WORKING PAPER

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From concept to impact: Evaluating the potential for emissions reduction in the proposed North Atlantic Emission Control Area under different compliance scenarios

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SUMMARY

This study assesses the potential for reducing emissions from ships in the North Atlantic Ocean by designating the region an Emission Control Area. The North Atlantic Emission Control Area (AtlECA) would impose stricter regulations aimed at reducing emissions of sulfur oxides (SO_X), fine particulate matter ($PM_{2.5}$), and nitrogen oxides (NO_X). The possible AtlECA includes the territorial seas and exclusive economic zones of the Faroe Islands, France, Greenland, Iceland, Ireland, Portugal, Spain, and the United Kingdom, with potential expansion to include the Azores and Madeira archipelagos of Portugal and the Canary Islands of Spain. The results of this study are intended to be a part of a submission to the International Maritime Organization's Marine Environment Protection Committee on designating the AtlECA, following the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI requirements.

We estimate that the AtlECA designation could lead to significant emission reductions in pollutants. In 2030, if distillate fuel is used to comply with the ECA regulations, there could be an 82% reduction in SO_X emissions, a 64% reduction in $PM_{2.5}$, and a 36% reduction in black carbon (BC) emissions when compared to a scenario without ECA regulations. Additionally, we project that if the outermost regions of Portugal and Spain join the AtlECA, air pollution near these islands could be significantly reduced. The projected reductions include 84% in SO_X, 67% in $PM_{2.5}$, and 41% in BC emissions if distillate is used as the compliance fuel.

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The choice of fuels and technologies to comply with ECA regulations may result in different emissions reductions. Using ultra-low sulfur fuel oil would produce 9% more SO_x, 55% more $PM_{2.5}$, and 36% more BC emissions than using distillates to power ships. While scrubbers can be equally effective in reducing SO_x emissions, the heavy fuel oil used with the scrubbers would generate 17% more $PM_{2.5}$ and 32% more BC emissions than distillate fuel. We also estimate that current Tier III standards for reducing NO_x emissions will have a limited impact in the short term. These standards for new ships would reduce NO_x emissions by 3% in 2030, assuming that the AtlECA comes into force in 2027. However, retrofitting older ships sailing in the AtlECA to Tier III standards could result in a 71% reduction in NO_x emissions.

INTRODUCTION

In 2023, 11 countries and the European Commission submitted a joint paper to the Marine Environment Protection Committee (MEPC), part of the International Maritime Organization (IMO), updating efforts to coordinate the required studies concerning the establishment of a new North Atlantic Emission Control Area (AtlECA).[1] The submission (MEPC 80/INF.35) was led by Portugal's Directorate-General for Natural Resources, Safety, and Maritime Services. Depending on the outcome of the studies, a formal proposal would be submitted to designate the AtlECA. The International Council on Clean Transportation (ICCT) was appointed to lead a technical assessment study in close collaboration with the Faculty of Engineering of the University of Porto.

This study supports the initial phase of the ongoing assessment of designating an Emission Control Area (ECA) for the territorial seas and exclusive economic zones of the Faroe Islands, France, Greenland, Iceland, Ireland, Portugal, Spain, and the United Kingdom. The ECA proposals must include a submission of proof that there is a need for the designation. The International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, Appendix III (MEPC 58/23/Add.1 Annex 13) specifies eight criteria for establishing an ECA. The full list of criteria is in Appendix A.

This study addresses the following criteria of MARPOL Annex VI, Appendix III:

- For criterion 3.1.1, the study outlines the proposed AtlECA and potential expansion to the outermost regions of Spain and Portugal.
- For criteria 3.1.2 and 3.1.6, the study examines shipping traffic patterns and density and identifies emissions for control.
- The study partly addresses criterion 3.1.4 by assessing emissions from ships operating in the area and projecting ECA compliance scenarios using various fuel mixes and compliance technologies allowed by MARPOL.

To fulfill the above criteria, we analyze shipping traffic and power demand in the proposed AtlECA and projected this demand to 2030. We model ECA compliance scenarios using low-sulfur fuels or equivalent technologies approved by MARPOL Annex VI and assess the capacity of these fuels and technologies for reducing sulfur oxides (SO_x), nitrogen oxides (NO_x), fine particulate matter ($PM_{2.5}$), and black carbon (BC) emissions.

In conclusion, we offer recommendations for the geographical scope of the AtlECA and on the optimal compliance mechanisms having the highest emission reduction benefits under an AtlECA designation. The findings of this study, including the gridded spatial emission inventories, will be used in a follow-up analysis to estimate ambient

1 Submitted by Austria, Estonia, Finland, France, Iceland, Ireland, Luxembourg, Netherlands, Portugal, Spain, the United Kingdom, and the European Commission

concentrations of air pollutants and the related environmental and health impacts. This follow-up analysis will also address additional criteria specified in MARPOL Annex VI.

BACKGROUND AND OBJECTIVE

In recent years, there has been a growing body of research focused on the impact of shipping emissions on human health. Maritime shipping has traditionally relied on large diesel engines fueled by heavy fuel oil (HFO), which emit harmful air pollutants like SO_x and NO_x. These emissions have strong adverse effects on air quality, particularly in coastal areas (Nunes et al., 2020). SO_x and NO_x are significant contributors to the formation of $PM_{2.5}$. These pollutants pose substantial health risks, including respiratory diseases, cardiovascular diseases, and increased mortality (Zhang et al., 2021). A study by Sofiev et al. (2018) estimated that shipping-related emissions contributed to up to 265,000 premature deaths worldwide in 2020, equivalent to roughly 0.5% of global mortality. In addition, NO_x emissions from shipping were directly associated with an increased incidence of asthma, particularly among children. A study conducted by the ICCT in 2019 (Anenberg et al., 2019) estimated that the transport sector contributed to 385,000 deaths globally in 2015, with approximately 15% of these fatalities, or 60,000 deaths, attributed to the shipping sector (Rutherford & Miller, 2019). Discrepancies between findings on shipping-related mortality primarily stem from variations in the assumed dose-response functions; for instance, the ICCT applies the methods from the Global Burden of Disease Study 2017 (James et al., 2018). Nevertheless, the research underscores the significant global burden posed by emissions from the shipping sector.

One way to mitigate this impact is to establish an ECA, a designated maritime region where stricter regulations are enforced to prevent, reduce, and control air pollution from ships. The concept of ECAs was introduced under the IMO's MARPOL Annex VI in 1997, which entered into force in 2005. In 2008, the IMO's Marine Environment Protection Committee (MEPC) revised and strengthened the regulations in the Amendments to Annex VI (MEPC 58/23/Add.1, Annex 13). The criteria for ECAs include parameters such as the maximum allowable levels of sulfur content in fuel, use of emission control technologies, and compliance mechanisms. Depending on the type of emissions regulated, an ECA can be a Sulfur Emission Control Area (SECA), a Nitrogen Emission Control Area (NECA), or both.

Currently, there are five ECAs designated by the IMO. Four of the five IMO-designated ECAs regulate SO_x and NO_x emissions, while one ECA (Mediterranean Sea) currently regulates only SO_x emissions but there are plans to incorporate NO_x emissions in the future (Table 1 and Figure 1). All ECAs are estimated to substantially reduce SO_x, NO_x, and PM emissions, resulting in significant health benefits. For instance, the North American ECA designation was estimated to prevent 3,700 to 8,300 premature deaths each year (MEPC 59/6/5). The Mediterranean Sea ECA is expected to avert between 3,100 and 4,100 cases of premature deaths in 2030, with approximately one third occurring in European Union Member States. By 2050, the Mediterranean Sea ECA will prevent over 10,000 premature deaths annually in the Mediterranean Sea region (MEPC 78/11). However, for the ECA to be the most effective, it must extend at least 100 nm from the coast to deter ships from rerouting (Mao & Rutherford, 2018).

Table 1
Designated and anticipated Emission Control Areas

Emission Control Area		Date amendment to MARPOL Annex VI adopted	Date amendment entered into force	Date more stringent measures took effect
Baltic Sea[a]	SECA	—	—	May 19, 2006 SO_x and PM
	NECA	July 7, 2017 MEPC.286(71)	January 1, 2019	January 1, 2021 NO_x
North Sea	SECA	July 22, 2005 MEPC.132(53)	November 22, 2006	November 22, 2007 SO_x and PM
	NECA	July 7, 2017 MEPC.286(71)	January 1, 2019	January 1, 2021 NO_x
North American	SECA (SO_x and PM)	March 26, 2010 MEPC.190(60)	August 1, 2011	August 1, 2012 SO_x and PM
	NECA			January 1, 2016 NO_x
U.S. Caribbean Sea	SECA (SO_x and PM)	July 15, 2011 MEPC.202(62)	January 1, 2013	January 1, 2014 SO_x and PM
	NECA			January 1, 2016 NO_x
Mediterranean Sea	SECA (SO_x and PM)	December 16, 2022 MEPC.361(79)	May 1, 2024	May 1, 2025 SO_x
	Potential future extension of amendment to include NECA			
Canadian Arctic	SECA and NECA proposed MEPC 81/11; adoption set for MEPC 82 in October 2024			
Norwegian Sea	SECA and NECA proposed MEPC 81/11/1; adoption set for MEPC 82 in October 2024			

Notes: NECA is a NO_x Emission Control Area; SECA is an SO_x Emission Control Area. Restricting the sulfur content in fuel also reduces PM from shipping. Tier III rules apply only to ships constructed after the date indicated in the "Date more stringent measures took effect" column. Information provided in this table is based on MEPC.1/Circ.778/Rev.4 from October 30, 2023.

[a] The Baltic Sea was designated as an ECA for SO_x when MARPOL Annex VI, which entered into force on May 19, 2005, was first adopted on September 26, 1997.

MARPOL Annex VI includes two specific regulations with requirements and rules for control of emissions from ships: Regulation 13, applicable to NO_x emissions, and Regulation 14, applicable to SO_x and PM emissions (MEPC 58/23/Add.1 Annex 13).

REGULATING NO_X EMISSIONS

Ships operating in ECAs must comply with the Tier III requirements of MARPOL Annex VI, as detailed in section 5.1 of Regulation 13. The Tier III regulation limits grams of NO_x emissions per engine kilowatt-hour. Engines with a rated speed of less than 130 rpm are limited to NO_x emissions of 3.4 g/kWh. For engines of 130–1,999 rpm, the limit is $8*rpm^{(-02)}$g/kWh NO_x, while engines equal to or over 2,000 rpm are limited to 2.0 g/kWh NO_x. The primary methods for achieving compliance with Tier III NO_x standards are through the use of selective catalytic reduction (SCR) and exhaust gas recirculation (EGR) systems or through the use of liquefied natural gas (LNG) in low-pressure fuel injection engines. The most common compliance strategy involves installing SCR systems to reduce NO_x emissions by introducing a reductant (most commonly urea) into the exhaust stream, converting a portion of nitrogen oxides into nitrogen and water vapor (Azzara et al., 2014).

The Tier III standards are expected to reduce NO_x emissions for individual ships by 80% compared to Tier I standards. However, the standards apply only to ships constructed on or after the effective implementation date for the specific ECA in which the ships are operating. This limits the impact of Tier III regulations, especially during the first years of an ECA's implementation. For instance, it has been shown that if all European seas were subject to ECA Tier III regulations in 2025, it would not prevent an increase in NO_x emissions by 2030. However, if all existing vessels operating in these seas were also retrofitted to comply with Tier III, NO_x emissions could be reduced by 16%–31%, depending on the compliance scenario (Cofala et al., 2018). Furthermore, MARPOL Annex VI allows the ship's constructed date to be defined as the keel-laying date, which can happen a few years before the actual construction date. Therefore, ships with keels laid before a new ECA comes into force do not have to comply with Tier III NO_x regulations, even if the rest of the ship is built after the ECA enters into force. Norway calls attention to this issue as part of its proposal to designate the Norwegian Sea as an ECA. Norway's submission includes a proposed amendment to MARPOL clarifying the date criteria to include a ship's building contract date and delivery date (MEPC 81/11/1, Annex 1).

In addition to this issue, real-world measurements of NO_x emissions show that tier-based regulations might have unforeseen flaws. Measurements conducted in Danish waters between the North Sea and the Baltic Sea in 2019 revealed that Tier II engines exhibit significantly higher NO_x emission rates than Tier I engines. Furthermore, there were no statistically significant differences between unregulated Tier 0 engines and Tier II engines (Comer et al., 2023). This suggests that NO_x regulations could be improved by retrofitting more vessels to comply with Tier III or by introducing new standards based on not-to-exceed limits in the ECA, complemented by continuous emissions monitoring systems for enforcement.

REGULATING SO_x AND PM EMISSIONS

MARPOL regulates SO_x emissions by limiting the sulfur content in fuel oil used by ships operating in ECAs. As of January 1, 2020, the global sulfur limit outside of ECAs is 0.50% m/m. Within a SECA, Regulation 14 sets the limit at 0.10% m/m. Although MARPOL Annex VI does not impose specific limits on PM emissions in ECAs, they are expected to decrease due to the significantly lower sulfur content of ECA-compliant fuels.

While any fuels with a sulfur content below allowable limits can be used, the most economically attractive fuels for compliance are distillate fuels such as marine gas oil (MGO) and some residual fuels such as ultra-low sulfur fuel oil (ULSFO). With a sulfur limit equal to or below 0.1%, ULSFO might share some similarities with distillates, but they are not identical. Distillates like MGO typically have an even lower sulfur content (0.06% in 2022) (MEPC 80/INF.4) than ULSFO and undergo different refining processes. As a result, the density and viscosity of ULSFO are higher and its energy content is closer to HFO. ULSFO is expected to have higher SO_x and $PM_{2.5}$ emissions than distillate fuel and, therefore, is less effective in reducing shipping pollution compared to MGO (Fridell et al., 2020). Despite this, the availability and use of ULSFO have both increased in recent years as the IMO imposed stricter sulfur content limits on marine fuels. ULSFO is often chosen over MGO because it has a more attractive price. In February 2024, one metric ton of ULSFO cost US$584 compared to US$769 for one metric ton of MGO (OilMonster, n.d.). The price gap is even larger than the per-ton cost because ULSFO has a higher energy density compared to MGO.

In addition to using low-sulfur fuels, MARPOL Annex VI Regulation 4 accepts any compliance technologies that "are at least as effective in terms of emissions reductions as that required by this Annex." Exhaust-gas cleaning systems (scrubbers) employed on a ship can reduce sulfur emissions in the exhaust to allowable levels, and therefore, are considered a compliance technology. In response to the 2020 IMO's sulfur cap, the uptake of scrubbers has grown drastically in the last several years. As of 2018, only 732 ships had scrubbers installed, but in 2020 this number had grown to 4,341 (Osipova et al., 2021). Scrubbers have proven effective in curbing SO_x emissions from exhaust, but they fall short in mitigating PM emissions. Compared to MGO, using 2.6% sulfur HFO in combination with a scrubber emits 61% higher PM and 81% greater BC emissions than a distillate like MGO when a medium-speed diesel engine is used and 353% more BC emissions when a slow-speed diesel engine is used (Comer et al., 2020).

Moreover, open-loop scrubbers discharge high volumes of acidic and turbid washwater into the marine environment. This washwater, used to remove SO_x from the exhaust, contains nitrates, polycyclic aromatic hydrocarbons (PAHs), and heavy metals (Comer et al., 2020; Osipova et al., 2021). Some of these contaminants can accumulate over time in ports, especially in enclosed estuaries, and have been proven to have toxic effects on marine organisms (Magnusson & Granberg, 2022; Teuchies et al., 2020; Ytreberg et al., 2019). This practice contradicts MARPOL Annex VI Regulation 4.4, which requires the use of equivalent technology to "endeavor not to impair or damage its environment, human health, property, or resources of those of other States." Additionally, the discharge of scrubber washwater may violate the United Nations Convention on the Law of the Sea (UNCLOS, 1982), Article 195, which requires parties "not to transfer, directly or indirectly, damage or hazard from one area to another or transform one type of pollution into another." Despite scrubbers being allowed as an alternative SO_x compliance option by the IMO, multiple ports and coastal states have limited or prohibited the use of scrubbers in their jurisdictions (Carraro, 2023). Five of the eight AtlECA member states, including Portugal, France, Spain, Ireland, and the United Kingdom, have already imposed bans on the use of open-loop scrubbers in some ports.

Despite the caveats described above, establishing an ECA remains an effective way to curb air pollution in coastal states. IMO member states proposing to establish or expand ECAs include Norway, which submitted its Norwegian Sea ECA proposal to MEPC 81 (MEPC 81/11/1), and Canada which proposed expanding its portion of the North American ECA to cover Canadian Arctic waters in the same meeting (MEPC 81/11). If adopted, the North Atlantic Emission Control Area has the potential to become the world's largest ECA, covering the exclusive economic zones of eight territories and potentially incorporating three additional outermost regions. When fully implemented, it would combine two existing and two proposed ECAs into a unified low-emission area, offering substantial health and environmental benefits to the residents of the Atlantic coastal states.

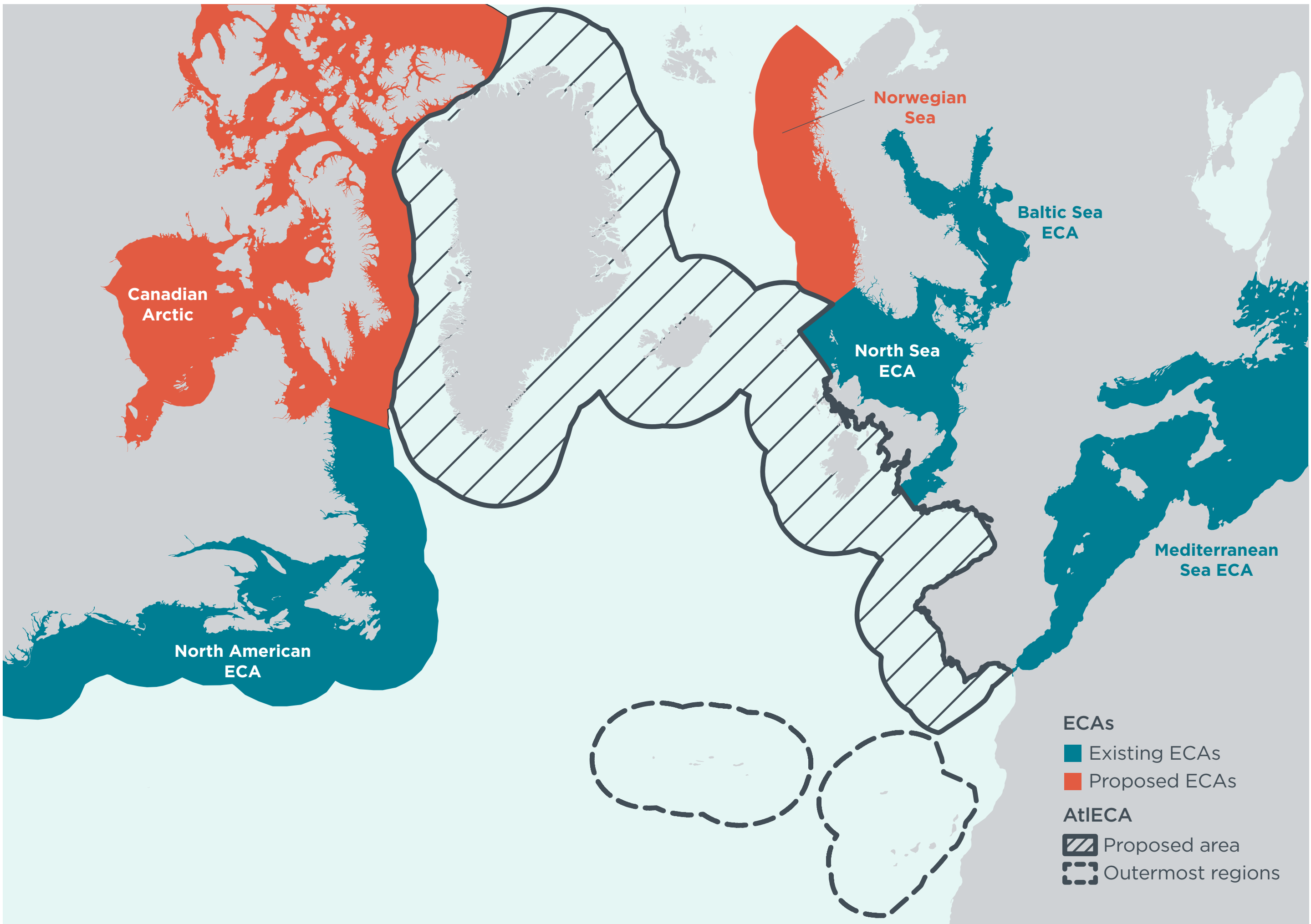
METHODOLOGY

GEOGRAPHIC AREA AND TYPES OF EMISSIONS COVERED IN THIS STUDY

The AtlECA would encompass approximately 5.05 million km^2 of the North Atlantic, including the territorial seas (12 nm) and exclusive economic zones (up to 200 nm) of four EU member states (Spain, Portugal, France, and Ireland), one country in the European Economic Area (Iceland), one autonomous territory associated with the EU (Greenland), the United Kingdom, and the Faroe Islands. Additionally, we have considered the potential geographical expansion of the proposed AtlECA to include one outermost region of Spain (Canary Islands) and two regions of Portugal (Azores and Madeira) (Figure 1). Expanding the proposed AtlECA area to include the outermost regions would add another 1.47 million km^2, resulting in a total area of 6.52 million km^2.

The southern border of the proposed AtlECA connects with the westernmost border of the Mediterranean Sea ECA through the Strait of Gibraltar (MEPC 78/11). The eastern border of AtlECA adjoins the North Sea ECA and the proposed Norwegian Sea ECA (MEPC 81/11/1). The northwest boundary of the AtlECA, encompassing the Faroe Islands and Greenland, is situated above 59°North in the Arctic region. This Arctic segment of the AtlECA would connect the North Sea ECA and the proposed Norwegian Sea and Canadian Arctic ECAs.

Figure 1
Established and proposed Emission Control Areas



Note: Map does not show the entirety of some ECAs.

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INVENTORY OF SHIPPING ACTIVITIES, FUEL CONSUMPTION, AND SO_X, $PM_{2.5}$, BC, AND NO_X EMISSIONS

We use the ICCT's Systematic Assessment of Vessels Emissions (SAVE) model (Olmer et al., 2017a, 2017b) to analyze and plot shipping activities, fuel consumption, and SO_X, $PM_{2.5}$, NO_X, and BC emissions in the proposed and extended AtlECA for the baseline year 2021. While MARPOL Annex VI does not directly regulate BC, it is a component of particulate matter produced through incomplete combustion of fuel and contributes to air pollution and poses health hazards. Consequently, we projected a reduction in BC emissions in addition to regulated pollutants to demonstrate the additional benefits of an AtlECA designation.

SAVE is a global shipping inventory model built by the ICCT that uses automatic identification system (AIS) data (Spire, n.d.) and the ship characteristics dataset from IHS Markit (S&P Global, n.d.).[2] The detailed methodology used for this inventory is available in Olmer et al. (2017b) and has been updated to align with the *Fourth IMO Greenhouse Gas Study* (Faber et al., 2020). The SAVE model estimates hourly ship-specific power demand and fuel consumption based on the engines and fuel type

2 IHS Markit merged with S&P Global in 2022.

used by each ship. The model accounts for the impact on energy use and emissions of ship age, speed, draught, hull-fouling factors, and weather conditions. It also accounts for regional regulations and allows switching between fuels to comply with local requirements. Thus, we presume ships use distillate fuels when local regulations restricted sulfur in fuels to a maximum of 0.1%, such as in Iceland's national waters (12 nm from the shore) and while berthing at EU ports to comply with the EU Sulfur Directive (European Union, 2016).

Fuel consumption and emissions (SO_X, $PM_{2.5}$, BC, and NO_X) are summarized for eight ship types, which were aggregated from the 19 ship classes used by the SAVE model. These ship types include cargo ships, containers, tankers, passenger ships, vehicle carriers, roll-on/roll-off passenger ferries (RoPax), fishing vessels, and others (such as service and offshore vessels, yachts, and miscellaneous; see Appendix B for details).

Emission factors for SO_X depend on the fuel consumption rate and the sulfur content of the fuel. The IMO reports the average sulfur content of marine fuel oils every year based on global sampling data. In this study, we use IMO's 2022 sulfur fuel content statistical data (MEPC 80/INF.4, see Table 2). Note that sampling of the fuels compliant with the ECA regulations has mainly been done for distillate fuels, with only a small fraction (less than 4%) of samples for ULSFO. This means that the 0.06% average low-sulfur content is attributed mainly to the distillate fuels. Due to a lack of data on sulfur content specific to ULSFO, we set its sulfur content to the allowed upper limit (0.1%) in the ECA regulations.

Table 2
Sulfur content of fuels used in this study

Fuel	Sulfur fraction	Equivalent sulfur content
Distillate (MGO)	0.0006	0.06%
LNG	0.000016	0.0016%
Methanol	10% of residual[a]	10% of residual[a]
Residual (VLSFO)	0.005	0.5%
Residual (ULSFO)	0.001	0.1%
Residual (HFO)	0.026	2.6%

[a] Based on assumed emissions from methanol-fueled engines (Faber et al., 2020)

PM emissions are directly affected by the sulfur content of the fuel and are estimated as a function of sulfur content, engine type and tier (age), and engine load-specific fuel oil consumption parameters. Low-load adjustment factors are applied for all cases when engine loads are below 20%, as suggested by the *Fourth IMO Greenhouse Gas Study*. We assume $PM_{2.5}$ emissions constitute 92% of the estimated total PM emissions, consistent with the *Fourth IMO Greenhouse Gas Study*. The details of the PM emission estimates, including the emission equation and correction factors, are published in Faber et al. (2020) and Olmer et al. (2017a, 2017b).

BC emission factors are a function of fuel type, engine type, and engine load. For the ships using residual fuels and distillates in slow-speed diesel (SSD), medium-speed diesel (MSD), and high-speed diesel (HSD) engines, BC emissions are taken from Faber et al. (2020); these BC emissions were originally estimated by the ICCT in Comer et al. (2017). BC emission factors from distillates are generally 40%–50% lower than from residual fuels for 4-stroke engines and up to 80% lower for 2-stroke engines. For other engine and fuel types, we apply energy-based emission factors and the instantaneous power output of an engine consistent with Faber et al. (2020) and Comer et al. (2017).

Ships with scrubber installations use HFO even when they are sailing in ECAs by adjusting scrubber performance to regulate SO_x emissions in the exhaust gas; these emissions are equivalent to 0.1% of the fuel's sulfur content inside ECAs and 0.5% outside of ECAs. Therefore, we identify the ships with scrubbers in the IHS Markit dataset and adjust emissions from scrubbers depending on whether the ship was inside or outside an ECA. We apply emission factors for the exhaust of scrubber-equipped ships as estimated by Comer et al. (2020).

NO_x emissions are estimated using energy-based emission factors and instantaneous power output. NO_x emission factors vary by engine type, fuel type, and the ship's tier (age), and are modified by a low-load adjustment factor when engine loads are estimated to be below 20%. The engine's age and speed (rpm) determine how much NO_x is permitted to be emitted by a ship; see Faber et al. (2020) for more details. Thus, Tier I standards are applied only to ships with engines above 130 kW and built after January 1, 2000. Tier II standards apply to ships built after January 1, 2011. Tier III standards apply for ships built after an ECA's NO_x requirements become effective. All other ships with engines below 130 kW or built before January 1, 2000, are assigned to Tier 0 and do not have to comply with international NO_x regulations.

The estimated fuel intensity of the shipping traffic and all air pollutants distributions have been inferred and plotted on a grid with a spatial resolution of 0.1° x 0.1° of longitude and latitude.

SHIPPING EMISSIONS AND EMISSION CONTROL AREA COMPLIANCE SCENARIOS

Projecting future 2030 fuel demand

To project the future 2030 fuel demand, we used the ICCT's global maritime fuel demand and emissions projection model Polaris (International Council on Clean Transportation, 2022). Polaris is used to predict fleet turnover and energy demand by ship type and fuel type. These projections, based on historical shipping demand reported by the United Nations Conference on Trade and Development (UNCTAD, 2021), account for technical efficiency improvements under the IMO's greenhouse gas policies.

For this project, we use the Polaris model to estimate growth in energy and fuel demand for all ship classes up to 2030. Future shipping activity is estimated using a linear projection from the historical shipping demand reported by UNCTAD, as explained above. The fundamental unit of analysis in Polaris is the individual vessel. The model considers the retirement of older vessels and introduces new ships to the global fleet to meet demand targets. We expect the increase of shipping activity in the proposed AtlECA and outermost regions to align with the global growth trend. Therefore, we apply these growth coefficients to the hourly power demand in the study area to estimate future power and fuel demand for ships in 2030. We also assume that traffic patterns will remain unchanged.

Polaris integrates technical efficiency improvements under the IMO's greenhouse gas policies: the Energy Efficiency Existing Ship Index (EEXI) for the existing fleet and the Energy Efficiency Design Index (EEDI) for the newly built ships. Polaris also calculates the operational carbon intensity indicator (CII), but because ships are not required to achieve a particular grade, the CII is assumed to not influence ship behavior. EEXI is also expected to have a very limited effect on a ship's energy efficiency improvement. In our previous study, we showed that applying EEXI will result in just 0.7%–1.3% CO_2 reduction by 2030 because it does not limit engine power below current operational levels (Rutherford et al., 2020). Therefore, the existing vessels will most likely comply with the EEXI requirement without significant energy efficiency adjustments.

Emission Control Area compliance scenarios

We model four 2030 AtlECA compliance scenarios in addition to a 2030 Business-As-Usual (BAU) scenario. The main compliance assumptions for these scenarios are presented in Table 3. We model two plausible scenarios and two extreme scenarios. In the plausible scenarios, we assume that only ships operating on VLSFO will be affected by ECA sulfur requirements. In contrast, the extreme scenarios can be used to understand the minimum and maximum potential emissions reduction within the ECA. All scenarios assume that the shipping traffic pattern will remain unchanged in 2030 compared to 2021, as illustrated in Figure 2. Additionally, we assume that ship power demand and associated fuel consumption will grow as predicted by the ICCT Polaris model.

The scenarios and assumptions used in this study are as follows:

Business-As-Usual (2030): This assumes no AtlECA implementation in the study area. Consequently, vessels are expected to use fuel as predicted by the Polaris model.

MGO Mix (plausible): This scenario assumes that the fleet operating on VLSFO will switch to MGO. Ships already using distillates, LNG, and methanol are not expected to change behavior. Ships predicted to have installed scrubbers will need to adjust performance to be equivalent to 0.1% fuel sulfur content, in contrast to the 0.5% sulfur content in the BAU scenario.

ULSFO Mix (plausible): This scenario is similar to the MGO Mix scenario, with the distinction that ships operating on VLSFO will switch to ULSFO instead of MGO. It is assumed that the sulfur content of ULSFO does not exceed 0.1% while other properties and emissions remain similar to VLSFO.

MGO Max (extreme): In this scenario, we assume that scrubbers are not allowed as an alternative sulfur compliance method and ship owners utilize only MGO for compliance. In this case, no ships will have scrubber installations in 2030.

Scrubber Max (extreme): In this scenario, it is assumed that all ships currently using HFO with scrubbers will continue to do so. Ships currently operating on VLSFO will install scrubbers and use HFO instead of opting for 0.1% sulfur-compliant fuels. Like all other scenarios, the ships already using MGO, LNG, and methanol for compliance are not expected to change behavior.

Table 3

AtlECA 2030 compliance scenario assumptions on fuel mix and percentage of sulfur, or equivalent with scrubbers, for each fuel

Fuel, SO_x%	BAU	Plausible scenarios		Extreme scenarios	
		MGO Mix	ULSFO Mix	MGO Max	Scrubber Max
VLSFO, 0.5%	●				
ULSFO, 0.01%			●		
HFO + scrubber, 0.5%	●				
HFO + scrubber, 0.1%		●	●		●
MGO, 0.06%	●	●	●	●	●
LNG, 0.002%	●	●	●	●	●
Methanol, 10% of HFO	●	●	●	●	●

NO_x Tier III compliance. For modeling NO_x Tier III compliance, a different approach is employed because NO_x emissions depend mainly on engine type, age, and revolutions per minute (rpm). Depending on the engine type, Tier III compliance can be achieved by installing SCR or EGR systems. The regulations apply only to ships built after an ECA designation and operating within that ECA's boundaries. Therefore, to model the NO_x emission reduction induced by the AtlECA designation, we assumed a potential AtlECA designation year of 2027 and estimated the number of newly built ships from 2027 to 2030. Consistent with MARPOL Annex VI Regulation 13, for engines larger than 130 rpm, we assume ships achieve 3.4 g NO_x/kWh. Engines equal to or larger than 2,000 rpm are assumed to emit 2.0 g NO_x/kWh. For engines between 130 rpm and 2,000 rpm, NO_x emissions in g/kWh are calculated as $9 \times rpm^{-0.2}$.

To understand the impact of an AtlECA on NO_x emissions, we apply the Polaris model to estimate the number of newly built ships in the AtlECA area between 2027 and 2030. To predict where these newly built ships will operate, we assumed that the shipping traffic patterns in 2030 would remain similar to those in 2021. We made a randomized selection within each ship class sailing in the AtlECA in 2021 and assume that the new Tier III ships will follow similar routes. The number of newly built ships within each class was obtained from the Polaris model, and NO_x emissions from these ships are assumed to meet Tier III requirements.

In our analysis, we assume that ships built between 2027 and 2030 always emit the test-cycle weighted Tier III amounts (e.g., 3.4 g NO_x/kWh for engines larger than 30 rpm) when operating inside the AtlECA. However, real-world measurements indicate that ships with Tier III engines often exceed the weighted Tier III limits when operating at below 25% main engine load (Comer et al., 2023). The issue of potential Tier III noncompliance is outside this work's scope. Additionally, we calculate the potential NO_x reduction that could be achieved if all ships predicted to sail in the AtlECA in 2030 are retrofitted to achieve Tier III compliance. We make no claims about the practical feasibility of retrofitting all engines to achieve Tier III.

RESULTS

SHIPPING TRAFFIC AND FUEL BURNED IN 2021

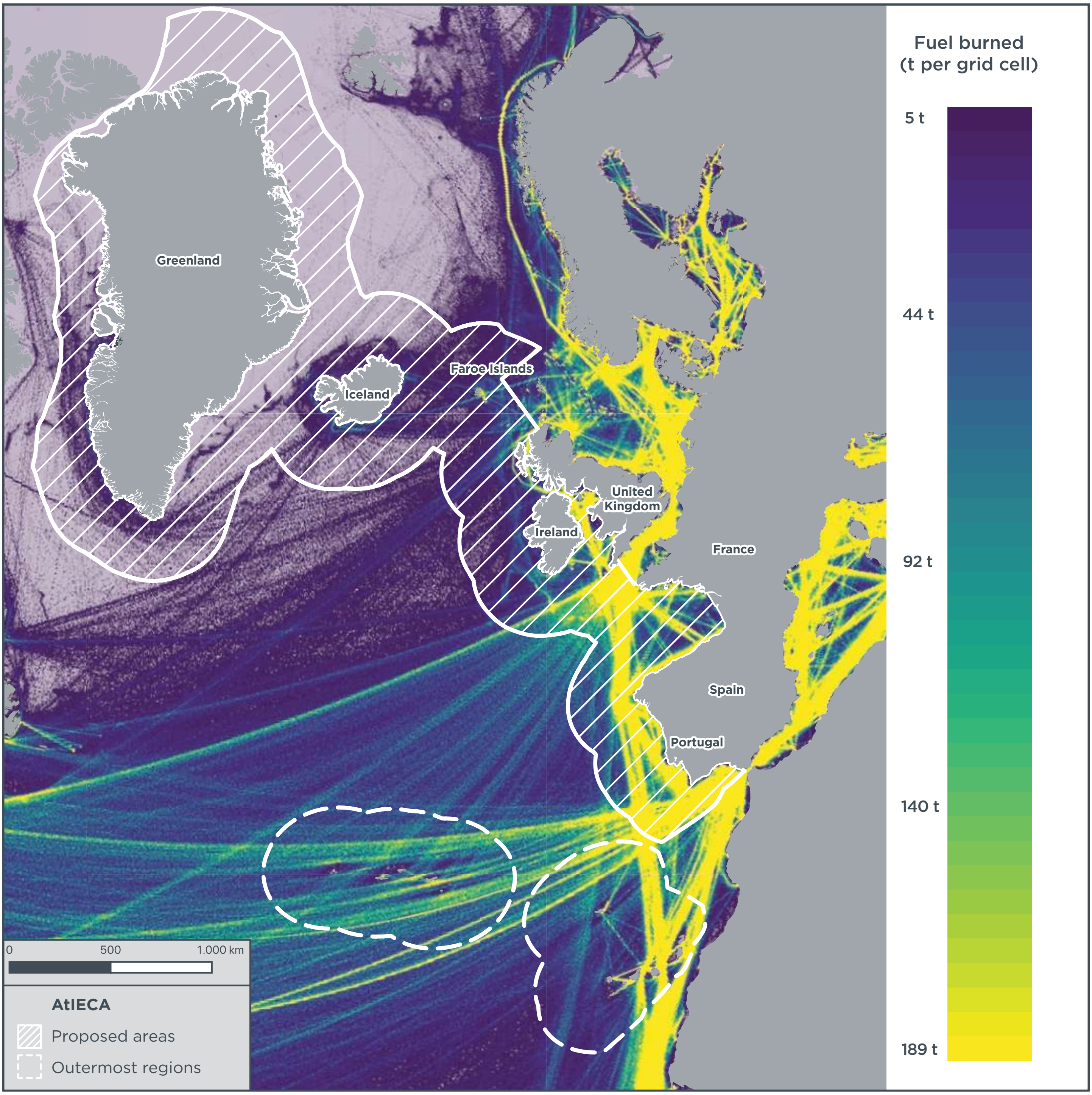
We identified 17,640 vessels sailing in the proposed AtlECA (excluding the outermost regions) in 2021; 21% of the vessels were built before 2000 (Tier 0), 45% of the vessels were built after 2000 and before 2011 (Tier I), and 34% were built in 2011 or later (Tier II). The shipping traffic and fuel consumption in the proposed AtlECA area is unevenly distributed, as shown in Figure 2.

The vessels sailing in the proposed AtlECA in 2021 consumed fuels equivalent to 265 petajoules (PJ). We estimate that 64% of all fuel burned in the AtlECA in 2021 was VLSFO, and only 13% of the energy consumed was by ships using HFO with installed scrubbers (Figure 2). The remaining 23% of the 2021 fuel mix was distillate fuels (18%) and LNG (nearly 5%). Six ships in the AtlECA used methanol as a primary fuel (less than 0.1% of the total).

Vessels sailing in the exclusive economic zones of Portugal, Spain, and the United Kingdom consumed 187 PJ of fuel, as shown in Figure 4; this represents 70% of the total fuel consumption in the AtlECA region. In Portugal and Spain, fuel consumption is mainly by container ships and tankers; in the United Kingdom, it is mainly tankers and RoPax vessels. Fishing activities largely impact Iceland, Greenland, and the Faroe Islands; 48% of all fuel burned in Iceland's waters is by fishing vessels, followed by the Faroe Islands and Greenland (40% and 31%, respectively) (Figure 2 and Appendix 3).

Figure 2

Shipping traffic and fuel consumption in the area of the proposed AtlECA during 2021



Note: The hatched area inside the solid white line delineates the proposed AtlECA. The dashed white line delineates the outermost regions (Azores, Madeira, and Canary Islands).

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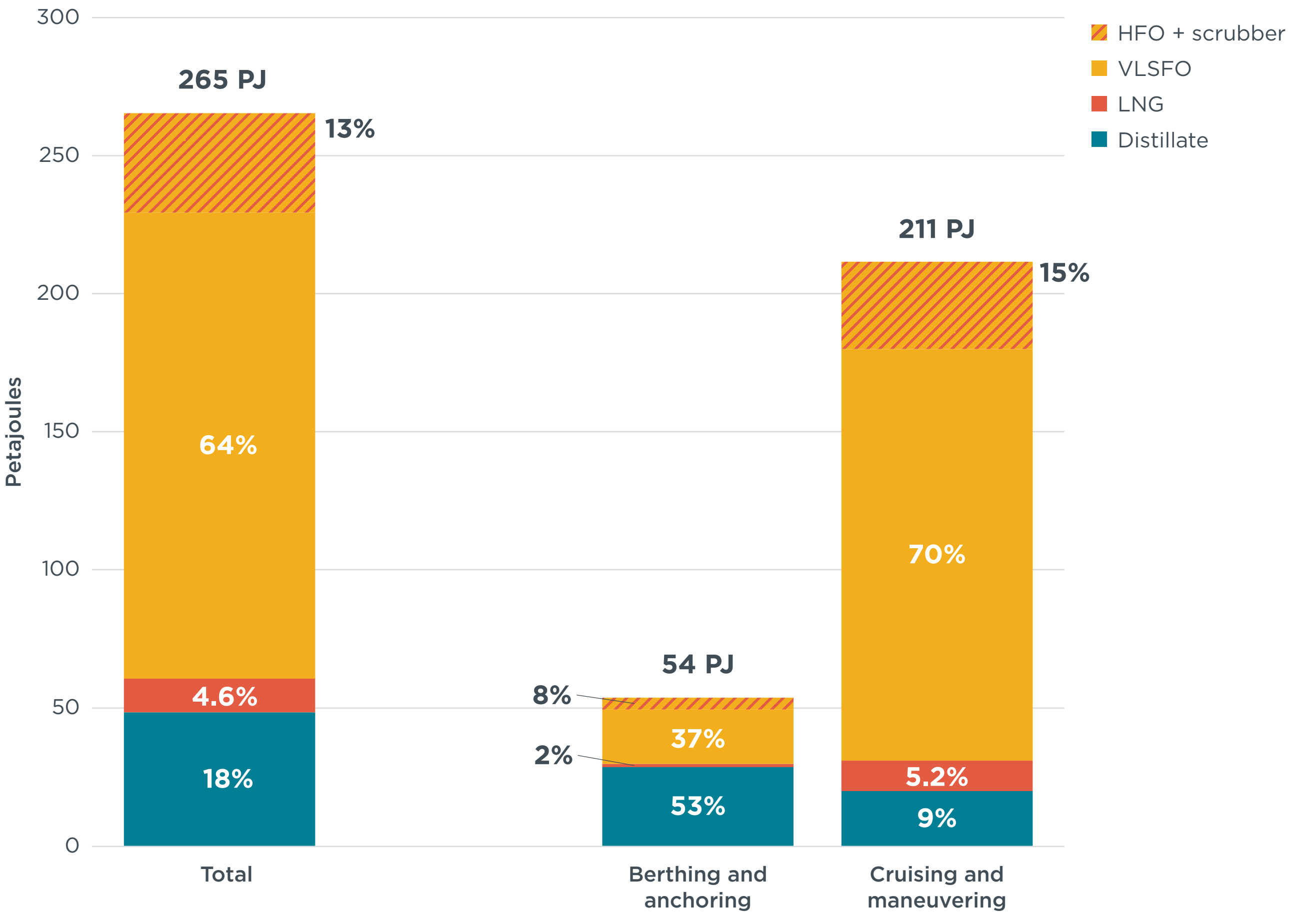
Figure 3

Fuel consumption of ships operating in the proposed AtlECA in 2021



Note: Methanol represents less than 0.1% of the 2021 fuel mix and is not shown in the figure.

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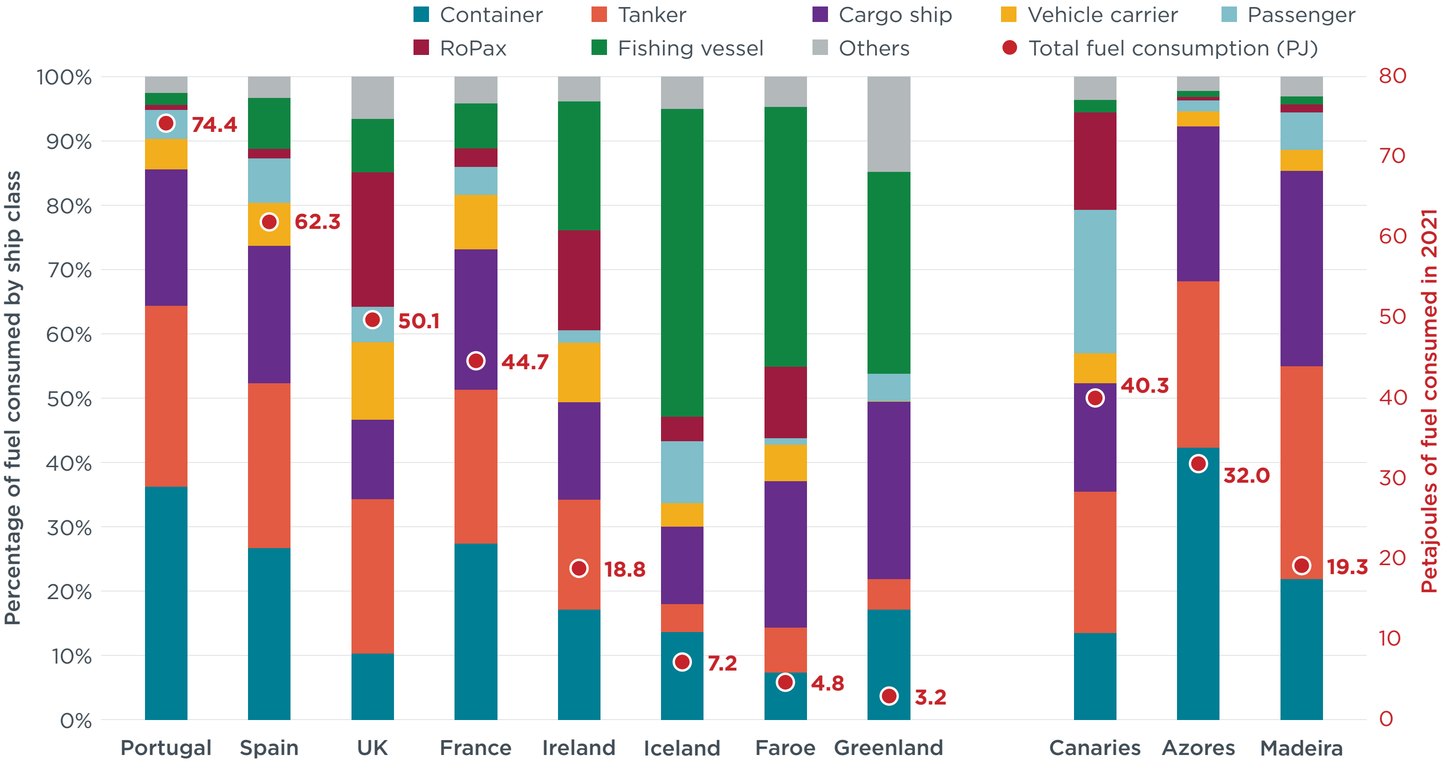
Ships berthing and anchoring used 20% of the 265 PJ consumed in 2021 (Figure 3). About 53% of the fuels burned in ports are distillates such as MGO, but only 9% of fuels burned while ships cruising and maneuvering are distillates. Instead, residual fuels (VLSFO and HFO with scrubber) accounted for 85% of fuels burned during cruising and maneuvering. This difference is explained by the EU Sulfur Directive requiring ships at berths in EU ports to use marine fuel with a sulfur content lower or equal to 0.1% or to use an emission-abatement method (i.e. scrubbers) providing emission reductions at least equivalent to those achievable by using low sulfur fuel (European Union, 2016). Ships using HFO with scrubbers accounted for 8% of in-port fuel consumption. Ships at ports within the AtlECA area not covered by the EU Sulfur Directive accounted for 37% of in-port ULSFO consumption.

If the ECA area were extended to the outermost regions, this would add another 92 PJ of fuel used by 11,380 vessels, resulting in a total of 357 PJ of fuel consumed in both areas (Figure 4). In the extended area, 44% of the total fuel consumption occurs around the Canary Islands, followed by the Azores and Madeira (35% and 21%, respectively). The outermost regions experience heavy container, tanker, and cargo shipping traffic; these ship types are responsible for 73% of the total fuel burned in the area. Unlike the Azores and Madeira, the waters of the Canary Islands are crossed by significantly fewer container ships and are mostly impacted by passenger vessel traffic, with 38% of all fuel burned by passenger and RoPax vessels.

Figure 4

Estimate of fuel consumption in 2021 in the exclusive economic zones and territorial seas in a potential AtlECA



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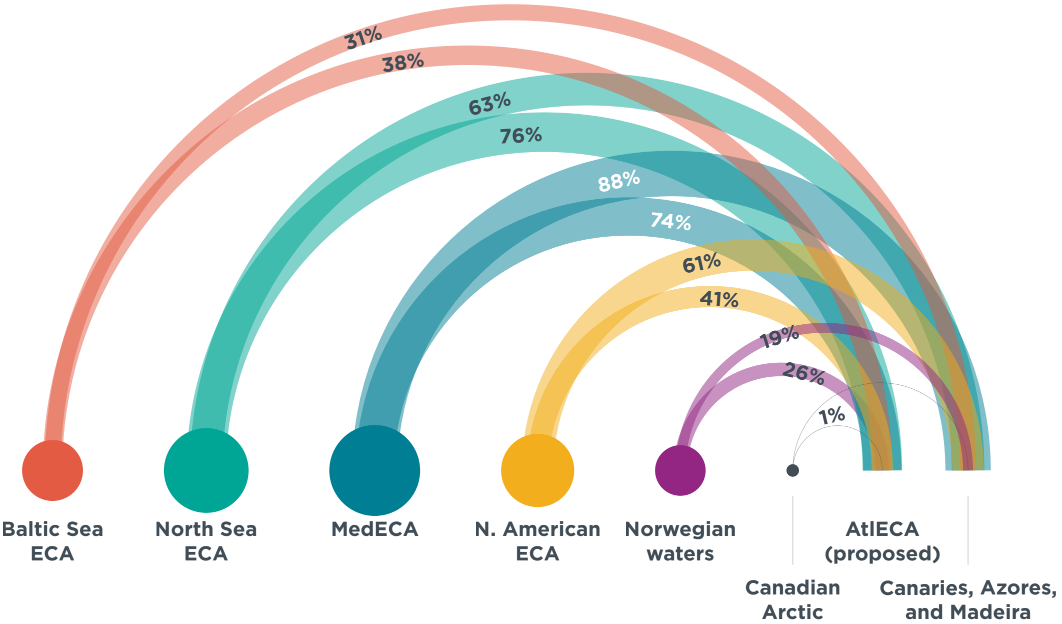
We estimate that 88% of the vessels sailing in the proposed AtlECA, along with 94% of the ships operating in the Azores, Madeira, and Canary Islands, are already navigating in other established or proposed ECAs (Figure 5). Out of 17,640 ships detected in the AtlECA area in 2021, 76% also navigated in the North Sea ECA and 74% in the Mediterranean Sea SECA, where fuel sulfur requirements begin 2025. Furthermore, 87% of vessels recorded in the outermost regions were also sailing within the AtlECA region. Similarly, 88% were sailing in the Mediterranean Sea SECA, 63% in the North Sea ECA, and 61% in the North American ECA (61%). Ships operating in active ECAs will already bunker low-sulfur fuels that comply with fuel sulfur requirements or otherwise use HFO with scrubbers. Newer ships will also have installed NO_x reduction technologies if they are subject to Tier III requirements in the North American, Baltic Sea, or North Sea ECAs.

Figure 5

Percentage of vessels navigating in established and proposed ECAs that operate in the proposed AtlECA and outermost regions



Note: The diameter of each circle representing an ECA is proportional to the percentage of ships operating in both that ECA and in the proposed AtlECA and outermost regions.

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FUTURE FUEL DEMAND AND RELATED EMISSIONS

Projected growth in fuel demand between 2021 and 2030

We predict that total fuel demand in the proposed AtlECA region will grow by 17% between 2021 and 2030, from 265 PJ to 311 PJ (Figure 6a). However, fuel consumption is expected to grow unevenly among different ship types.

In the BAU scenario, residual fuels (VLSFO and HFO) will have the largest share of the 2030 fuel mix (227 PJ out of the total 311 PJ) but that represents an increase of only 11% from 2021. In contrast, the demand for distillate and LNG fuels will grow by 41% and 29%, respectively, by 2030. Their joint share in the fuel mix will increase from 23% in 2021 to 27% in 2030. Methanol uptake will grow by 76% compared to 2021, but its share will remain very low. Because of the small number of ships operating on methanol in this area, methanol's total share of the fuel mix will remain less than 0.1% in the 2030 fuel mix.

If we include the outermost regions (Canary Islands, Azores, and Madeira) in our projections, fuel consumption would grow by about the same percentage, from 357 PJ to 416 PJ, between 2021 and 2030 (Figure 6b).

Figure 6a

Predicted fuel consumption by ship class and fuel type for the proposed AtlECA region in 2021 and 2030

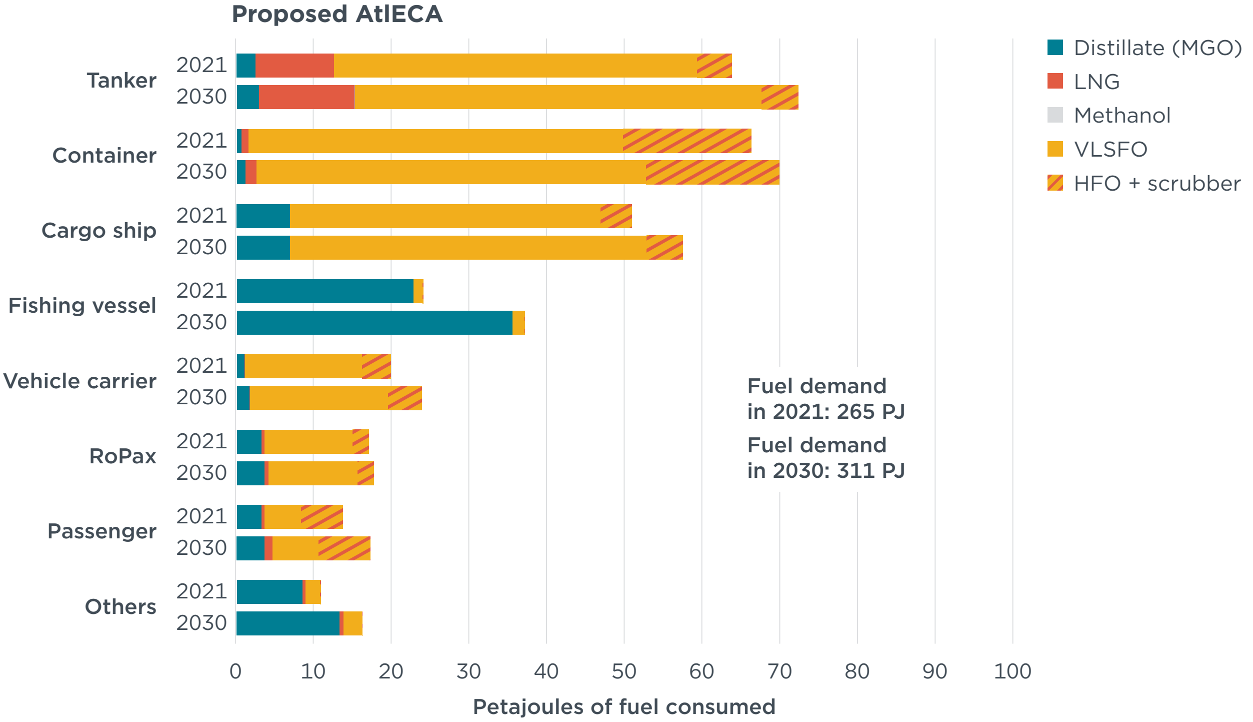
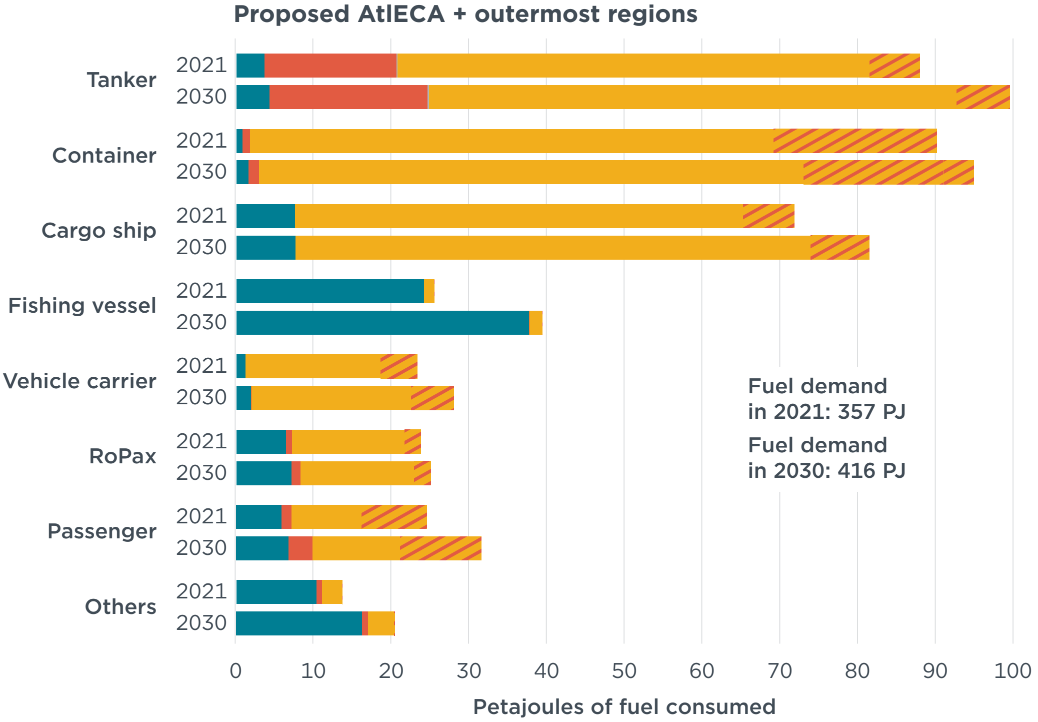


Figure 6b

Predicted fuel consumption by ship class and fuel type for the proposed AtlECA region and the outermost regions in 2021 and 2030



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Projected growth in SO_x, NO_x, $PM_{2.5}$, and BC shipping emissions between 2021 and 2030

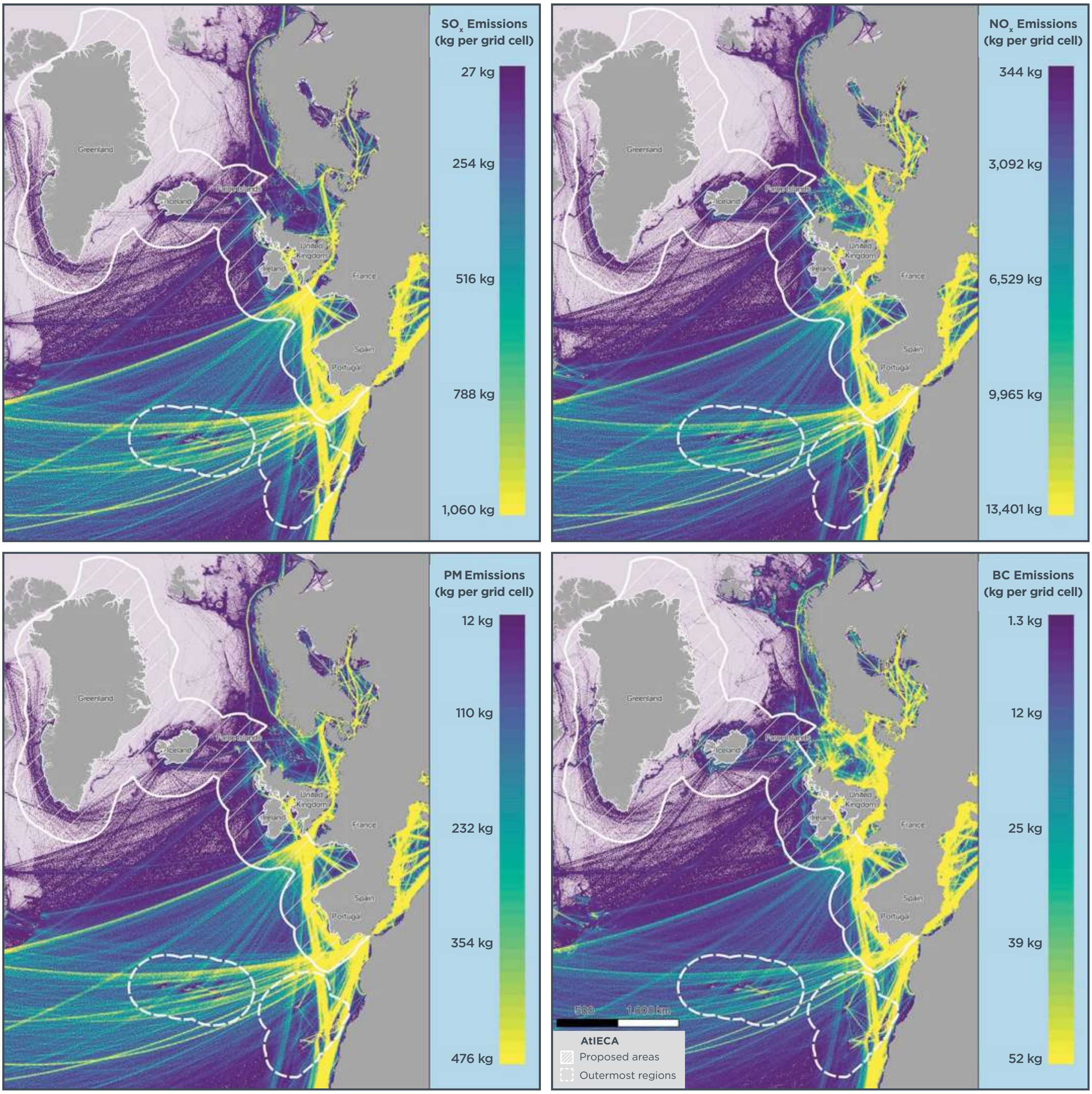
We estimate that all ships sailing in the proposed AtlECA in 2021 emitted 433 kt of NO_x, 40.6 kt of SO_x, 16.8 kt of $PM_{2.5}$, and 2.1 kt of BC (see tables in Appendix D). Most of the NO_x (226 kt, or 52% of the total) were emitted by Tier I ships, followed by Tier II ships (129 kt), and Tier 0 ships (78 kt). Without any policy intervention by 2030, these emissions are expected to grow to 500 kt of NO_x (15% increase), 45.5 kt of SO_x (12% increase), 18.9 kt of $PM_{2.5}$ (12% increase), and 2.5 kt of BC (18% increase), as shown in Figure 7 and Appendix D.

Expanding the geographical coverage of the AtlECA to the outermost regions reveals the potential for regulating an additional 171 kt of NO_x, 15.6 kt of SO_x, 6.7 kt of $PM_{2.5}$, and 0.7 kt of BC in 2030. These values are equivalent to 25%, 26%, 26%, and 22% of the total emissions within the extended area, respectively (refer to Appendix D for detailed data).

The geographical distribution of pollutants aggregates over the shipping lanes, creating emissions intensity hotspots, as shown in Figure 7. The emission concentrations follow the pattern of the burned fuel intensity and cause an uneven burden for different member states (Figure 2). Portugal, Spain, the United Kingdom, and France experience the highest emissions due to heavy traffic of container ships, tankers, and cargo ships burning predominately heavy fuel oil. Ships sailing in the exclusive economic zones of these four countries combined emit 90% of the SO_x emissions in the proposed AtlECA, along with 89% of $PM_{2.5}$ emissions, 82% of BC, and 87% of NO_x emissions. Notably, air pollution from shipping activities in the outermost regions surpasses the levels observed around Portugal, the country exposed to the highest emissions within the proposed AtlECA. This emphasizes the importance of addressing and mitigating maritime emissions in the outermost regions to achieve comprehensive regulations and safeguard against disproportional pollution burdens.

Figure 7

Maps of SO_X, $PM_{2.5}$, NO_X, and BC emissions in 2021



Note: Maps show kilograms of emissions per cell in a grid of 0.1° x 0.1° of longitude and latitude.

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EMISSION REDUCTIONS UNDER DIFFERENT COMPLIANCE SCENARIOS

Fuel mix in compliance scenarios

Figure 8 shows the projected fuel mix assumed for the ECA compliance scenarios based on the predicted 311 PJ of total fuel used in the proposed AtlECA region (excluding outermost regions) in 2030. Around 95% of this demand is from fuel oils (HFO, VLSFO, and MGO) with the rest being LNG (5%) and a small amount of methanol (< 0.1%).

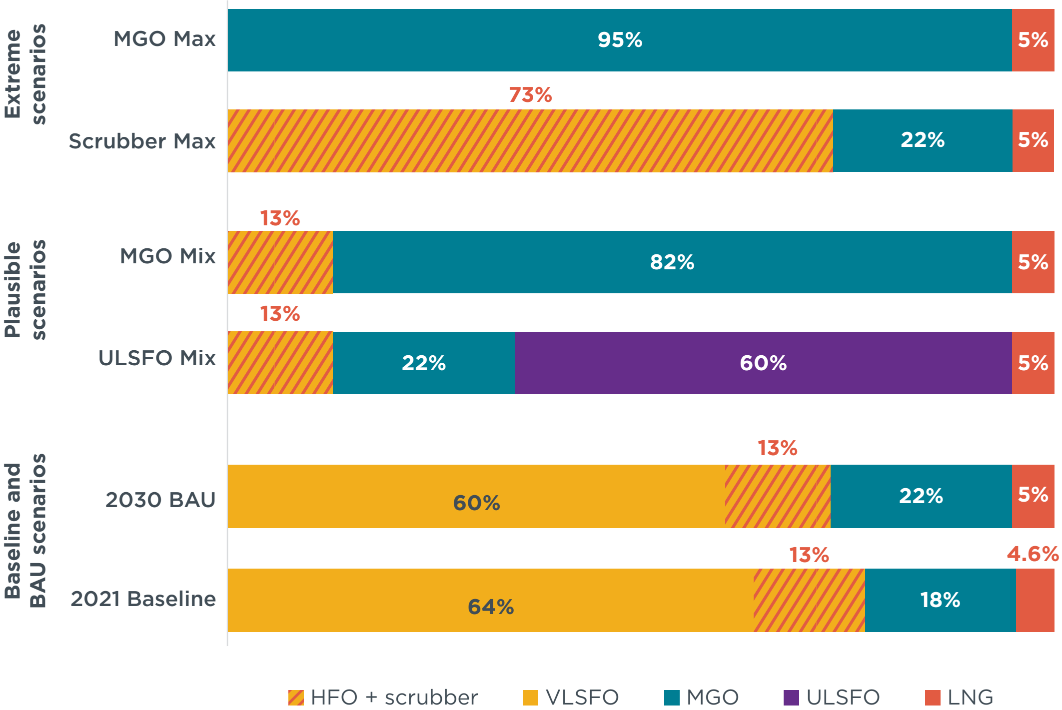
In the BAU 2030 scenario, vessels using HFO with scrubbers represent 13% of the total fuel consumption (17% of all residual fuels), while VLSFO composes 60% of the projected fuel within the proposed AtlECA. Following the AtlECA designation, vessels would have the option of using distillate, ULSFO, or scrubbers instead of VLSFO to comply with the new emission standards. Predicting the compliance choice is challenging due to the various factors influencing ship owners' decisions, including economic and technical considerations. However, we do not expect a substantial surge in scrubber installations. Globally, scrubber installations peaked in 2019 before the global sulfur cap took effect in 2020, but have since plateaued (DNV, n.d.). Although establishing a new ECA might boost scrubber uptake, our analysis shows that 88% of all ships operating in the AtlECA are concurrently active in other ECAs; 67% operate in the North Sea ECA, where the Emission Control Area has been in effect since 2006. This suggests that ship owners have already installed scrubbers for compliance with the 2020 sulfur cap or operations in other ECAs, whereas other vessels may opt for low-sulfur fuels to ensure regulatory compliance.

Therefore, for the two plausible scenarios, we assume that the proportion of ships with scrubbers would not grow substantially following the designation of an ECA as compared with the BAU 2030 scenario (13% in the fuel mix). These vessels are expected to maintain using HFO with scrubbers but with the adjusted sulfur limits equivalent to 0.1% sulfur fuel content. As for the remaining residual fuels, we either assumed a mix of MGO and ULSFO (22% and 60%, respectively, for the ULSFO Mix scenario) or a significant increase of MGO uptake from 22% to 82% in the MGO Mix scenario, as shown in Figure 8.

In the extreme scenarios depicted in Figure 8, we explored two options. In the MGO Max scenario, all residual-fueled ships exclusively adopt MGO for compliance, including those with installed scrubbers (95% uptake of MGO in the fuel mix). In the Scrubber Max scenario, all ships projected to operate on residuals in 2030 would install scrubbers instead of choosing compliant low-sulfur fuels (73% uptake of HFO with scrubbers in the fuel mix). These two scenarios aim to quantify the range of emissions that could occur as ships comply with the ECA requirements.

Figure 8

Fuels consumed in 2021 and 2030 under the Business-As-Usual and four Emission Control Area compliance scenarios



Note: Methanol constitutes less than 0.1% of the total fuel mix in each scenario and is not shown in the figure.

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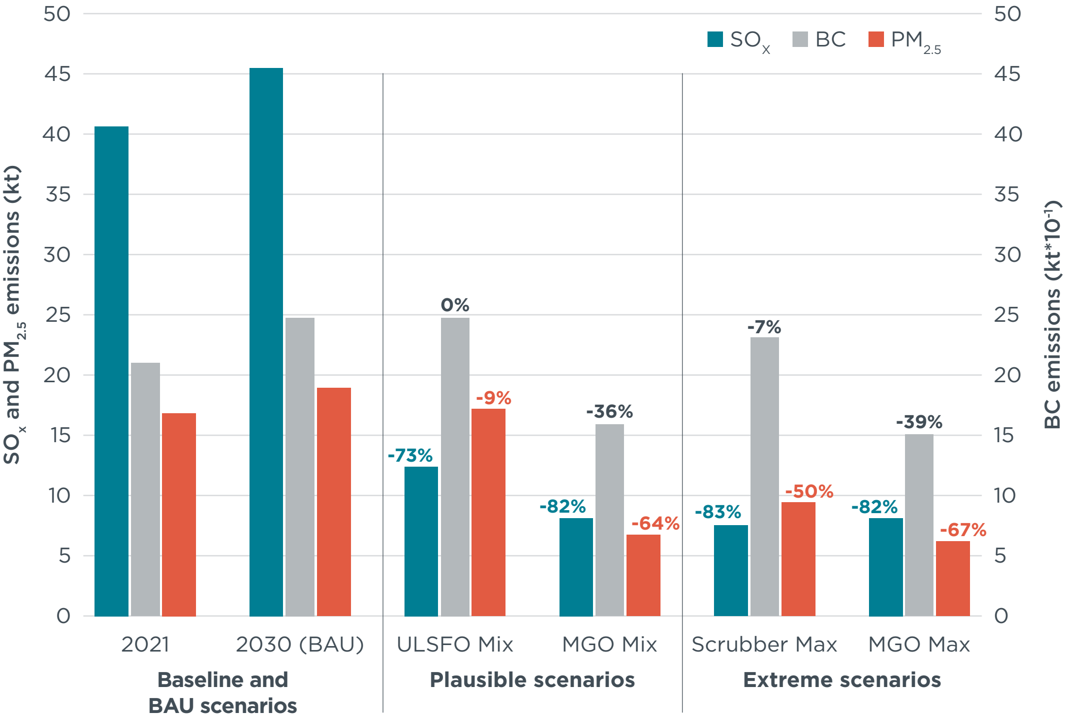
Projected reduction in SO_X, $PM_{2.5}$, and BC emissions

Figure 9 shows the expected reductions in SO_X, $PM_{2.5}$, and BC emissions across four compliance scenarios. The expected emissions for each scenario are plotted next to the baseline 2021 emissions and the Business-As-Usual (BAU) projection for 2030. Detailed breakdowns of total emissions by scenario for each member state's exclusive economic zones are provided in Appendix D.

Figure 9

Emissions in the proposed AtlECA (excluding outermost regions) by compliance scenario and reductions in emissions compared with the BAU scenario



Note: The percentages indicate the decrease in emissions compared to the 2030 Business-As-Usual scenario.

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As expected, the most substantial emission reductions can be achieved when all vessels, including those equipped with scrubbers, use distillate fuel to comply with ECA regulations, as shown in the MGO Max scenario in Figure 9. When compared to BAU, the MGO Max scenario results in an 82% reduction in SO_x emissions, a 67% reduction in $PM_{2.5}$, and a 39% reduction in BC emissions. Emissions in the MGO Mix scenario where some vessels adopt scrubbers for compliance instead of MGO, in line with the current installation trends, are not very different from the MGO Max scenario; SO_x emissions stay the same while the MGO Mix scenario reduces emissions of $PM_{2.5}$ and BC by 3% less than the MGO Max scenario. This small variance is explained by the fact that scrubber-equipped vessels are responsible for only 17% of the total residual fuel consumption, and therefore, their effect on total emissions is limited.

However, BC and $PM_{2.5}$ emissions can be significantly higher if a larger proportion of vessels opt for scrubbers to meet ECA compliance. Thus, in the extreme scenario where about three fourths of all ECA-bound ships use scrubbers while burning heavy fuel oil—the Scrubber Max scenario shown in Figure 9—BC and $PM_{2.5}$ emissions are reduced by 7% and 50%, respectively. In the MGO max scenario, BC and $PM_{2.5}$ emissions are reduced by 39% and 67%, respectively.

Using ULSFO for compliance within the AtlECA is the least favorable compliance path for reducing air pollution. Unlike MGO, ULSFO is a residual fuel that does not go through the distillation process but is desulfurized so that it has a significantly lower sulfur content than heavy fuel oil. It is most commonly used in low-speed engines of larger container ships. ULSFO has a viscosity and density comparable with heavy fuel oil and we assume it has similar BC emissions as HFO. Using ULSFO for ECA compliance results in a 9% reduction in $PM_{2.5}$ emissions compared to the BAU scenario and no reduction in BC emissions compared to BAU (Figure 9). Furthermore, the effectiveness of ULSFO in reducing SO_x emissions is inferior to that of MGO. The ULSFO Mix scenario reduces SO_x emissions by 73% from BAU, compared with an 82% reduction for the MGO Mix scenario. This is because the sulfur content of distillates such as MGO falls well below the mandatory 0.10% limit; the global average sulfur content of distillates was 0.06% in 2022 (MEPC 80/INF.4), whereas the sulfur content of ULSFO is assumed to be 0.10%.

Figure 10 illustrates the emissions reductions attainable by each member state in the MGO Mix and ULSFO Mix scenarios. Across all countries except Iceland, using MGO for ECA compliance is expected to reduce SO_x emissions by 72%–85%, while using ULSFO for compliance is projected to result in SO_x reductions of 61%–76%.

Iceland has already imposed a 0.1% sulfur content limit within its territorial seas and internal waters, resulting in lower ECA-related advantages than other member states. However, because the ECA would cover the 200-nautical-mile exclusive economic zone of Iceland, rather than the 12-nautical-mile territorial seas and internal waters, the introduction of AtlECA can still bring benefits for the country.

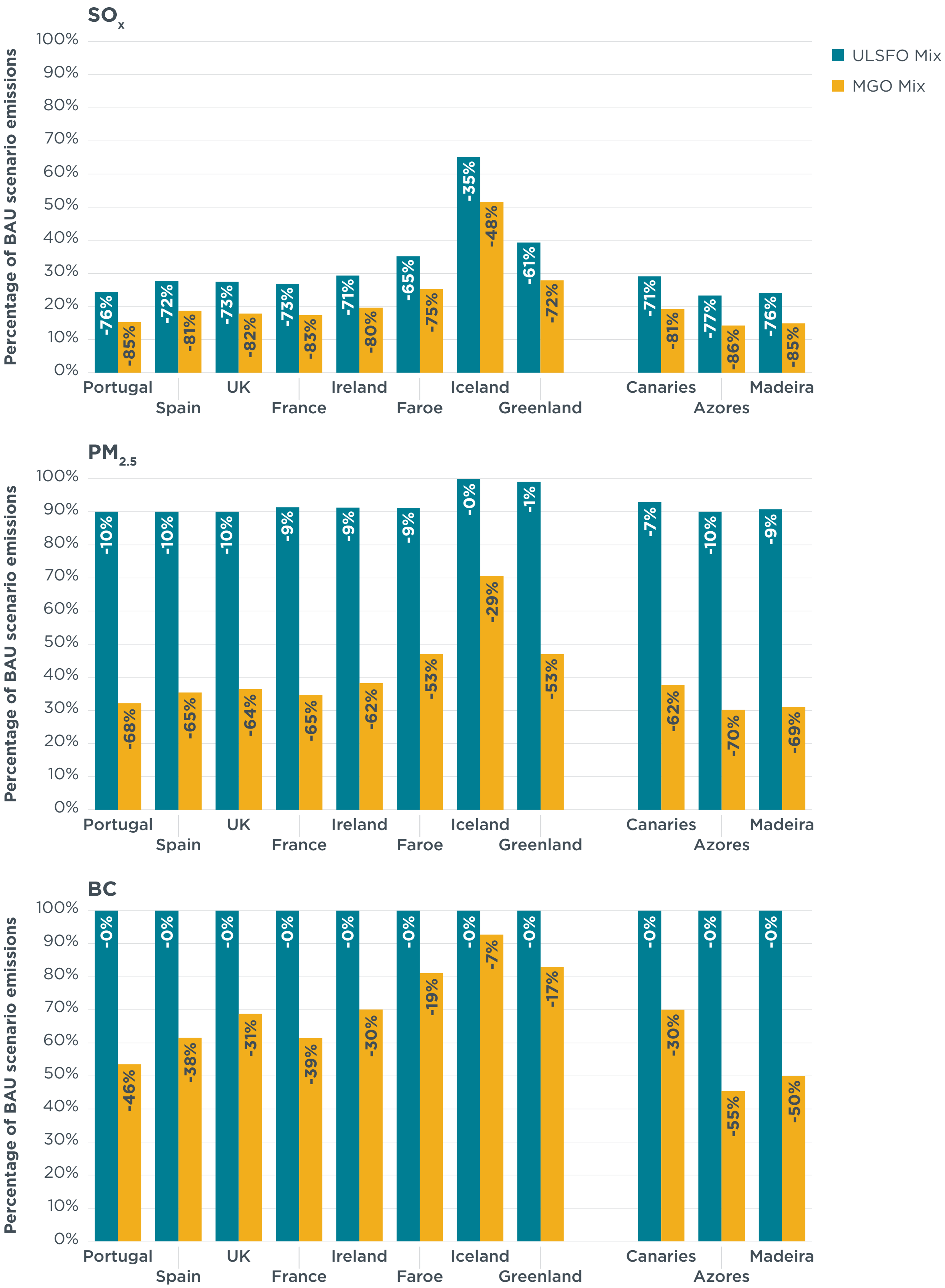
If MGO were used for compliance, the ECA in Iceland would result in a 48% reduction in SO_x emissions, a 29% reduction in $PM_{2.5}$, and a 7% reduction in BC emissions compared to the BAU scenario. Opting for ULSFO as a compliance fuel reduces these benefits; there would be a 35% reduction in SO_x emissions and no apparent changed for $PM_{2.5}$ and BC emissions, as shown in Figure 10 for Iceland.

All member states can expect substantial reductions of $PM_{2.5}$ and BC emissions when MGO is chosen as a primary compliance fuel; the reductions range from 53% to 68% for $PM_{2.5}$ and 17% to 46% for BC, depending on the country. In contrast, using ULSFO as the primary compliance fuel brings significantly more modest emission reductions, varying between 1% and 10% for $PM_{2.5,}$ and showing no effect on BC emissions across all member states. For the Arctic states (Greenland, Iceland, and the Faroe Islands), the expected reduction in $PM_{2.5}$ and BC emissions an ECA would bring is not as high as in other states. This is primarily because a large portion of the shipping traffic in these states consists of smaller fishing vessels that already use low-sulfur distillate fuel.

We identified significant benefits for all three outermost regions—the Canary Islands, Madeira, and Azores—if they are included in the AtlECA region. Assuming MGO Mix compliance, these regions can achieve a substantial reduction in SO_x emissions (81%–86%), $PM_{2.5}$ emissions (62%–70%), and BC emissions (30%–55%). The largest emissions reductions are seen in the Azores, which copes with high-density traffic coming from the Mediterranean Sea and the United States.

Figure 10

Expected reductions in SO_X, $PM_{2.5}$, and BC emissions in 2030 under two compliance scenarios as compared with the Business-As-Usual scenario



Note: The number above each bar indicates the percentage decrease in emissions compared with the 2030 Business-As-Usual scenario.

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Projected reduction in NO_x emissions

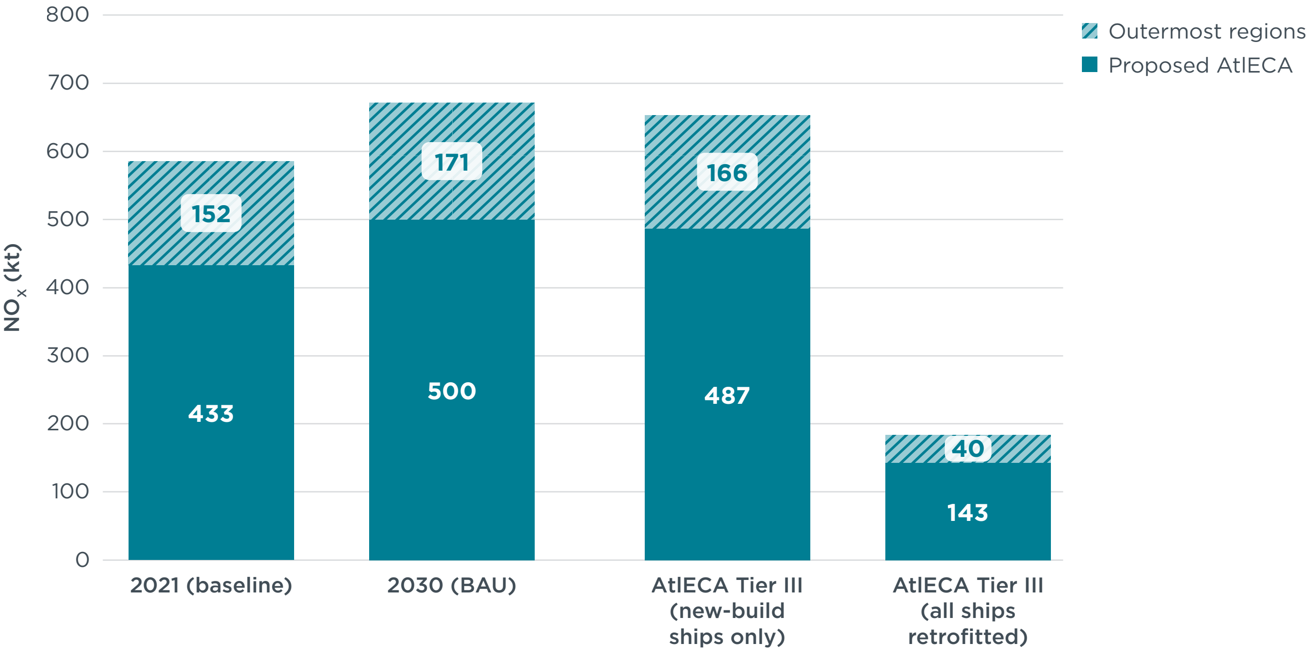
Given that NO_x Tier III standards apply only to ships newly built after an ECA's designation year, the impact on NO_x emissions is not expected immediately after the AtlECA designation. Assuming that the tentative AtlECA designation year is 2027—and that only vessels built that year and after will need to comply with the Tier III NO_x regulations—a 3% reduction in NO_x emissions can be expected by 2030 compared to the Business-As-Usual scenario (Figure 11 and Appendix D). Additionally, growth in shipping traffic will offset the effects of Tier III regulations in the initial years. NO_x emissions will still increase in the AtlECA, but at a slower pace; NO_x emissions in 2030 will be 12% greater than 2021 levels with Tier III regulations compared to 15% greater without the Tier III regulations.

The potential of Tier III regulations to reduce NO_x emissions could be significantly enhanced by requiring older ships operating in the ECA to be retrofitted to meet Tier III standards. Figure 11 shows a scenario where all ships are retrofitted to comply with Tier III, leading to a potential reduction of up to 71% of NO_x emissions in the proposed AtlECA and 76% in the outermost regions in 2030 compared to the BAU scenario. Similar conclusions have been drawn by the International Institute for Applied Systems Analysis in their cost-benefit analysis of an ECA designation in EU waters (Cofala et al., 2018). They estimated that applying Tier III regulations solely to newly built ships in 2025 would result in an increase in NO_x emissions of up to 5% by 2030. In contrast, retrofitting old engines to Tier III could yield emission reductions ranging from 16% to 31% by 2030. The technical and practical feasibility of retrofitting older engines to achieve Tier III is beyond the scope of this project.

While the impact of an AtlECA designation on NO_x emissions may not be immediate, a gradual reduction is expected with fleet turnover. The effect of Tier III regulations can be strengthened by retrofitting engines of all ships, or at least retrofitting Tier II ships. This could be an important policy improvement since there is a growing body of evidence from real-world NO_x emission measurements indicating that Tier II engines have higher emissions than older Tier I engines, especially at lower engine loads (Comer et al., 2023).

Figure 11

Total NO_x emissions and Tier III-affiliated reductions in the proposed AtlECA and the outermost regions in 2030



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CONCLUSIONS

In this study, we estimated the expected reduction in emissions from shipping as a direct outcome of a new proposed Emission Control Area—the North Atlantic Emission Control Area (AtlECA)—where more stringent regulations regarding the emissions of SO_x, NO_x, and PM from ships are enforced, as defined by the MARPOL Annex VI.

We estimate that the designation of the AtlECA holds the potential to considerably reduce these emissions. If distillate fuel is used for compliance, the ECA would result in an 82% reduction in SO_x emissions, a 64% reduction in $PM_{2.5}$, and a 36% reduction in BC emissions. Expanding the scope of the AtlECA area to include the outermost regions of Portugal and Spain, namely the Azores, Madeira, and Canary Islands, would increase the amount of fuel covered by the ECA by 34%. If distillate fuel is used for compliance, this would decrease SO_x emissions by 84%, $PM_{2.5}$ by 67%, and BC by 41%. This could bring significant emissions reductions to people living in these regions, especially in the Azores, which has the highest ship traffic of the three regions.

Notably, 88% of the vessels in the proposed AtlECA, as well as 94% in the outermost regions, also sail in other existing or proposed Emission Control Area. Consequently, most ships navigating the proposed AtlECA and outermost regions are already ECA-ready, indicating that establishing a new ECA would not require significant technical modifications of these vessels.

By 2030, Tier III standards will reduce expected NO_x emissions by about 3% below the Business-As-Usual scenario if they apply only to ships built in 2027 or later. However, NO_x emissions will still be about 12% higher than in 2021 because of growth in shipping traffic. Larger NO_x reductions could be achieved by applying Tier III standards to engines on all ships.

The biggest reductions in emissions can be achieved when ships use distillate fuels such as MGO to comply with the ECA. Using ULSFO or HFO with scrubbers is not as effective at reducing SO_x, PM, or BC. The use of ULSFO produces 9% more SO_x, 55% more $PM_{2.5}$, and 36% more BC emissions compared to distillates. While scrubbers are shown to be equally effective as distillates in reducing SO_x emissions, they generate 17% more $PM_{2.5}$ and 32% more BC emissions.

RECOMMENDATIONS

Based on this analysis, we suggest the Atlantic ECA member states consider the following recommendations:

» Include the full exclusive economic zones of Spain, Portugal, France, the United Kingdom, Ireland, Iceland, Faroe Islands, and Greenland in the geographic scope of the AtlECA. This would strategically connect the surrounding established or proposed ECAs and would be the largest low-emission shipping zone in the world. All states within the ECA can expect a substantial pollution reduction in their national waters after the designation. In the Arctic states, where absolute emissions may appear lower than in other areas, there is still a substantial opportunity for pollution reduction. Additionally, there are substantial co-benefits in reducing the warming effect caused by BC emissions in the Arctic waters.

» Include the outermost regions of Portugal (Azores and Madeira) and Spain (Canary Islands) in the geographic scope of the AtlECA. Our analysis shows that 94% of the traffic crossing these islands is already shipping in other existing or proposed Emission Control Area. Thus, these vessels will not need significant investments in technical modifications to comply with the new emission standards, while reducing air pollution from shipping could bring substantial public health benefits.

» Incentivize the use of distillates over ULSFO or scrubbers for ECA compliance in the national waters of AtlECA member states. ULSFO and scrubbers do not perform as well as MGO in reducing air pollution. While they exhibit comparable effectiveness in reducing SO_x emissions, they are not as effective in reducing PM and BC. Therefore, they should not be considered as equal substitutions.

» Consider restricting the use of scrubbers in the national waters and ports of AtlECA member states to reduce BC and PM and to avoid scrubber discharges. Alternatively, mandate ships with scrubbers to connect to shore power while at berth. Five of eight AtlECA member states, including Portugal, France, Spain, Ireland, and the UK, have already imposed bans on the use of open-loop scrubbers in certain ports. Globally, 45 countries have either limited or prohibited the use of scrubbers in their ports or national waters.

» Consider supporting Norway's suggestion to amend MARPOL to use the "three dates criteria" for the designation of newly built ships subject to Tier III NO_x emission standards. The current definition, which relies on the keel-laying date of a new ship, delays the desired effect of new NO_x regulations. Norway's proposed amendment would clarify the date criteria to include a ship's building contract date and delivery date. (MEPC 81/11/1, Annex 1).

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APPENDIX A

MARPOL Annex VI (MEPC 58/23/Add.1 Annex 13) includes the following criteria for designating Emission Control Area:

Appendix III

Criteria and procedures for designation of Emission Control Area (Regulation 13.6 and regulation 14.3)

3. Criteria for designation of an Emission Control Area

3.1 The proposal shall include:

.1 a clear delineation of the proposed area of application, along with a reference chart on which the area is marked;

.2 the type or types of emission(s) that is or are being proposed for control (i.e. NO_x or SO_x and particulate matter or all three types of emissions);

.3 a description of the human populations and environmental areas at risk from the impacts of ship emissions;

.4 an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts to terrestrial and aquatic ecosystems, areas of natural productivity, critical habitats, water quality, human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified;

.5 relevant information pertaining to the meteorological conditions in the proposed area of application to the human populations and environmental areas at risk, in particular prevailing wind patterns, or to topographical, geological, oceanographic, morphological, or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts;

.6 the nature of the ship traffic in the proposed Emission Control Area, including the patterns and density of such traffic;

.7 a description of the control measures taken by the proposing Party or Parties addressing land-based sources of NO_x, SO_x and particulate matter emissions affecting the human populations and environmental areas at risk that are in place and operating concurrent with the consideration of measures to be adopted in relation to provisions of regulations 13 and 14 of Annex VI; and

.8 the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade.

APPENDIX B

Ship types used in this study were drawn from ICCT's Systematic Assessment of Vessels Emissions (SAVE) model.

	Ship types	SAVE ship classes
1	Container	Container
2	Tanker	Chemical tanker
		Liquified gas tanker
		Oil tanker
		Other liquids tanker
3	Cargo ship	Bulk carrier
		General cargo
		Refrigerated bulk
4	Vehicle carrier	RoRo
		Vehicle carrier
5	Passenger	Cruise ship
		Ferry-passenger only
6	RoPax	Ferry-vehicles and passengers
7	Fishing vessel	Miscellaneous-fishing
8	Others	Offshore
		Service-other
		Service-tug
		Yacht
		Miscellaneous-other

APPENDIX C

Fuel used by ship type in the proposed AtlECA and outermost regions (Canary Islands, Azores, and Madeira) in the baseline year 2021 and projected to 2030

2021 fuel consumption (PJ)											
Ship type	Proposed AtlECA								Outermost regions		
	Portugal	Spain	UK	France	Ireland	Iceland	Faroe	Greenland	Canaries	Azores	Madeira
Container	26.97	16.64	5.15	12.24	3.23	0.98	0.35	0.54	5.44	13.52	4.22
Tanker	20.91	15.95	12.04	10.68	3.21	0.32	0.34	0.15	8.85	8.26	6.38
Cargo ship	15.77	13.33	6.18	9.75	2.85	0.87	1.09	0.87	6.81	7.70	5.86
Vehicle carrier	3.55	4.15	6.03	3.78	1.75	0.26	0.28	0.00	1.87	0.77	0.62
Passenger	3.33	4.32	2.76	1.95	0.36	0.69	0.04	0.14	8.98	0.54	1.13
RoPax	0.56	0.89	10.46	1.29	2.92	0.27	0.54	0.00	6.14	0.18	0.23
Fishing vessel	1.44	4.98	4.17	3.14	3.79	3.45	1.95	0.99	0.78	0.28	0.25
Other	1.84	2.03	3.27	1.83	0.71	0.36	0.22	0.47	1.45	0.72	0.59
Total energy demand (PJ)	**74.4**	**62.3**	**50.1**	**44.7**	**18.8**	**7.2**	**4.8**	**3.2**	**40.3**	**32.0**	**19.3**

2030 fuel consumption (PJ)											
2030	Proposed AtlECA								Outermost regions		
Ship type	Portugal	Spain	UK	France	Ireland	Iceland	Faroe	Greenland	Canaries	Azores	Madeira
Container	28.31	17.64	5.36	12.85	3.36	1.23	0.37	0.56	5.78	14.10	4.39
Tanker	23.68	18.06	13.61	12.16	3.62	0.42	0.40	0.17	9.83	9.40	7.20
Cargo ship	17.97	15.07	6.92	10.95	3.23	0.92	1.21	1.00	7.78	8.86	6.77
Vehicle carrier	4.45	5.14	6.93	4.62	1.99	0.33	0.33	0.00	2.19	0.97	0.76
Passenger	4.19	5.50	3.45	2.53	0.43	0.82	0.05	0.15	11.96	0.66	1.46
RoPax	0.69	0.98	10.77	1.33	2.98	0.29	0.56	0.00	6.67	0.20	0.27
Fishing vessel	2.24	7.75	6.45	4.89	5.85	5.33	2.93	1.54	1.20	0.44	0.38
Other	2.69	3.04	4.96	2.73	1.08	0.56	0.35	0.71	2.19	1.02	0.82
Total energy demand (PJ)	**84.2**	**73.2**	**58.4**	**52.1**	**22.5**	**9.9**	**6.2**	**4.1**	**47.6**	**35.7**	**22.1**

APPENDIX D

Emissions from shipping by country and outermost regions in the proposed AtlECA in baseline year 2021 and projected to 2030 under a Business-As-Usual scenario and various ECA compliance scenarios

SO_x emissions (kt)						
	Current 2021	**BAU 2030**	**ULSFO Mix**	**Scrubber Max**	**MGO Mix**	**MGO Max**
Portugal	12.48	13.88	3.38	1.90	2.12	2.18
Spain	9.60	10.84	3.01	1.88	2.02	1.91
United Kingdom	7.70	8.47	2.33	1.40	1.51	1.54
France	6.86	7.72	2.07	1.22	1.34	1.36
Ireland	2.71	3.01	0.88	0.56	0.59	0.60
Faroe Islands	0.54	0.64	0.23	0.17	0.16	0.16
Iceland	0.40	0.51	0.33	0.28	0.26	0.27
Greenland	0.34	0.41	0.16	0.11	0.11	0.11
Outermost regions:						
Canary Islands	5.41	6.05	1.76	1.06	1.16	1.19
Azores	5.51	6.06	1.41	0.76	0.86	0.89
Madeira	3.09	3.47	0.84	0.45	0.52	0.53
Total (AtlECA)	**40.63**	**45.48**	**12.39**	**7.51**	**8.13**	**8.14**
Total (AtlECA + outermost regions)	**54.65**	**61.05**	**16.40**	**9.78**	**10.68**	**10.75**

$PM_{2.5}$ emissions (kt)						
	Current 2021	**BAU 2030**	**ULSFO Mix**	**Scrubber Max**	**MGO Mix**	**MGO Max**
Portugal	5.24	5.83	5.23	2.76	1.87	1.70
Spain	4.00	4.52	4.08	2.25	1.60	1.44
United Kingdom	2.90	3.23	2.90	1.61	1.18	1.11
France	2.97	3.35	3.06	1.65	1.16	1.06
Ireland	1.11	1.25	1.14	0.64	0.48	0.45
Faroe Islands	0.23	0.28	0.25	0.16	0.13	0.13
Iceland	0.23	0.30	0.31	0.23	0.21	0.20
Greenland	0.16	0.19	0.19	0.11	0.09	0.09
Outermost regions:						
Canary Islands	2.26	2.54	2.37	1.29	0.96	0.87
Azores	2.39	2.63	2.36	1.21	0.79	0.72
Madeira	1.34	1.51	1.37	0.70	0.47	0.43
Total (AtlECA)	**16.84**	**18.94**	**17.17**	**9.40**	**6.73**	**6.18**
Total (AtlECA + outermost regions)	**22.83**	**25.62**	**23.26**	**12.60**	**8.95**	**8.20**

BC emissions (kt)						
	Current 2021	BAU 2030	ULSFO mix	Scrubber Max	MGO mix	MGO Max
Portugal	0.50	0.57	0.57	0.52	0.30	0.28
Spain	0.45	0.53	0.53	0.50	0.33	0.30
United Kingdom	0.47	0.55	0.55	0.51	0.38	0.37
France	0.34	0.40	0.40	0.37	0.24	0.23
Ireland	0.17	0.20	0.20	0.19	0.14	0.14
Faroe Islands	0.05	0.07	0.07	0.07	0.06	0.06
Iceland	0.08	0.11	0.11	0.11	0.10	0.10
Greenland	0.03	0.04	0.04	0.04	0.03	0.03
Outermost regions:						
Canary Islands	0.32	0.36	0.36	0.34	0.26	0.24
Azores	0.18	0.20	0.20	0.19	0.09	0.08
Madeira	0.11	0.13	0.13	0.12	0.06	0.06
Total (AtlECA)	**2.10**	**2.47**	**2.47**	**2.31**	**1.59**	**1.51**
Total (AtlECA + outermost regions)	**2.71**	**3.17**	**3.17**	**2.96**	**2.00**	**1.89**

NO_x emissions (kt)				
	Current 2021	BAU 2030	Tier III new ships only	Tier III all ships retrofitted
Portugal	129.7	145.0	141.9	34.5
Spain	103.4	119.5	116.8	34.6
United Kingdom	70.8	82.1	79.6	26.9
France	76.9	88.2	86.2	24.5
Ireland	29.7	35.1	33.6	12.5
Faroe Islands	7.1	9.2	8.7	3.0
Iceland	10.5	14.4	13.4	5.3
Greenland	5.1	6.6	6.4	2.0
Outermost regions:				
Canary Islands	58.5	67.0	64.3	16.9
Azores	59.8	66.0	64.9	14.9
Madeira	33.7	38.1	37.0	8.7
Total (AtlECA)	**433.3**	**500.3**	**486.7**	**143.3**
Total (AtlECA + outermost regions)	**585.2**	**671.4**	**653.0**	**183.8**

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