shipping that are assumed not to accrue to the UK under the central case analysis because they do not call at the UK – the central case does not consider costs or benefits incurred by other states.

This is shown more evidently in Figure 30**.**

In this case, option 2 provides the highest net present value (and not option 3 as was the case under central assumptions).

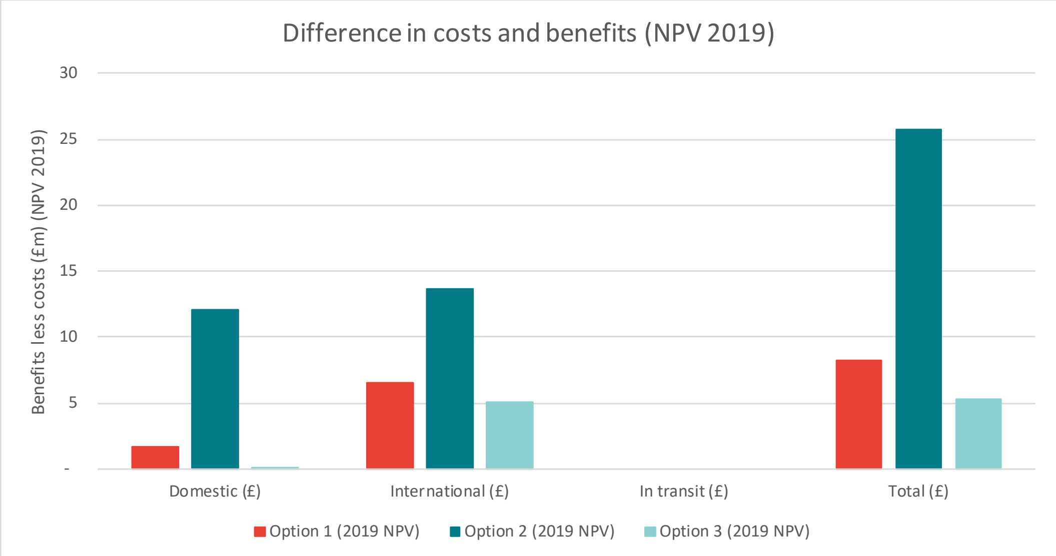
Figure 30 Net present values of the three ECA extension policy options, discounted to 2019 (2017 prices), including all costs and benefits for domestic, international and in-transit shipping (sensitivity analysis)

	UK domestic (£m)	UK international (£m)	In-transit (£m)	Total (£m)
Option 1	1.7	8.1	0.1	9.9
Option 2	12.1	14.9	0.8	27.8
Option 3	0.1	1.3	-19.9	-18.4

Source: Frontier analysis of UMAS GloTraM modelling
Note: Figures are rounded

Secondly, if costs and benefits to the UK are defined to be the same as the central case for each of domestic and international shipping only, and in-transit costs and benefits are excluded, results are as in Figure 31.

Figure 31 Net present values to the UK, as per the central case but excluding in-transit costs and benefits (sensitivity analysis)



Source: Frontier analysis of UMAS GloTraM modelling

Note: Discounted to 2019, in 2017 prices. The figure includes all costs and benefits to UK domestic shipping; all costs and benefits to UK international shipping (apart from GHG changes, in line with BEIS guidance) and excluding all cost and benefits to in-transit shipping.

When in-transit benefits are excluded from the central case costs and benefits, the net present values are substantially lower than under the central case. This is because the benefits accruing from in-transit shipping were a key driver of the overall net benefits of all options, particularly option 3.

The more detailed results are shown in Figure 32.

Again, this shows that option 2 delivers the highest net present value under these assumptions.

Figure 32 Net present values of the central case, but excluding benefits to in-transit shipping for the three ECA extension policy options, discounted to 2019 (2017 prices) (sensitivity analysis)

	UK domestic (£m)	UK international (£m)	In-transit (£m)	Total (£m)
Option 1	1.7	6.6	-	8.3
Option 2	12.1	13.7	-	25.7
Option 3	0.1	5.1	-	5.3

Source: Frontier analysis of UMAS GloTraM modelling

Note: Figures are rounded

5.5.2 The year to which costs and benefits are discounted

When the profile of costs and benefits of each policy option is discounted to the policy start date rather than back to 2019, the results are as shown in Figure 33 for the central case (Figure 34 and Figure 35 shows the estimated present values of all of the impacts under each scenario).

For option 1 there is relatively little impact on the net present value when discounting of costs and benefits is to the policy start date rather than 2019. The impact on option 2 is also relatively low. However, the impact is material for option 3 because it has a later start date and hence there is a greater difference in the number of years between 2019 and the assumed start date of the policy than for the other two options.

Figure 33 Net present values of the three ECA extension policy options, discounted to policy start date (2017 prices) – central case

	UK domestic (£m)	UK international (£m)	In-transit (£m)	Total (£m)
Option 1	1.8	7.0	6.5	15.3
Option 2	12.9	14.6	47.6	75.2
Option 3	0.2	6.5	520.9	527.6

Source: Frontier analysis of UMAS GloTraM modelling

This shows that under the central case assumptions about costs and benefits, the NPV for option 3 increases from £414.7 million (2017 prices) under central case assumptions to £527.6 million (2017 prices). For options 1 and 2, NPVs are higher relative to the central case discounted to 2019 at £15.3 million compared to £14.3 million, and £75.2 million compared to £70.2 million under central assumptions discounted to 2019.

Figure 34 Present values of all impacts for the three ECA extension policy options, discounted to policy start date (2017 prices)

	UK Domestic Shipping			UK International Shipping			In-transit shipping		
	Benefits (£m)	Fuel costs (£m)	GHG costs (£m)	Benefits (£m)	Fuel costs (£m)	GHG costs (£m)	Benefits (£m)	Fuel costs (£m)	GHG costs (£m)
Option 1	44.3	41.9	0.5	58.7	51.6	-1.7	6.5	6.4	-0.0
Option 2	405.7	390.0	2.8	219.2	204.6	-1.4	47.6	46.5	0.3
Option 3	449.1	439.9	8.9	470.4	463.8	4.8	520.9	537.2	9.0

Source: Frontier analysis of UMAS GloTraM modelling

Note: Figures are rounded

Figure 35 Present values of all impacts for the three ECA extension policy options, discounted to 2019 (2017 prices)

	UK Domestic Shipping			UK International Shipping			In-transit shipping		
	Benefits (£m)	Fuel costs (£m)	GHG costs (£m)	Benefits (£m)	Fuel costs (£m)	GHG costs (£m)	Benefits (£m)	Fuel costs (£m)	GHG costs (£m)
Option 1	41.4	39.1	0.5	54.8	48.2	-1.5	6.0	5.9	-0.0
Option 2	378.7	364.0	2.6	204.6	191.0	-1.3	44.5	43.4	0.3
Option 3	353.0	345.8	7.0	369.7	364.6	3.8	409.4	422.2	7.0

Source: Frontier analysis of UMAS GloTraM modelling

Note: Figures are rounded

6 POLICY IMPLICATIONS

This analysis has compared the costs and benefits of three illustrative ECA extension policy options.

In line with best practice cost-benefit analysis, and as advocated in the Green Book (HMT, 2018), the options have all been assessed against the outcomes that would be likely in the absence of the interventions. This is known as the 'business as usual' case.

It should be noted that the options differ in terms of both their geographical coverage, and the time period over which they are assumed to be in operation. For these reasons, the business as usual is specific to each option and only ships operating within the specified ECA extension areas for each policy option are considered.

The actions that ship owners and operators are permitted to take within the analysis to comply with the emissions regulations imposed within the ECAs are the following:

Compliance with the ECA sulphur limit:

- If ships are using fuel oil under the business as usual scenario, including if they are expected to be using 0.5% compliant low sulphur fuel oil, then when operating in the extended ECA they are expected to switch to Marine Diesel Oil (MDO) to be in compliance of the 0.1% limit. This has the impact of increasing the operating costs to the relevant ship owners and operators. For ships not using fuel oil (e.g. using MDO or LNG), these ships will be in compliance and therefore they are assumed to continue to use the same fuel when operating in the extended ECA. If the ship is specified in the business as usual scenario as already having a sulphur scrubber fitted, then the ship is assumed to continue to use high sulphur fuel when operating in the extended ECA, with the scrubber used to reach the compliance limit.

Compliance with the ECA NOx limit:

- Compliance is only required for newbuild ships that are required to meet the Tier III NOx limit (e.g. ships built after 2021). It is assumed, given expectations of interoperability between coasts of the UK, that ships that need to be Tier III compliant will already have a Selective Catalytic Reduction system (or equivalent Tier III compliant machinery) fitted under the business as usual case. They will therefore just be required to operate it in the extended ECA.

Key observations from the analysis are several fold.

First, under options 1 and 2, UK domestic shipping (ships which both begin and end their voyage at a UK port) accounts for 12% and 17% respectively of the overall NPVs, whereas for option 3, the equivalent share of UK domestic shipping is just 0.03%. UK international shipping (ships which serve the UK for imports or exports) account for 45.8% and 19.5% of total NPV for options 1 and 2 respectively, whereas for option 3 the equivalent share is just 1.2%. Finally, in-transit shipping (ships that pass through the ECA but do not call at a UK port) accounts for 42.2%

for option 1, 63.3% for option 2 and 98.7% for option 3. Therefore, this shows that the benefits of the ECA from regulating in-transit shipping are a key driver of the net benefit of each option, particularly option 3. This is because for the purposes of this analysis, as the focus is on the costs and benefits to the UK, the benefits to the UK of reduced emissions to air of pollutants from in-transit shipping are included, but the costs of the ECA extension to in-transit ships are not treated as costs to the UK, and nor are any increases in greenhouse gas emissions from those ships.

Second, the absolute scale of costs to the UK from regulating UK domestic shipping (both fuel costs and increases in GHG emissions) is much lower in option 1 (around £39.7 million in discounted present value terms[33], 2017 prices) compared to option 2 (around £366.6 million in discounted present value terms[34]. and option 3 (around £352.8 million in discounted present value terms[35], 2017 prices).

Third, in all options, emissions to air of pollutants from shipping would be expected to be lower than under the business as usual scenario. However, emissions of SO_2 and $PM_{2.5}$ could in some cases initially decline but then rise again over the ten-year period of the policy under consideration due to the expected growth in shipping transport demand.

Fourth, there is an apparent trade-off such that when air pollution is targeted through the ECA extension, this has the effect under all options of increasing greenhouse gas emissions from UK domestic shipping, which is an issue in the context of UK carbon budgets. This is because more vessels that utilise HFO with a scrubber will enter the fleets to comply with the sulphur requirements in and outside of the ECA which, in turn, will increase the GHG emissions due to an intensified usage of a scrubber. Therefore, **complementary policy would be needed to provide appropriate incentives to reduce greenhouse gas emissions, while also remaining compliant with air pollution regulations**.

Fifth, the costs of the ECA extensions to UK domestic and international shipping are likely to fall more heavily on some ship types than others. For option 1, 94% of the changes in fuel costs is expected to be incurred by four ship types: RoRo, oil tankers, RoRo & passengers and 'other'[36]. For option 2, the same four ship types plus container ships account for 93% of the change in fuel costs; with the same finding for option 3. This reflects the prevalence of these ship types in the respective areas.

[33] Over the ten-year period of the policy, discounted to 2019

[34] Over the ten-year period of the policy, discounted to 2019

[35] Over the ten-year period of the policy, discounted to 2019

[36] "Other" vessels comprise the non-modelled in GloTraM vessel types that include chemical tankers, general cargo vessels, liquefied gas tankers, other liquids tankers, refrigerated bulk carriers, vehicle carriers, yachts and miscellaneous – fishing vessels.

7 ANNEX: GLOSSARY OF SHIP TYPES

A brief description of ship types is as follows:

- Bulk Carrier: A bulk carrier, bulk freighter, or colloquially, bulker is a merchant ship specially designed to transport unpackaged bulk cargo, such as grains, coal, ore, and cement, in its cargo holds
- Container: a ship which is designed to carry goods stored in containers
- Oil tanker: a ship designed to carry oil in bulk
- Ferry-pax only: Ferries designed for the transportation of passengers only
- Cruise: a large ship that carries people on voyages for pleasure
- Ferry-RoPax, also referred to as RoRo & passengers: Roll-on/Roll-off passenger. It is a ro-ro vessel built for freight vehicle transport with passenger accommodation
- RoRo: Roll-on/Roll-off. Also called RORO, these are conventional ferries that can let vehicles easily leave
- Service – tug: is a type of vessel that manoeuvres other vessels by pushing or pulling them either by direct contact or by means of a tow line
- Offshore: ships that specifically serve operational purposes such as oil exploration and construction work at the high seas
- Service – other service vessels

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