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Shipping in the EU emissions trading system: implications for mitigation, costs and modal split

Jonas Flodén[a], Lars Zetterberg[b], Anastasia Christodoulou[c,d], Rasmus Parsmo[b,e], Erik Fridell[b], Julia Hansson[b,e], Johan Rootzén[b] and Johan Woxenius[a]

[a]Department of Business Administration, School of Business, Economics and Law, University of Gothenburg, Gothenburg, Sweden; [b]IVL Swedish Environmental Research Institute, Gothenburg, Sweden; [c]World Maritime University, Malmö, Sweden; [d]Department of Maritime Studies, School of Maritime and Industrial Studies, University of Piraeus, Athens, Greece; [e]Department of Mechanics and Maritime studies, Chalmers University of Technology, Gothenburg, Sweden

ABSTRACT

EU recently decided to include shipping, meaning all intra-European shipping and 50% of extra-European voyages, in the EU Emissions Trading System (ETS) beginning in 2024. This article provides an early assessment of the impacts of the EU ETS on the shipping sector's potential reductions in greenhouse gas emissions for different types of ships. It further examines selected mitigation measures and the impact on modals split and costs. The study employs a mixed-methods approach combining quantitative estimates (based on data from the EU monitoring, reporting and verification system) with qualitative data and information from interviews with key actors and from previous literature. This approach aims to provide a comprehensive understanding of the impacts of the EU ETS. The inclusion of shipping in the EU ETS is expected to introduce significant incentives to reduce emissions. We estimate that switching to bio-methanol at an emissions allowance price of €90–100/tCO_2 will be cost-effective for a minor share of shipping segments (representing about 0.5-5% of all ships), whereas at a price above €150/tCO_2 it could be cost-effective for a considerable share (potentially 75%) of ships. In the short term, the costs incurred by the EU ETS will be passed on to transport customers as a surcharge. The increased cost may, unless properly addressed, drive carbon leakage. Meanwhile, a modal shift away from shipping may occur in the roll-on, roll-off (RoRo) and roll-on passenger (RoPax) segments due to direct competition with road and rail transport and the relative ease of shifting to other modes of transport.

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Shipping; EU ETS; modal shift; emissions trading; mitigation; maritime transport; bunker fuel

Key policy insights

- Integrating shipping into the EU ETS is an important step towards reducing GHG emissions in the sector but also will reduce emissions of NO_X, SO_X, and PM.
- CO_2 emissions from shipping constitute about 8% of GHG emissions from all sectors in the EU ETS.
- The need to purchase allowances will increase operating costs, which will initially be passed on to transport customers as a surcharge.
- Interviews confirm that a modal shift away from shipping to road and rail may occur in the RoRo and RoPax segments.

CONTACT Jonas Flodén jonas.floden@handels.gu.se Department of Business Administration, School of Business, Economics and Law, University of Gothenburg, P.O Box 610, Gothenburg 405 30, Sweden
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- Switching to bio-methanol may be cost-effective mainly for some ships in the RoRo, RoPax and reefer segments at an allowance price below €100/tCO_2, while for most ships (about 85–100% of ships) it will be cost-effective above €200/tCO_2.

Introduction

Maritime transport represents about 3–4% of total carbon dioxide (CO_2) emissions in the EU (EP and EUCO, 2023a). Although the shipping sector has long evaded most restrictions imposed by climate policy, EU institutions recently decided, following a drawn-out political process (Faber et al., 2009, 2010; Kågeson, 2007), to include shipping in the EU Emissions Trading System (ETS) beginning in January 2024. The EU ETS will encompass CO_2 emissions from all ships with a gross tonnage (GT) of at least 5000 that enter ports in the EU, regardless of the country where they are registered. The EU ETS will also increase costs for CO_2 emissions from shipping with the aim of incentivising a shift to alternative fuels and propulsion technology as well as operational changes to increase energy efficiency. However, concerns have been raised that it will drive a shift to other modes of transport and attempts to circumvent the legislation by, for example, calling ports just outside the EU (Lagouvardou & Psaraftis, 2022; Transport & Environment, 2021). Meanwhile, the economic impact of including shipping emissions in the ETS will depend on various design-related factors, including the system's geographic scope, market conditions, and the allowance price (Christodoulou et al., 2021; Faber et al., 2010; Psaraftis et al., 2021; Wang et al., 2015). In Psaraftis et al. (2021) EU ETS for shipping is compared with other policies in terms of some selected overall aspects (e.g. greenhouse gas (GHG) reduction effectiveness). Christodoulou et al. (2021) assessed the direct economic impacts of including shipping in the EU ETS and concluded that the increased costs would be disproportional among the shipping segments.

Many CO_2 abatement measures lack cost estimates for various shipping segments and/or for specific ships. Kanchiralla et al. (2023) and Lagouvardou et al. (2023) represent recent notable exceptions that demonstrate the potential for various fuel and propulsion options for specific ships. Available abatement costs for operational measures, but not generally ship- or segment-specific ones, include speed reductions (Goicoechea & Abadie, 2021; Jivén et al., 2020), and other efficiency measures (Brynolf et al., 2016; Faber et al., 2012). However, these costs are somewhat outdated and thus uncertain.

In our study, following a mixed-methods approach, we assess the potential impacts on mitigation and costs of including shipping in the EU ETS. First, we estimated the GHG emissions covered per shipping segment, defined by the type of cargo that they are designed to transport, to clarify the influence of certain key design features. Next, we estimated the potential to reduce CO_2 emissions per shipping segment by switching to biomass-based methanol, one of the most feasible and low-cost available mitigation measures. Afterwards, we estimated the economic impacts of the new legislation. In interviews, we also solicited insights from leading commercial actors on potential strategies to cope with the inclusion of shipping in the ETS and the additional associated costs. In this article, emission estimates represent data from 2019 to 2022, while projected abatement costs and opinions in interviews focus on the years to come.

The study offers novel insights into the potential impacts on the maritime sector of including shipping in the EU ETS, specifically for different shipping segments and types of ships, considering impacts not only on the environment and economy but also modal splits. Its key contributions are quantifications of the emissions covered for different shipping segments and the ranges of allowance prices for which bio-methanol may be feasible for different ships and shipping segments, including an estimate of the associated potential for CO_2 reduction. Furthermore, the study identifies potential measures for shipping lines and customers to adapt to the ETS and highlights shipping segments vulnerable to modal shift away from shipping.

In what follows, Section 2 describes how the revised EU ETS legislation came to be, after which Section 3 presents the scope and methods of our study. The legislation's ramifications for the shipping sector in terms of potential impacts on the environment, the economy, and modal splits are analysed in Section 4. The results are discussed in Section 5, and our conclusions are articulated in Section 6.

Policy background

An amendment to the EU ETS Directive, enacted in 2018, emphasized the need to act on shipping emissions (European Commission [EC], 2018). The following year, the EU Green Deal was presented, along with a general review of all policies relevant to achieving the EU-wide climate target (Wettestad & Gulbrandsen, 2022). In 2020, the EC (2020a) indicated that the revised EU ETS Directive would require assessing the impact of 'including at least internal EU emissions of the maritime sector'. In 2021, as part of the Fit-for-55 package, the EC presented its legislative proposal for including shipping in the ETS, and, in 2022, the European Parliament (EP) presented its position. In a trilogue in 2023, the European Council (EUCO), EP, and EC resolved to include shipping in the ETS beginning in January 2024, and associated amendments to the emissions trading directive were adopted and entered into force in mid-2023 (EP and EUCO, 2023a).

The EU ETS maritime emissions regulations will be accompanied by a range of implementing and delegated acts to specify the rules. As of this article's writing, some of those acts have been finalized, whereas others continue to be processed. This brief background provides an overview of key considerations of specific design features of maritime transport's inclusion in the ETS, subsequently summarized in Table 1.

Ship categories covered

Ships exceeding 5000 GT will be included in the EU ETS. That cut-off mirrors the coverage stipulated by the EU Monitoring, Reporting and Verification (MRV) system, which already documents CO_2 emissions and other relevant information for ships that load and/or unload cargo and/or passengers at ports in the European Economic Area (EEA). The ships included will cover 55% of all cargo and passenger ships calling at ports in the EEA and account for more than 90% of the CO_2 emissions from shipping in the EU (EC, 2020b). The EC will examine the feasibility and sustainability of including emissions from ships exceeding 400 GT from 2027.

GHGs included

CO_2 will initially be covered in the shipping sector, whereas methane (CH_4) and nitrous oxide (N_2O) will be included beginning in 2026. CH_4 emissions will be included due to the increased use of liquefied natural gas (LNG) as a maritime fuel that can lead to CH_4 slip from marine engines. Meanwhile, N_2O, a highly potent GHG, will be included due to the risk of future emissions when new fuels such as ammonia are introduced. Although the EU ETS legislation covers six types of GHGs – CO_2, CH_4, N_2O, SF_6, hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) – only CO_2 is currently covered in all sectors of the ETS (i.e. iron and steel, cement, pulp and paper, refineries, and energy); N_2O and PFCs are covered only for specific industrial processes, and CH_4 emissions are, in practice, completely ignored (EC, 2015; Mellin et al., 2020).

Geographical coverage

Per the new legislation, all ship emissions from voyages and in ports within the EU or EEA and 50% of extra-EU traffic (determined by the last or first port of call outside the EU/EEA) are included in the EU ETS. The latter

Table 1. Overview of key design features in the revised EU ETS directive (June 2023) (EP and EUCO, 2023a).

Ship categories covered	Ships >5000 GT. Offshore ships specifically serving operational purposes such as oil exploration will be included from 2027. Including ships exceeding 400 GT will be considered following an investigation of its economic, environmental, and social impacts.
GHGs included	CO_2 included from 2024 and CH_4 and N_2O emissions from 2026.
Geographical coverage	All intra-EU traffic, including port emissions, and 50% of the emissions from incoming and outgoing traffic.
Entities regulated	The shipowner responsible for surrendering emissions allowances.
Allocation of allowances	Via auction.
Use of revenues from allowance sales	Revenues transferred to member states' budgets and should be used mainly for climate-related purposes. The EU Innovation Fund should support investments to decarbonise the maritime transport sector.
Time frame	The surrendering of allowances by shipping companies will be gradually increased with respect to verified emissions reported for 2024 (40%) and 2025 (70%) until full inclusion beginning in 2026.

stipulation has raised concerns regarding carbon leakage, whereby inbound ships might call to a port just outside the EU before stopping at an EU port (see Section 4.2). According to Psaraftis et al. (2021), that risk could be avoided by an appropriate definition of 'port of call', which the legislation currently defines as the port at which a ship stops to load or unload cargo or to embark or disembark passengers. However, stops to refuel, take shelter from adverse weather, or receive repairs are excluded (EP and EUCO, 2023a). The EC also specifies several 'neighbouring container transhipment ports' located outside EU but less than 300 nautical miles from a port under the jurisdiction of a member state that will not fall under the definition of 'port of call' (EC, 2023). The Commission intends to monitor potential evasive behaviour and propose, where appropriate, measures to address such behaviour (EC, 2023).

Entities regulated

The legislation defines the 'shipowner' as the regulated entity responsible for surrendering emissions allowances to the regulator. That definition follows the logic of the rest of the EU ETS, wherein the owner of the installation releasing emissions is the regulated entity. The shipowner is also responsible for reporting to the MRV system.

Allocation of allowances

Auctioning, the primary method used to allocate allowances in the EU ETS (Sato et al., 2022), will be applied for shipping. Auctioning is transparent, aligns with the 'polluter pays' principle, and creates strong incentives for reducing emissions.

Use of revenues from allowance sales

As with auction revenues from other sectors covered by the ETS, auction revenues from the shipping sector accrue to the member states and should, with a few exceptions, be used for climate-related purposes. The overall size of the EU Innovation Fund, which is funded by auction revenues, will also be increased from 450 million ETS allowances to approximately 530 million. The Innovation Fund can support an array of projects and innovative solutions, and the list of those purposes has been expanded to explicitly cover measures to decarbonize the maritime sector (EP and EUCO, 2023a).

Along with the EU ETS, several other EU regulations addressing maritime transport's impact on the climate were introduced in 2023, including Fuel EU Maritime Regulation (EP and EUCO, 2023b), the Renewable Energy Directive (RED) (EP and EUCO, 2023c), and the Directive on Deployment of Alternative Fuels Infrastructure (EP and EUCO, 2023d). A proposed revision of the Energy Taxation Directive (ETD) is also planned, although no agreement has yet been reached.

Methods

We applied mixed methods to analyse the effects of shipping's inclusion in the EU ETS from several perspectives.

GHG emissions covered per shipping segment

We analysed 11 shipping segments, categorized according to the type of cargo carried (see Figure 1). For a description of ship types, see Babicz (2015) and Stopford (2009). The CO_2 and GHG emissions per segment in the EU, in total, and for the geographical coverage in the legislation were estimated using the MRV system's data for 2019 (EMSA, 2022) to avoid the influence of the COVID-19 pandemic's impacts. We revised the MRV system's data, which include mandatory reported emission data on individual ships in the EU (MRV, 2023), to remove obvious reporting errors. The data, illustrating the approximate shipping emissions to be covered by the EU ETS when implemented in full scale, indicate the influence of the legislation's primary

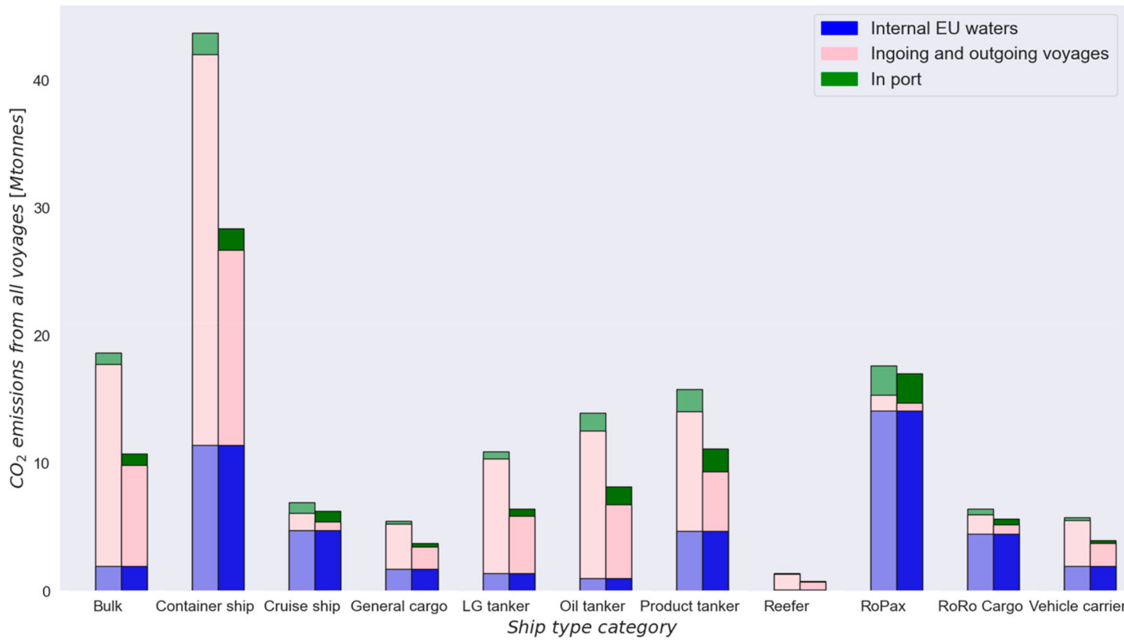

Figure 1. CO_2 emissions per shipping segment in 2019 for ships with GT >5000. Left bars show emissions from internal EU/EEA ship emissions, from ports, and from all incoming and outgoing voyages. Right bars are limited to 50% of the latter. All estimates are based on the MRV data.

design features (i.e. geographic scope, GHGs covered, and ship size). Although the data focus on CO_2 emissions, the potential impacts regarding CH_4 and N_2O emissions are indicated as well.

We estimated the global warming potentials over 20-year and 100-year horizons (i.e. GWP20 and GWP100) for CO_2, CH_4 and N_2O based on the values used for reporting to the EC following the IPCC's (2007) Fourth Assessment Report. The same GWP100 values are used in the EU ETS. Direct emissions of CH_4 and N_2O were calculated based on estimated levels of fuel used and emissions factors from the International Maritime Organization (IMO) (Faber et al., 2021). Meanwhile, the specific fuel used was estimated based on the reported levels of CO_2 emissions and specific fuel oil consumption. Tank-to-wake emissions (i.e. direct emissions from fuel use on board ships) were considered, as in the legislation. By contrast, well-to-tank emissions (i.e. GHG emissions from upstream activities, including the extraction, production, and distribution of fuels) were estimated using the default upstream emission values from the FuelEU Maritime regulation (EP and EUCO, 2021).

Alternative fuels as an abatement measure

Bio-methanol is expected to rank among alternative fuels with the least costs (Korberg et al., 2021) and thus can serve as a suitable benchmark. The total potential to reduce CO_2 emissions per shipping segment by shifting to bio-methanol was estimated for ships for which the associated CO_2 abatement cost will be cost-effective (i.e. less costly than an assumed emissions allowance price). The emissions allowance prices considered are €90, €100, €150, and €200/tCO_2 which represent a range of recent, current, and potential future emissions allowance prices. Between 2019 and 2022, the price varied between €20 and €100/tCO_2 with a price of approximately €75 in December 2023 (Trading Economics, 2023).

The annual CO_2 abatement cost, in €/tCO_2, of switching to bio-methanol was estimated at the level of individual ships based on the MRV's data from 2019. The CO_2 abatement cost represents the quotient of the cost difference between bio-methanol and conventional fuel and the possible reduction in GHG emission reduction when by shifting to biomethanol; it also includes the capital cost for the investment and operational costs in the form of fuel cost. Meanwhile, the cost for converting a ship to methanol propulsion was assumed to be

€225,000-451,000/MW depending on the ship's size (Winnes et al., 2020). The assumed fuel production cost was €19.2/GJ for bio-methanol (Korberg et al., 2021), €14.5/GJ for marine gas oil (MGO), and €10/GJ for heavy fuel oil (HFO) (Brynolf et al., 2022), all of which reflect projections for 2025–2030. An interest rate of 10% and depreciation period of 10 years were assumed, and no extra cost for fuel storage on board was included.

Economic impact

The economic impacts of shipping's inclusion in the EU ETS were estimated using allowance prices between €20 and €200/tCO_2, which represent a range of potential prices. The added cost per tonne of MGO is calculated considering the geographical coverage of the system either aligned with the final legislation or restricted to intra-EU voyages (Christodoulou et al., 2021). Adding CO_2 costs from surrendering the emissions allowances to fuel price clarifies the increase in operational costs for shipping companies.

Impacts on modal splits

To gain an in-depth understanding of stakeholders' views on planned actions following shipping's inclusion in the EU ETS and its anticipated impacts on modal splits, we conducted seven semi-structured interviews, one workshop, and a reference group validation meeting in spring 2022 with representatives of Scandinavian roll-on, roll-off (RoRo) and roll-on–passenger (RoPax) shipping lines, transport customers, ports, NGOs, and authorities (see Supplementary Material). We selected the RoRo segment, which transports rolling cargo including truck and semi-trailers, and the RoPax segment, which transports both rolling cargo and passengers, because they mostly operate ships exceeding 5000 GT, serve intra-European routes, and often compete directly with land-based modes of transport. Because the interviews and workshop were designed to gain insights into how key actors perceive the problems and opportunities presented by shipping's inclusion in the EU ETS and what drives their actions in response to the legislation, respondents were selected to represent a range of shipping routes with different groups of customers, as well as authorities involved in implementing the ETS, NGOs attempting to influence it, and transport customers, who generally place demand on the transport system and may use modes of transport other than maritime transport. The results of the interviews, workshop, and reference group meeting represent the views and opinions of the participants and should not be interpreted as neutral fact.

The interviews were recorded, transcribed, and analysed in the software NVivo, which is commonly used to organize and analyse unstructured texts in qualitative data analysis. At the workshop, seven logistics managers met to discuss trends in transport and the impact of shipping's inclusion in the EU ETS. Although we took notes during the workshop and added them to NVivo, the participants did not consent to a full recording. The results of the interviews and workshop were also presented, discussed, and validated at the reference group meeting with seven representatives of the shipping industry, NGOs, and authorities (see Supplementary Material), along with the authors, who took notes during the meeting. The meeting's overall aim was to gather comments and feedback to validate the results as fair, representative responses to shipping's inclusion in the ETS.

Results

Environmental impacts

The reductions in GHG emissions from shipping's inclusion in the EU ETS will result from mitigation measures implemented either in the maritime sector (i.e. in-sector abatement) or in other ETS sectors via the purchase of ETS allowances (i.e. out-of-sector abatement). In this section, we provide estimates of ETS-covered GHG emissions (i.e. CO_2, CH_4, and N_2O) per shipping segment based on 2019 shipping data and make an initial assessment of the potential reductions in CO_2 emissions per segment if bio-methanol were implemented. We also discuss the extent to which different abatement measures might be competitive.

Importance of geographic scope and included GHGs

The total potential reduction in CO_2 and GHG emissions depends on the geographic scope implemented and the types of ships covered. The total CO_2 emissions from EU shipping in 2019 included in the MRV system (i.e. GT >5000) amounted to approximately 144 Mt, 32.4% of which was from EU-internal shipping, 60.4% from ingoing and outgoing ships, and 7.1% from port-related emissions. The corresponding emissions for the geographic scope in the legislation amount to 99.2 Mt, with container and RoPax segments representing approximately 45% of the emissions. CO_2 emissions per shipping segment are presented in Figure 1, which also shows the shares from intra-EU shipping, ships in port, and incoming and outgoing voyages. For RoRo, RoPax, and cruise ships, most of the emissions originate from voyages made within the EU.

Figure 2 shows estimated total GHG emissions per shipping segment in the EU in 2019. Only tank-to-wake emissions have been considered. The total emissions for EU shipping from ships exceeding GT 5000 corresponds to 147 $MtCO_2$-equivalents (CO_2-eq.), with CH_4 representing 0.67 $MtCO_2$-eq. and N_2O representing 2.42 $MtCO_2$-eq for GWP100 (148 $MtCO_2$-eq. total for GWP20). For the 50% of incoming and outgoing voyages, the total GHG emissions amount to 101 $MtCO_2$-eq. for GWP100, which corresponds to approximately 8% of GHG emissions from all sectors covered by the EU ETS in 2022 (European Environment Agency, 2023).

Importance of ships included

The potential to reduce GHG emissions also depends on the size of the ships included. If ships exceeding 5000 GT are included, then the corresponding GHG emissions from intra-EU shipping and 50% of extra-EU voyages have been estimated to 9.6 $MtCO_2$ (Transport & Environment, 2022). According to the same study, the emissions from ship types not covered by the MRV system (e.g. yachts and offshore service, fishing, and military ships) correspond to approximately 6 $MtCO_2$ for ships exceeding 5000 GT and 10.1 $MtCO_2$ for ships with 5000 GT.

Potential for mitigation measures to be implemented

The extent of in-sector versus out-of-sector abatement for shipping will primarily depend on the price of emissions allowances in relation to the carbon abatement costs for different measures and their abatement potential. In general, it is more costly to reduce CO_2 emissions from the transport sector than from stationary sources included in the EU ETS (OECD, 2016). The potential of different mitigation measures for various shipping

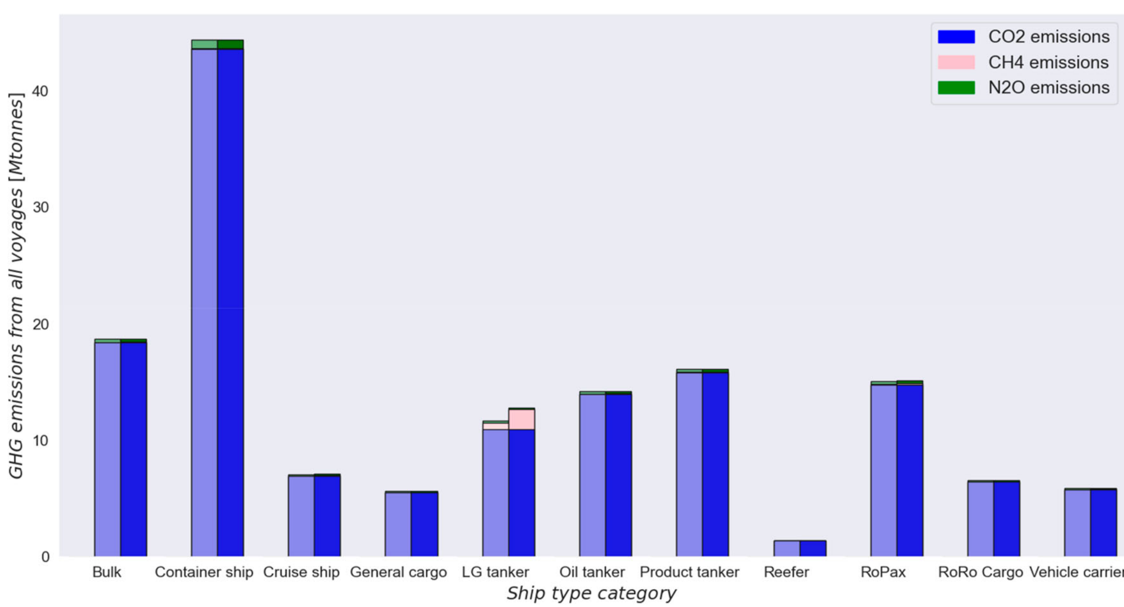

Figure 2. Estimated total GHG emissions per shipping segment in 2019 in the EU (in $MtCO_2$-eq., including CO_2, CH_4, and N_2O emissions) for GWP100 (left bar) and GWP20 (right bar), based on the MRV's data (ships exceeding 5000 GT).

segments depends on, for example, the ship's design, size, and speed and the distance travelled. For most measures, estimates of the CO_2 abatement cost specific to various ship segments are unavailable, while the available abatement costs for operational measures are often outdated and thus uncertain.

Abatement measures can be divided into operational, technical, and fuel substitution measures. For shipping, some CO_2 abatement measures, primarily operational measures, have relatively low or even negative CO_2 abatement costs, including weather routing, propeller polishing, and slow steaming (Eide et al., 2011; Nepomuceno de Oliveira et al., 2022; Wan et al., 2018). With shipping included in the EU ETS, some of those operational measures will likely be implemented. A high allowance price will increase the implementation of in-sector mitigation measures for shipping.

We estimated the potential of technical and operational abatement measures to reduce GHG emissions with either a low (<€18/tCO_2) or negative cost in EU-related shipping, using the total global mitigation potential for such measures presented in Nepomuceno de Oliveira et al.'s (2022) review. Such measures, listed in Table 2, are estimated to cover approximately 24% or 41% of the total EU shipping emissions in the MRV for 2019; the lower number refers to the implementation rate, as estimated by Nepomuceno de Oliveira et al. (2022), whereas the higher number represents the total mitigation potential gleaned from the literature (i.e. not specifically considering recent implementation of measures). The estimated potential to reduce GHG emissions is likely optimistic, however, because global mitigation potentials have been used, and EU shipping might have less remaining potential for mitigation. Furthermore, uncertainties remain about both mitigation potentials and implementation levels.

For some technical abatement measures (e.g. fixed sails or wings and auxiliary fuel cell engines), the estimated CO_2 reduction cost is €50–100/t. Abatement measures such as waste heat recovery and wind generators come with even higher costs (Eide et al., 2011; Nepomuceno de Oliveira et al., 2022; Wan et al., 2018; Yuan et al., 2016).

The abatement cost for replacing fossil fuels with renewable marine fuels is generally high. For liquefied biogas, biomethanol, and biodiesel for shipping, Chryssakis et al. (2017) have reported abatement costs of €150–200/tCO_2, while Lloyd's Register and UMAS (2017) have reported a cost of €230/tCO_2 for biofuel propulsion. More recently, Brynolf et al. (2022) estimated a carbon abatement cost for liquefied hydrogen for shipping in the range of €220–850/tCO_2 and for different electrofuels about €150–1250/tCO_2, with combined bio-methanol and electro-methanol in the lower range.

Table 3 presents the potential for each shipping segment to reduce CO_2 emissions by switching to bio-methanol for ships for which the measure would be less costly than the emissions allowance price. Our estimates assume that ships would apply mitigation measures when profitable, although such is not always the case. With an allowance price of up to €90/tCO_2, switching to bio-methanol is not a cost-effective measure for almost any ships and, up to €100/tCO_2, is cost-effective for only 17%–25% of RoRo and RoPax ships and only to a minor extent for most other segments. However, with an allowance price of €150/tCO_2, bio-methanol seems to represent a cost-effective measure for a considerable share of the ships in all segments and for nearly all RoPax and RoRo ships. At a price exceeding €200/tCO_2, bio-methanol seems to be cost-effective for nearly all

Table 2. Estimated total mitigation potential and implementation rate of technical and operational abatement measures with a low (<€18/tonne of CO_2) or negative cost (Nepomuceno de Oliveira et al., 2022).

Measure	Total mitigation potential (%)	Implementation rate (%)
Speed reduction	7.5	66
Voyage optimisation	3.6	63
Hull maintenance	4.0	46
Propeller maintenance	4.0	26
Hull coating	2.6	46
Optimisation of water flow hull openings	3.0	9
Hull shape	8.0	40
Main engine improvements	0.5	53
Auxiliary systems	1.6	32
Propeller improvements	2.4	25
Reduced auxiliary power	0.7	37
Steam plan improvement	2.0	43

Table 3. Estimated potential for different shipping segments in the EU to reduce CO_2, expressed as a percentage of 2019 emissions, by switching to bio-methanol at various emissions allowance prices (not considering bio-methanol supply limitations).

Shipping segment	CO_2 reduction potential (%) for bio-methonal with an emissions allowance price of			
	€90/tCO_2	€100/tCO_2	€150/tCO_2	€200/tCO_2
Bulk	0.2	0.7	53	84
Container ships	0.1	1	73	91
Cruise ships	1.6	7.9	95	98
General cargo	0.2	2.2	71	92
Liquefied gas (LG) tankers	0	0	84	95
Oil tankers	0	0	68	92
Product tankers	0.4	1.3	79	95
Reefers	0	35.8	87	97
RoPax	3.9	26.2	99	100
RoRo cargo	0.3	17.1	97	99
Vehicle carriers	0.8	6.4	78	95
Total	0.6	5.2	76	93

ships in all shipping segments, assuming that the required amount of bio-methanol becomes available at the assumed price.

Impact on upstream emissions

Shipping's inclusion in the EU ETS encompasses direct emissions from fuel use in shipping but not the associated upstream well-to-tank emissions. Even so, the upstream GHG emissions from marine fuels are somewhat indirectly included in the ETS via other included sectors and activities. For example, direct emissions from refineries producing fuels (e.g. during flaring) are included. Meanwhile, emissions from the combustion of fuels linked to activities such as the extraction of natural gas or crude petroleum are covered by the ETS but receive free allocation due to the risk of carbon leakage. In terms of non-CO_2 emissions, leakage of methane from, for example, extraction is not covered, however, nor are upstream emissions from marine fuels produced outside the EU. We estimated the total well-to-tank GHG emissions from upstream activities linked to shipping fuels used in the EU in 2019 to be approximately 26.7 MtCO_2-eq. (i.e. approx. 15% of the well-to-wake emissions), a considerable of which is not regulated by the ETS.

Ancillary effects

Implementing mitigation measures will also affect emissions such as nitrous oxides (NO_X), sulphur oxides (SO_X), and particulate matter (PM). Because including shipping in the EU ETS will prompt significant reductions of in-sector emissions, a significant benefit for air quality can also be expected. For a rough estimate of all potential estimates in the literature, the EC (2021) has indicated that emissions of NO_X, PM10, and SO_X may each be reduced by 7%–8% in 2030 with shipping included in the EU ETS, assuming that various alternative fuels are introduced to a certain extent.

Economic impacts

Shipping's inclusion in the EU ETS will exert direct impacts on shipowners who will face increased operational costs due to the need to buy allowances.

Table 4. Increased costs of marine gas oil due to shipping's inclusion in the EU ETS.

Emissions allowance price, €/tCO_2	Additional cost per tonne of MGO for a geographical scope of …	
	50% of incoming and outgoing voyages	100% of intra-EU voyages
€20	€31	€63
€70	€110	€220
€90	€141	€283
€100	€157	€314
€150	€236	€471
€200	€314	€628

Increased costs

Obviously, the price of emissions allowances is critical (Kågeson, 2007; Zetterberg et al., 2021). For intra-EU voyages, assuming an allowance price of €70/tCO_2, the additional cost imposed by shipping's inclusion in the EU ETS will be approximately €220 (i.e. €110 for extra-EU voyages) per tonne of fuel, assuming MGO and that 1 T of MGO generates approximately 3.14 tCO_2 (see Table 4). That estimate can be compared with the price of MGO, which varied between about €600 and €1200/T during 2022 (Ship & Bunker, 2023) and the price of emission rights that varied between about €65 and €100/tCO_2 the same year (Trading Economics, 2023). Comparing the costs month by month shows that the cost increase from emission rights in 2022 would have constituted between approximately 20% and 45% of the price of MGO, with an average of 28%. The added cost for intra-EU voyages appears in Table 5 with a range of previous fuel and emission rights prices.

Costs passthrough

The effect of the additional costs of allowances depends on the supply and demand of shipping services. If the supply of maritime services exceeds demand, then freight rates will generally be limited to the marginal operational costs of the shipping companies, including the cost of emissions allowances (Faber et al., 2010; Stopford, 2009). In that case, the allowance costs will be passed on to customers and directly impact the price. However, if demand exceeds supply, then freight rates will instead be determined by the marginal benefit of the shipping companies. Although the cost of emissions allowances will be passed on to customers, it will not directly impact the price of the transport service. On the contrary, the cost of emissions allowances will lower the profit margin of the company. In that case, the companies will, by default, absorb a large part of the additional CO_2 emissions cost and experience reduced profit margins (Faber et al., 2010). Not all markets will be similarly influenced by the additional CO_2 cost of shipping (Zetterberg et al., 2021). The prices of importing high-value products, including liquid bulk cargo and manufactured goods, are unlikely to be substantially affected, for transport costs constitute only a minor part of their prices for customers. By contrast, the impact on the prices of dry bulk cargo will be stronger due to their low value and high volume.

Risk of carbon leakage

The literature highlights the risk of competitive distortion and carbon leakage by including shipping in a regional ETS (Psaraftis et al., 2021), for the ships included would face higher operational costs than ships operating outside the covered area (Faber et al., 2009; Hermeling et al., 2015). According to Transport & Environment (2021), the risk of carbon leakage due to including shipping in the EU ETS is low, because the additional emissions allowance cost is small compared with the extra costs associated with avoiding EU ports. According to their findings, at an allowance price of €123/tCO_2, the additional cost would equal the costs associated with evading EU ports. However, when Lagouvardou and Psaraftis (2022) compared the ports of Piraeus and İzmir as well as Algeciras and Tangier, they found that a carbon price due to the EU ETS would motivate ships to avoid the ports at Piraeus and Algeciras in favour of the ports at İzmir and Tangier. According to their findings, the risks of carbon leakage is high, even for carbon prices well below €25/tCO_2.

Table 5. Percentage increase in the cost of using marine gas oil depending on fuel and allowance prices for intra-EU voyages. The increase for incoming and outgoing voyages is half of this increase.

		Emissions allowance price, €/tCO_2									
		20	40	60	80	100	120	140	160	180	200
Price MGO, t/€	600	10%	21%	31%	42%	52%	63%	73%	84%	94%	105%
	650	10%	19%	29%	39%	48%	58%	68%	77%	87%	97%
	700	9%	18%	27%	36%	45%	54%	63%	72%	81%	90%
	750	8%	17%	25%	33%	42%	50%	59%	67%	75%	84%
	800	8%	16%	24%	31%	39%	47%	55%	63%	71%	79%
	850	7%	15%	22%	30%	37%	44%	52%	59%	66%	74%
	900	7%	14%	21%	28%	35%	42%	49%	56%	63%	70%
	950	7%	13%	20%	26%	33%	40%	46%	53%	59%	66%
	1000	6%	13%	19%	25%	31%	38%	44%	50%	57%	63%
	1050	6%	12%	18%	24%	30%	36%	42%	48%	54%	60%

However, the risk of carbon leakage also differs between shipping segments (Christodoulou & Cullinane, 2023). Considering the geographical scope and operational features of the different ships, the risk is minimal for short sea shipping (SSS), including RoRo and RoPax that operates mostly within the EU (see Figure 1). The relative lack of risk was confirmed in interviews with representatives of RoRo and RoPax shipping lines and their customers. By contrast, the risk of carbon leakage is relatively high for deep-sea shipping segments, including container, tank, and dry bulk, which face high additional CO_2 costs due to the long distances travelled. There is also a risk of carbon leakage with constructing and using ships with GT below 5000 (Psaraftis et al., 2021).

Impacts on modal split

Modal shift has been the subject of much research, as shown in reviews by Raza et al. (2020) and Holmgren et al. (2014). Regarding the EU ETS, several studies have suggested that increased emission costs will incentivise investments in emissions-saving technology but might also drive a shift towards land-based modes of transport (Christodoulou & Cullinane, 2023; Psaraftis et al., 2021) and changes in operational behaviours related to speed and routing (Faber et al., 2021; Gu et al., 2019; Lagouvardou & Psaraftis, 2022; Wang et al., 2021). However, that projection conflicts with the findings of other studies that suggest the limited impact of increased emissions costs because the additional cost is too low to induce any modal shift (Rojon et al., 2021; Vierth et al., 2023).

Price considerably influences how transport demand is split between modes of transport (Bergantino et al., 2013; Feo et al., 2011; Guilbault & Cruz, 2010), as do factors such as transport quality, speed, and flexibility (Flodén et al., 2017). The role of environmental sustainability in such decisions has also gained importance in recent years (Andersson & Styhre, 2021; Repka & Pöntynen, 2023). A transport customer typically selects a transport service by first filtering out options that will not fulfil their basic requirements in terms of service level, transport time, sustainability, and flexibility; thereafter, however, the choice of transport almost exclusively focuses on price (Flodén et al., 2017).

Assessing the impacts of shipping's inclusion in the EU ETS on modal shift depends heavily on the estimated costs of emissions allowances and volatilities in the industry, as clearly illustrated by the implementation of the Sulphur Emission Control Area (SECA) in Europe in 2015. A wide range of ex ante studies (e.g. Holmgren et al., 2014; Kehoe et al., 2010; Notteboom, 2011) predicted a modal shift away from shipping. However, when the price of crude oil decreased by 50% in the 6 months before SECA's implementation, the price of low-sulphur fuel after its implementation dropped below the price of high-sulphur fuel 6 months earlier, and the expected short-run modal shift did not materialise (Zis & Psaraftis, 2017, 2019).

The modal shift impact following shipping's inclusion in the EU ETS is likely to differ significantly across shipping segments. Shipping's strength as a mode of transport is its ability to move large volumes of goods with a low unit cost and low energy consumption due to significant economies of scale (Stopford, 2009). Shipping is therefore a traditionally strong player in the wet and dry bulk segments. In bulk shipping, a large share of contracts are traded on the highly competitive spot market, which is subject to large fluctuations in transport prices. For example, between May and December 2008, the Baltic Dry Bulk shipping Index dropped 94% from 11,800–660 points (Baltic Exchange, 2023). Bulk shipping also has a low elasticity of demand (Stopford, 2009), largely due to limited alternative transport options. Intercontinental container shipping is similarly inelastic, but freight rates for bulk shipping fluctuate even less, despite showing otherwise during the COVID-19 pandemic (UNCTAD, 2023). Meanwhile, air freight, significantly limited in terms of capacity and price competitiveness, can absorb only a fraction of the container shipping volumes. Although rail is an option between Europe and East Asia, it is currently hampered by sanctions and security concerns related to the war in Ukraine. A determining factor for a potential modal shift away from shipping is therefore the availability of competing modes of transport.

SSS within Europe competes directly with land-based modes of transport, for road and rail often offer similar transport services (Christodoulou & Woxenius, 2020). Such competition places SSS at risk of a modal shift (Raza et al., 2020), especially with respect to the RoRo and RoPax segments, which often participate in an intermodal transport chain that is already adapted to land-based transport. In that case, shipping constitutes a subcontractor to the forwarders and road hauliers, and, for example, a truck driver can easily choose between using a ferry or a bridge. Many SSS routes are close to land, such that a shorter sea voyage combined with road transport can

Figure 3. Map of competing routes between Gothenburg, Sweden, and Zeebrugge, Belgium.

replace a longer sea voyage (Christodoulou et al., 2019). For example, a 34-hour RoRo service between Gothenburg, Sweden, and Zeebrugge, Belgium, can be substituted by a combination of road transport through Sweden, a 20-minute RoPax service to Denmark, and road transport to Belgium, as shown in Figure 3.

SSS for containers, or 'feeder shipping', is often integrated with intercontinental container flows (Polat, 2017) and thus less susceptible to a modal shift. Transport operators avoid using containers for relatively long intra-European road transport because the weight and physical dimensions of containers are not adapted for road transport. Some shift to rail might occur, however, because its production profile, with a high capacity and low marginal cost for moving containers, resembles shipping's (Woxenius & Bergqvist, 2011).

Nevertheless, there is concern that the EU ETS will introduce long-term changes into the logistics structure. Transport flows are largely determined by trading patterns and the locations of factories, warehouses, and terminals. That structure tends to remain relatively stable over time, because those facilities are large investments and because redesigning the logistics network would require significant effort. Similarly, albeit on a shorter time frame, transport services are determined by transport contracts with durations typically in the range of 1–3 years (Andersson & Styhre, 2021). Research on transport disruptions has shown that once a disruption is large enough to motivate the transport operator to redesign its system, it becomes very difficult to revert to the previous design (Gonzalez-Aregall, 2018). The higher transport costs caused by the EU ETS may therefore influence new investments and redesigns of the logistics system, which could mean less shipping. Concerns have also been raised that sourcing patterns may change, such that higher transport costs from the EU might cause non-EU countries to source products elsewhere. However, the ETS is likely a minor factor compared with geopolitical tensions. An additional long-term uncertainty is the technical and regulatory development of competing modes of transport.

Insights from actors in the shipping sector

The interviews conducted with representatives of the shipping sector indicate that shipping companies have very positive attitudes towards taking on greater environmental responsibility and recognize that tougher environmental requirements are necessary for progressive shipping companies to remain competitive. Respondents further highlighted a rather rapid shift in such attitudes in the industry, wherein sustainability-related proposals confronted significant scepticism only 2–3 years ago. Respondents perceived shipping's inclusion in the EU ETS as an inevitability that they must accept and deal with, just as they have had to deal with changing conditions in the shipping sector caused by high fuel costs, geopolitical tensions, the COVID-19 pandemic, higher interest rates, and various new regulations. Even so, respondents emphasized that the implementation of the ETS needs to be fair so as not to disturb intramodal or intermodal competition.

The respondents also expected to incur significant costs due to the EU ETS and that it will lead to a modal shift away from shipping. The shift is expected to impact different routes differently. Longer routes have a higher fuel component in their total cost and are more exposed. The competition also differs because some routes compete primarily with other shipping routes, some compete with land-based modes of transport, and some gain a competitive edge by offering specific logistics services. Furthermore, given RoRo and RoPax shipping's role as a short link in intermodal chains, competition is also affected by operational considerations, including how well the departure and voyage times match the mandatory resting periods for truck drivers. The potential modal shift therefore depends heavily upon the context. Respondents anticipated that, in the long run, some routes could be cancelled. A special problem for RoPax, in particular, is allocating ETS costs between freight and passenger customers and especially for cruise ferries with a significant share of revenues from bars, restaurants, and shopping.[1]

Stating that the time until the EU ETS's implementation is too short, the representatives of the shipping lines did not indicate any planned short-term changes to their deployed ships, ship designs, routes, speeds, engines, or fuels. The service life of a ship is often 30–40 years, which means that technological shifts in the shipping industry occur slowly, and the choice of technology is a long-term decision, although some retrofits or changes in fuel might be feasible. All shipping lines interviewed, however, do plan to add the cost of EU ETS as a surcharge to their customers to emphasize that it is an externally introduced cost.

The interviewed transport customers, by contrast, resisted the idea of having to pay an additional surcharge and perceived it to be an unfair way to raise prices. They argued that all companies have to pay taxes and fees and that the EU ETS's cost should be included in the price. At the same time, the interviewed transport customers' understanding of the ETS was rather limited; several had not even heard that shipping is to be included in the ETS, but showed an interest in learning more. Even so, they perceived the application of the ETS and associated costs to be the responsibility of shipping lines. Their limited understanding was confirmed by the representatives of the shipping lines, who stated that only the very largest customers have any in-depth understanding of how the shipping industry works. The representatives were well aware of the EU ETS when interviewed in spring 2022 but still considered many details to be unclear and expressed reluctance to commit to any course of action without knowing more.

The representatives of the shipping lines, in the long term, expect that a higher cost for emitting CO_2 will influence investment decisions and that the EU ETS will facilitate previously unprofitable mitigation measures, including the use of alternative fuels. In general, respondents were positive about that development and admitted needing a push to advance the green transition of the shipping sector. The prevailing view was that the EU ETS will make the EU shipping sector more competitive than non-EU shipping by providing incentives for green investments.

Discussion

The increased cost for shipping due to its inclusion in the EU ETS will incentivise investment in abatement measures in the sector. With an allowance price at €100/tCO_2 or more, several low-cost abatement measures, including adjusted routing and logistics systems, could become financially sound. However, as shown in our study, that allowance price could also motivate a shift to biomethanol, primarily in some parts of the RoPax, RoRo, and reefer segments. To promote large-scale fuel shifts, an allowance price of at least €150–200/tCO_2 seems to be needed unless the cost difference between renewable and fossil fuels is substantially reduced owing to other reasons. However, uncertainty regarding the future development of propulsion technology, market developments in the energy sector, carbon abatement costs, and future policy incentives from the IMO and individual countries makes the choice of abatement measures for different ships challenging and not exclusively a technical issue (Balcombe et al., 2019; Viktorelius et al., 2022). For example, the potential supply of bio-methanol must also be considered when assessing the actual carbon abatement potential. A ship built with what turns out to be a less attractive mode of propulsion will lose value on the second-hand market, require expensive retrofits, or even become prematurely obsolete. Many shipping companies are inherently conservative, carefully watch market developments, and recognize the likely positive scale effects associated with choosing an abatement measure that will become common in the market – for example, more-widespread fuel availability, more technical development and know-how, shared development costs, and the higher value of second-hand ships. Old fleets in certain segments also make retrofits unlikely (Schwartz et al., 2020), although higher energy efficiency increases a ship's second-hand value (Adland et al., 2018). It is therefore unsurprising that many shipping lines plan to simply pass on the EU ETS's cost to their customers as a surcharge. It is also more straightforward to motivate, calculate and prove a surcharge for purchased emissions allowances or alternative fuels than to argue that customers should pay for energy-efficiency investments.

Even if the allowance price exceeds the abatement cost for a certain measure, shipowners may still not invest in those measures due to lack of information or trust in prognoses or due to competition with investment options with faster returns. Ships might also be too old to justify adaptations. At the same time, a shipowner may choose to invest in technology that is more expensive than the allowance price because of ancillary benefits, including security of supply, customers' requirements (Raza & Woxenius, 2023), public relations, or other benefits. Thus, it remains difficult to estimate the extent to which low-cost measures will meet the required emissions reductions. Further assessments of the potential of other abatement measures are needed.

Also, few transport customers are actively pushing environmental requirements for the shipping industry, and even fewer are willing to pay extra for such measures. Examples of customers who do push for environmental requirements are companies with explicit sustainability-related goals, such as companies committing to the UN-supported Science-Based Targets initiative (SBT, 2023). In our study, shipping line respondents also reported greater pressure from customers in segments that move finished goods and passengers (i.e. are closer to consumers) than in ones that move raw material earlier in supply chains.

The price of allowances is expected to increase further as the amount of allowances drops in the coming years to create a market for more expensive abatement methods. At the same time, it will add increase uncertainty in an already volatile market as the price of emissions allowances becomes a more significant part of operational costs. That likelihood presents an opportunity for policy interventions to reduce such uncertainty and thereby incentivise shipping companies to invest in abatement technology. Some shipping lines are forerunners in that transition – for example, Scandinavian shipping lines such as Stena Line (2022) and Wallenius Marine (2022) – and have thus made necessary, albeit uncertain, long-term investments (Monios & Wilmsmeier, 2020).

The increased costs due to shipping's inclusion in the EU ETS may also induce a modal shift to other modes of transport, specifically in the RoRo and RoPax segments, which often compete directly with road and rail. The modal shift's extent and its effect on GHG emissions, however, remains uncertain and depends on development in the road sector (e.g. the electrification of trucks and relevant policy initiatives). Research is also needed to determine whether road and rail transport systems have the required capacity and infrastructure and whether there are sufficient truck drivers to capture flows from shipping. However, emissions calculations (see Figure 1) show that RoRo and RoPax, when combined, constitute the second-largest emissions group, representing approximately 24% of total emissions from shipping in the EU ETS. Considering only intra-EU emissions, they are also the largest emissions group and responsible for approximately 40% of emissions.

The inclusion of GHGs other than CO_2 in the EU ETS for shipping beginning in 2026 is important. Although such GHGs currently account for a small share of all GHG emissions, it can increase with the expanded use of alternative fuels such as LNG, which may lead to the leakage of CH_4. The inclusion of CH_4, and N_2O in the ETS implies their need to be included in the MRV system as well, which will require new methods for calculating those emissions from ships that use different types of engines and fuels. To achieve decarbonisation in shipping, it is reasonable to also include smaller ships in the future and thereby cover more emissions. Also, the amount of shipping emissions included in the EU ETS will also depend on the future demand for shipping. The total fuel demand for EU-related shipping between 2019 and 2030 might increase by 5%–20% based on low and high scenarios in the DNV (2020), which expects a decrease for crude oil and product tankers and a considerable increase for container ships, cruise ships, RoPax, and LG tankers.

In the short term, owing to inertia in the shipping sector, we expect that shipping will only marginally reduce its emissions and that shipowners will need to buy allowances. The total number of allowances is limited and declining, and, in the long term, it is possible that actors in shipping will compete with other EU ETS participants (i.e. from industrial and energy sectors) for the available allowances. More abatement measures will then likely be implemented along with higher prices. However, because the shipping sector accounts for only a fraction of the overall EU ETS (about 8%), and because there is considerable potential for low-cost measures, it seems unlikely that the shipping sector's demand for allowances will have a significant short-term impact on the price of allowances. Looking beyond 2030, the total number of allowances will have decreased, with zero allocations in 2039, and sectors such as shipping will likely consume a sizeable share of the remaining allowances and receive more attention.

Conclusions

Shipping's inclusion in the EU ETS is an important step towards incorporating global bunker fuels into a binding commitment to protect the climate. The CO_2 emissions added to the EU ETS constitute approximately 100 Mt, which represents approximately 69% of shipping's total CO_2 emissions in the EU MRV system, or about 8% of GHG emissions from all sectors in the EU ETS in 2022. Mitigation measures will reduce GHG emissions and will also contribute to reducing other types of emissions, including NO_X, SO_X, and PM.

Interviewed shipping companies believe that the EU ETS will help them to transition to a more environmentally sustainable transport system and expect that it will make EU shipping more competitive than non-EU shipping. Increased costs for obtaining emissions allowances will incentivise shipowners to accelerate efforts to reduce GHG emissions; however, which abatement measures will be implemented depends on the cost of emissions allowances and the costs linked to different abatement measures. Key findings from our study show that with an allowance price below €90/tCO_2, alternative fuels, such as biomethanol, will not be substantially implemented (cost-effective for less than 0.5% of the ships) while with an allowance price of €100/tCO_2, switching to bio-methanol may be cost-effective for about 5% of the ships but only for a few of the shipping segments (mainly RoRo, RoPax and reefer segments). However, with an allowance price at €150–200/tCO_2, bio-methanol could be cost-effective for a majority share of all ships in all shipping segments (about 55-100% in each segment or, if expressed of all ships, about 75-95%), which could drive significant reductions in emissions provided that there are sufficient quantities of bio-methanol available (see Table 1).

In the short term, however, many shipowners are expected to buy emissions allowances because of the time that it takes to implement many abatement measures and uncertainties in determining the most appropriate abatement method. Costs will initially be passed on to transport customers as a surcharge, which customers perceive to be unfair. This will likely induce some modal shift away from shipping and affect the RoRo and RoPax segments the most due to their direct competition with road and rail transport and the relative ease of switching modes of transport. The RoRo and RoPax segments represent a significant share of the emissions from shipping in the EU ETS. Although the potential shift is highly contextual, the longest routes competing directly with road transport are the most exposed. However, the modal shift that does occur will also depend on costs and policy development in the road transport sector.

The economic impact of including shipping emissions in the EU ETS will depend on market conditions, fuel prices and the price of allowances, all of which are difficult to predict. This analysis shows that added costs are likely to range from about 20% of fuel price up to several times that. For example, with an allowance price of €70, the additional cost will be approximately €220 per tonne of fuel used or a 22% cost increase, assuming MGO at 1000€/tonnes and for intra-EU voyages. Voyages coming into or departing from the EU will incur half of the added cost since only 50% of the CO_2 emissions generated by those voyages will be included in the ETS. Shipping's inclusion in the ETS may induce carbon leakage, but it will likely vary substantially between different shipping segments. Usefully, the EC intends to monitor potential evasive behaviour and propose, where appropriate, measures to address such behaviour. This will increase policy effectiveness, as it limits the opportunities to avoid the policy, and support fair and equal competition.

Note

1. A *cruise ferry* is a RoPax ferry that caters primarily to leisure passengers by offering significant onboard entertainment. Many passengers travel simply to enjoy themselves on board and return on the same ship, which is common on the route between Stockholm, Sweden, and Helsinki, Finland.

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ORCID

Johan Woxenius http://orcid.org/0000-0001-9408-2382

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