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No. 1824 | January 2013

Web: www.ifw-kiel.de

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Including Maritime Transport in the EU´s Climate Change Policy: Country-Based Allocation and Effects*

Nadine Heitmann

Abstract:

The European Union (EU) is actively campaigning for the global regulation of carbon emissions generated by maritime bunker fuels because these emissions are presently barely regulated and are projected to increase significantly in the coming decades. However, since a global regulation has not been reached yet, the EU is seeking ways to include the shipping sector in its greenhouse gas reduction commitment for 2020.

In this paper, we look at the effect of including the shipping sector's emissions in the EU reduction commitment that is based on the nationality of a ship. Emissions that are generated by ships owned, operated or flagged by the 27 EU countries are allocated to the EU total GHG emissions. We first analyse the effects on the reduction commitment caused by the three allocations. We then use marginal abatement cost curves (MACCs) in order to determine how much the shipping sector of the 27 EU countries, defined by the three allocations, could contribute efficiently to a total given emission reduction target for all sectors in the EU. Moreover, we use MACCs in order to determine if some country fleets could reduce emissions in the shipping sector relatively more efficiently than other countries under a given emission reduction target for all sectors. Our findings indicate that the shipping sector could contribute efficiently to the EU's emission reductions by up to 8.5%. Since the composition of the individual country fleets and applied measures are similar across countries, their individual reductions relative to their fleet-specific business-as-usual (BAU) emissions are on average the same.

Keywords: EU, climate change, shipping sector, CO2 emissions, marginal abatement cost curve

JEL classification: Q52, Q54, Q58

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* I am grateful to Katrin Rehdanz for her helpful suggestions and comments. Moreover, I would like to thank Matthias Weitzel and Alvaro Calzadilla Rivera, who provided the MACC generated with the DART model, Hendrik Goll for his research assistance, and Paul Kramer for his linguistic assistance. The German Research Foundation (DFG) provided welcome financial support through The Future Ocean Cluster of Excellence. The usual caveats apply.

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1. Introduction

Carbon dioxide emissions generated by the shipping sector accounted for about 3% of global carbon emissions in 2007.[1] These emissions are projected to increase significantly by 2050 and are presently barely regulated (Buhaug et al., 2009). Discussions on how to regulate such carbon dioxide emissions[2] have originated over 15 years ago in the UN Framework Convention on Climate change (UNFCCC) and are still continuing in the International Maritime Organization (IMO), in the European Union (EU), and in the scientific community. These discussions focus on the question whether the shipping sector's emissions should be capped or whether they should be subject to other means of regulation (UNEP, 2011). The EU is actively engaged in making progress in this matter with a global solution being the most preferred way. On the one hand, it has proposed a global reduction target of 20% relative to 2005 levels by 2020 for the shipping sector (Council of the European Union, 2009). On the other hand, it is seeking ways to include emissions generated by the shipping sector in its greenhouse gas reduction commitments should no global regulation be reached in the IMO (EU, 2009).[3]

An important question that needs to be addressed before implementing any regulation as regards the shipping sector's emissions is the size of emission reduction that the shipping sector could contribute efficiently to a given overall target. In this paper, the focus is thus on how much the shipping sector could contribute to a given emission reduction target for all sectors in the EU, assuming a policy instrument that equalizes the marginal abatement costs of all sectors. This gives us an idea if the shipping sector could at all contribute efficiently to a given emission reduction target. In order to do this, we first have to define a way of allocating a proportion of the shipping sector's emissions generated globally to the EU consisting of 27 countries. In doing this, we look at a way that is based on suggestions made by the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC. It has suggested using various

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[1] The shipping sector's emissions can be divided into international and domestic shipping emissions. However, the major share of emissions is caused by international shipping (Buhaug et al., 2009).

[2] We denote carbon dioxide emissions from now on as emissions.

[3] Background information of the European Climate Change Programme (ECCP) Working Group on reducing greenhouse gas emissions from ships is available at http://ec.europa.eu/clima/events/0035/index_en.htm.

allocation rules to allocate the shipping sector's emissions to individual countries (SBSTA, 1996).[4] One rule (SBSTA rule No. 4) is to use (1) the nationality of the ship owner, (2) the nationality of the ship operator, or (3) the flag state registration to allocate emissions. Doing so, would increase the EU countries' total national emissions and thus the EU's reduction effort to achieve its committed emission target. However, if abatement in the shipping sector is more cost-effective than in the currently regulated sectors, then including the shipping sector in the reduction efforts to achieve the EU's target may reduce overall abatement costs.

Several studies (Eide et al., 2011, Faber et al., 2011, Buhaug et al., 2009, Faber et al., 2009) conclude that there are ways that the shipping sector could reduce emissions cost-effectively. Moreover, another study (Heitmann and Peterson, 2012) discusses the shipping sector's potential contribution to efficient global emission reductions and its effect on global cost savings. However, the magnitude of the contribution and the cost savings depend heavily on the assumed reduction potentials and costs of the various measures applied to specific shipping fleets. Hence, from a regional or a country perspective, the contribution of a country's or region's fleet to reducing total national emissions efficiently might be important.

While there is a growing number of studies that look at the effects on regions or countries of various allocation rules applied to the shipping sector's emissions (den Elzen et al., 2007, Gilbert and Bows, 2012, Heitmann and Khalilian, 2011, Wang, 2010), only a few studies exist on how to include the shipping sector's emissions in the EU reduction commitment (Faber et al., 2009, Nelissen and Faber, 2012).[5] Faber et al. (2009) provide estimates of emissions generated by ships in various regions and in particular in the EU region, whereby emissions generated by ships in a region refer to emissions generated by ships calling at or departing from ports in a particular region. In doing so, Faber et al. (2009) show that the EU accounted for 31% of the shipping

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[4] The SBSTA suggested 8 allocation rules in total, e.g. allocating emissions in proportion to the national emission inventories of countries or allocating emissions according to the country that owns the transported cargo. Note, that the allocation of emissions to regions or countries leaves the way of how to effectively regulate the shipping sector's emissions to the regions'/countries' discretion, for example, the regions/countries could use market-based or command-and-control policy instruments in order to regulate the emissions.

[5] Not only is the EU actively engaged in seeking solutions. The UK is also actively seeking solutions, e.g., it is seeking ways to include the aviation and shipping sectors' emissions in its 2050 emission target and carbon budgets to be legislated in the future (Committee on Climate Change, 2011).

sector’s emissions generated globally in 2006. Moreover, they present and discuss various policy instruments on how to reduce the shipping sector’s emissions in a European framework, namely: an emission trading scheme (ETS), an emission-based tax, an efficiency standard, a baseline-and-credit trading scheme, and voluntary action. They conclude that emissions generated by ships in the EU region account for a large share of the shipping sector’s emissions generated globally and that an ETS would be the policy instrument that is environmentally effective and feasible to implement. Nelissen and Faber (2012) carry out a qualitative analysis of how the main policy instruments that are currently discussed at the EU level, namely two types of compensation funds managed by industry, an ETS, a fuel-based or emission-based tax, and two types of mandatory emission reduction per ship (for more details, see ECCP, 2011) would affect emissions in the EU. They conclude that an ETS covering emissions of ships calling at, departing from, or moving between EU ports would be the best choice as regards environmental effectiveness. However, Nelissen and Faber point out that controlling for emissions of ships departing from EU ports may be challenging. Moreover, they point out that a quantitative assessment is currently not possible because detailed data as regards the ships that would be in the scope of the various policy instruments is lacking.

We contribute to the literature by analyzing how the allocation rule No. 4 of the SBSTA, which includes three allocation ways, would alter the EU’s total emissions and its reduction commitment for the year 2020. Beyond that, in a first step, we determine with the help of marginal abatement cost curves (MACCs), how much the EU shipping sector (defined by the three allocation ways), compared to the other EU sectors, could contribute to the reduction commitment. In a second step, we determine if some country fleets could reduce emissions in the shipping sector relatively more efficiently than other countries under the given emission reduction commitment. Furthermore, we assess the increase in abatement costs that is caused by including the shipping sector’s emissions in the reduction commitment.

The paper is structured as follows. In Section 2, an overview of climate change policy is given. In Section 3, the three allocation ways are presented and how they would affect the EU’s reduction commitment is discussed. In Section 4, MACCs for the EU shipping sector in accordance with the three allocation ways and a MACC for all other EU sectors are presented. In Section 5, emission targets are determined and policy scenarios are described. Further, the results of the policy scenarios, including the country-level analysis, are presented. In Section 6, the results are discussed. In Section 7, the final section, a summary is given and conclusions are drawn.

2. Climate change policy

The anthropogenic emission of greenhouse gases (GHG) causes an increase in the atmosphere's GHG concentration, thereby affecting the Earth's average global temperature and causing climate change (IPCC, 2007). The emission of GHG is a negative externality that impacts mankind globally and independent of its geographical location (see, e.g., Perman et al., 1999). It is thus a global problem that requires a global solution. Climate change policy to combat climate change takes place on various levels. It takes place on the international level within the framework of the UNFCCC, on regional levels, e.g., in the framework of the EU climate and energy package,[6] and even on national levels, e.g., in the framework of the German Integrated Energy and Climate Package (BMU, 2007) and Energy Concept Germany (BMWi and BMU, 2010).

The first step undertaken towards combating climate change internationally was that the world community adopted the Kyoto Protocol in 1997 in the framework of the UNFCCC. It obliged a group of industrialized countries to reduce their greenhouse gas emissions (GHG) by 5% in the period 2008–2012 (called first commitment period) against 1990 emission levels (the countries, which committed themselves to an emission reduction target, are called Annex I countries). Emissions of the international sectors aviation and maritime shipping are excluded from the 1990 emission levels.[7] The Kyoto

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[6] The EU climate and energy package aims to achieve the EU' s climate and energy targets for 2020 (called 20-20-20 targets) and consists of four legislative acts: Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community ("ETS-Directive"), Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020 ("Effort Sharing Decision"), Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC ("Renewable Energy Directive"), and Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide (CCS-Directive).

[7] Article 2.2 of the Kyoto Protocol states that Annex I countries should reduce emissions from international aviation and marine bunker fuels with the help of the International Civil Aviation Organization (ICAO) and the IMO.

Protocol has been prolonged for 8 more years (second commitment period 2013–2020) at the UN Climate Change Conference in Doha in December 2012 (UNFCCC, 2012).

Currently, the Kyoto Protocol is the only existing international agreement that is legally binding. However, not all countries have legally binding reduction commitments under the Kyoto Protocol (these countries are called non-Annex I countries).[8] Despite this, many non-Annex I countries, in particular major emitters such as China and India, pledged in addition to many Annex I countries national reduction targets for 2020 in the course of the UNFCCC conference in Copenhagen in 2009 (UNFCCC, 2010a, 2010b), called the Copenhagen Pledges. These pledges, however, are not legally binding.

The EU belongs to the group of Annex I countries of the Kyoto Protocol and it also committed itself to reduce its GHG emissions in the course of the UN Climate Change Conference in Copenhagen. The EU pledged to reduce its emissions unilaterally by 20% by 2020 relative to 1990 levels (this reduction is called the unconditional or low pledge because it is not conditional on other countries pursuing more ambitious reduction targets). In addition, the EU also pledged to reduce its emissions by 30% by 2020 relative to 1990 levels conditional on other countries also pursuing more ambitious reduction targets (this reduction is called the conditional or high pledge). According to den Elzen et al. (2011), the EU's maximum GHG emissions would amount to 4.45 $GtCO_2$-eq. with the unconditional pledge and to 3.90 $GtCO_2$-eq. with the conditional pledge in 2020. According to a European Environment Agency report (EEA, 2012), the EU's GHG emissions amounted to 4.60 $GtCO_2$-eq. in 2011 and to 5.58 $GtCO_2$-eq. in 1990.

To reach the emission reductions in the first commitment period of the Kyoto Protocol and under the Copenhagen Pledges, the EU has implemented various climate change policy instruments, whereby the EU ETS is the most important one. It includes over 11,000 power and heat plants, energy-intensive industrial plants, and commercial airlines.[9] However, the shipping sector's emissions are neither included in the EU ETS nor tackled by any other climate change policy instrument.

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[8] Canada withdrew from the Kyoto Protocol and Japan indicated not to take on a commitment to reduce emissions in the second commitment period 2013–2020 (UNFCCC, 2012).

[9] http://ec.europa.eu/clima/policies/ets/index_en.htm.

3. Allocation rules and effects of including the shipping sector’s emissions in the EU reduction commitment

3.1. Absolute versus relative target

As mentioned in the introduction, the EU is seeking ways to include the shipping sector’s emissions in its 20% reduction target. Possible approaches to include the shipping sector’s emissions are: (1) keeping the absolute target for 2020 and enlarging the set of regulated sectors or (2) reassessing the 1990 base year emissions and enlarging the set of regulated sectors.[10] In the following, we focus on the EU’s 20% reduction target, the unconditional pledge, because it seems more realistic when looking at the current status of climate negotiations (see Section 2).

The first approach (Figure 1) assumes that the absolute emission target in the reference year remains constant and that shipping emissions are added on top of the currently regulated business-as-usual emissions in the reference year (2020). The base year emissions (emissions in 1990) remain the same, i.e., no shipping emissions are added on top. We call this approach the *partial integration approach*.

The second approach (Figure 2) assumes that the relative reduction target in the reference year 2020 remains the same (20%), but that the shipping sector’s emissions are both included in the set of base year emissions (emissions in 1990) and added on top of the regulated business-as-usual (BAU) emissions in the reference year (2020). This approach would cause an increase in the base year emissions and would make it necessary to raise the absolute emission target in the reference year (2020) in order to achieve the same relative target of 20% reduction (see Figure 2).

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[10] Emission reduction commitments are in general based on a specific set of GHG emissions and included sectors in a base year. Ideally, the required emission reductions in the reference year are also based on the same specific set of GHG emissions and sectors as the emissions in the base year. We define these emissions as currently regulated emissions. In the case of the current EU reduction commitment, the set does not include all the relevant GHG emissions and sectors. The carbon emissions from land use, land-use change and forestry (LULUCF) or from the international shipping and aviation sectors are not included in the EU’s 1990 base year emissions, as is evident, for example, when looking at the European Environment Agency report (EEA, 2012).

Raising the absolute emission target would allow more emissions to be emitted and thus less emission reduction is required than with the first approach. We call this approach the *full integration approach*.

In both cases, under the partial and full integration approach, the EU's emission reduction requirements would increase. They would increase more under the partial integration approach than under full integration approach.

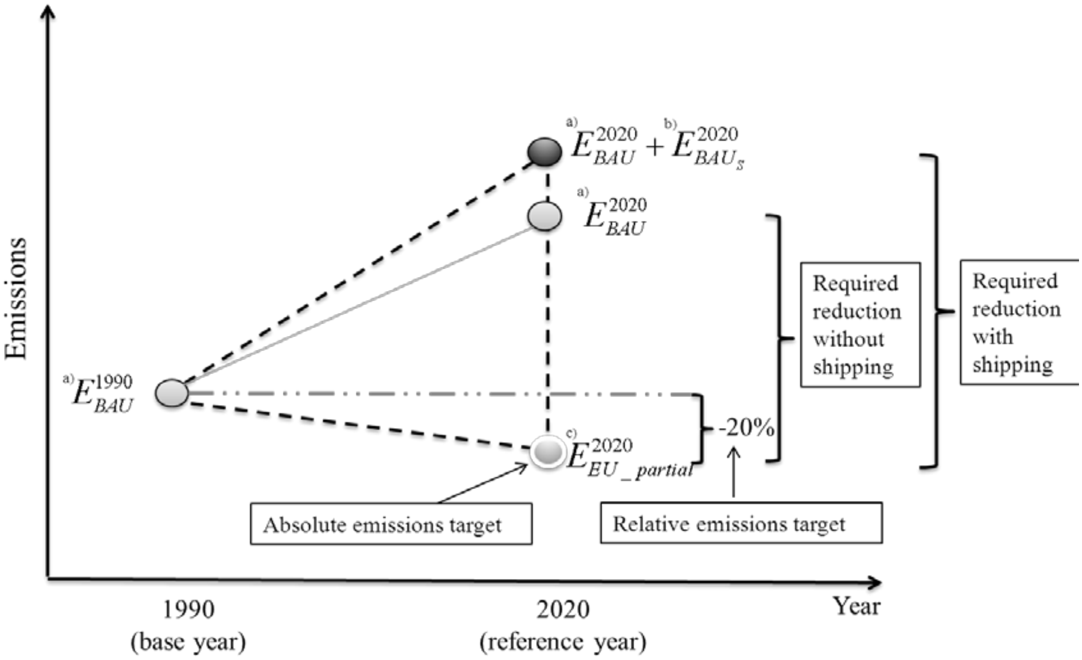

Figure 1: *Partial integration* approach (absolute reduction target remains constant)
Source: Own presentation.

***Notes on variables used in Figure 1*:**

a) *denotes the regulated BAU emissions in the base year 1990 and in the reference year 2020 (without the shipping sector's emissions being included)*
b) *denotes the shipping sector's BAU emissions in base year 1990 and in reference year 2020;*
c) *denotes the target when the partial integration approach (absolute target remains= the current 2020 target of the EU) would be applied*

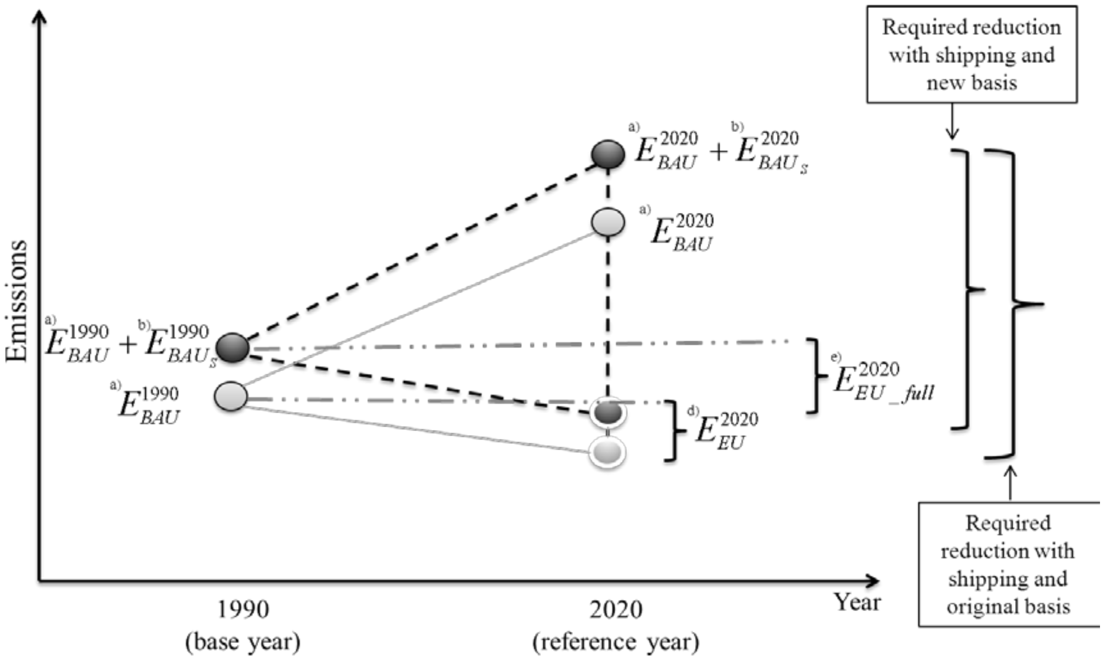

Figure 2: *Full integration* approach (relative reduction target remains the same)
Source: Own presentation.

***Notes on variables used in Figure 2**:*

a) *denotes the regulated BAU emissions in the base year 1990 and in the reference year 2020 (without the shipping sector's emissions being included)*
b) *denotes the shipping sector's BAU emissions in base year 1990 and in reference year 2020;*
d) *denotes the current 2020 target of the EU (without the shipping sector's emissions being included)*
e) *denotes the target when the full integration approach (relative target remains) would be applied*

3.2. Applying the UNFCCC allocation rule: the resulting emissions

As mentioned in the introduction, the SBSTA of the UNFCCC suggested various allocation rules to allocate emissions to countries (SBSTA, 1996). In the following, we focus on one of the allocation rules called "allocation according to the nationality of the transporting company, or to the country where the vessel is registered, or to the country of the operator" (SBSTA, 1996). This allocation rule, which actually deals with three different ways to allocate emissions (henceforth allocation ways), mirrors the complex structure of the shipping sector: a ship may have owners and operators of different nationalities and, in addition, may be registered (flagged) in a third country. We therefore look at the three ways to allocate emissions according to this allocation rule separately.

Before we can investigate the effect of the various allocation ways on the emission reduction target in 2020, however, a number of steps need to be taken. This includes (1) the determination of the number of ships in 2020 per allocation way, (2) the determination of the BAU emissions in the reference year 2020 per allocation way, and (3) the determination of the emissions in the base year 1990.

The first step is to determine the number of ships, i.e., the number per ship-type/ship-segment[11] and ship-age category, that are currently owned by, operated by, or registered in the 27 EU countries. In doing so, we use data from SeaWeb (IHS Fairplay, 2012). The ship-type and ship-segment categorization we use corresponds basically to the categorization used in Buhaug et al. (2009), which categorizes the world fleet into 18 ship types and 70 segments. However, we consider only 14 major ship types that are divided into 53 size segments.[12] This gives us three different EU fleets, which we define as *EU-owned fleet, EU-operated fleet,* and *EU-registered fleet*. Then, we use the current fleet composition and ship type specific growth and scrapping rates to determine what the composition of these three EU fleets will be in the reference year 2020. We apply the same procedure to the three EU fleets as Heitmann and Peterson (2012) apply to the world fleet, that is, we take growth and scrapping rates from Eide et al. (2011), apply them to the total number of ships in each ship segment, add the number of new ships to the first age category, and subtract the number of scrapped ships from the last age categories.

The second step is to determine the BAU emissions of the three EU fleets in 2020 by multiplying the number of ships per ship-segment/ship-age category in 2020 by the fuel consumption of ships (the BAU emissions of the three EU fleets in 2020 are presented in Table 1).[13]

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[11] Buhaug et al. (2009) categorize a ship type in various ship segments depending on specific characteristic, e.g., such as deadweight for crude oil tankers.

[12] The reason for this is that in Section 3.1 we use data from Wang et al. (2010) on marginal abatement costs that is available for only 14 of the 18 ship types. The 14 ship types that are included are predominately merchant ships and ferries/passenger ships. The 4 ship types that are excluded are of less importance including the following: yacht, offshore (such as tug boats), service (such as research ships), miscellaneous (such as trawlers) (for more details, see Buhaug et al., 2009).

[13] The fuel consumption of a ship per year is determined by the operational profile and the ship-type-specific characteristics of a ship (for more details, see Buhaug et al., 2009). To determine the fuel consumption per ship type/segment, we follow Eide et al., (2011), who assume that the projected fleet has the same operational profile as the fleet presented in Buhaug et al. (2009), which is based on activity data

Table 1: BAU emissions of the EU fleet in 2020 according to the three ways of allocating emissions: *owner*, *operator*, and *flag registration*.

	Owner	*Operator*	*Flag*
BAU emissions of the EU fleet in Mt	286	276	173

Source: Own calculations.

BAU emissions are the highest when emission allocation is based on the nationality of the *owner* and the lowest when it is based on *flag state registration*. The difference in BAU emissions between the two allocation ways *operator* and *owner* is not significant, but it is significant between the two ways and *flag registration*. More ships are owned or operated by the 27 EU countries than are registered under the flags of these countries (IHS Fairplay, 2012).[14] In terms of the individual countries' share of the total number of EU 27 ships, we find that Denmark, Germany, Greece, Italy, the Netherlands, and the United Kingdom (listed in alphabetical order) are the top six as regards the categories *owner* and *operato*r (with a total joint share of 79% and 76%, respectively). This is not true for the category *flag*. Here, Malta, Greece, Italy, Cyprus, the Netherlands, and the United Kingdom are the top six (with a total joint share of 79%). The top five ship types, which have a total joint share of over 70% as regards all three categories, are general cargo, bulker, container, chemical tanker, and (ropax) ferry. Of these five ship types, container ships contribute the most to the BAU emissions in 2020.

Now that we have determined the BAU emissions in 2020, the third step is to determine the effects the two approaches, the *partial integration approach* (absolute target remains constant) and the *full integration approach* (relative target stays constant, but base year emissions change) would have on the emission reduction target in 2020. To determine the effects of the *partial integration approach*, we add the shipping sector's BAU emissions to the regulated BAU emissions in 2020. The difference between the sum of the shipping sector's BAU emissions and regulated BAU emissions and the absolute emission target of 4.45 GtCO$_2$-eq in 2020 gives us the required emission reductions.

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from 2007. However, unlike Buhaug et al. (2009), Eide et al (2011) apply a general improvement factor of 5% to ships built as of 2010 and a general improvement factor of 8% to ships built as of 2020.

[14] Once again, we consider only the 14 ship types as described earlier.

To determine the effects of the *full integration approach* (relative target stays constant, but base year emissions change) on the emission reduction target in 2020, we need to determine the new basis, i.e. the reassessed base year emissions, which is defined as the sum of original base year emissions and the shipping sector's emissions. Thus, we have to make assumptions about the amount of the shipping sector's emissions in 1990. We know from Heitmann and Peterson (2012) that BAU emissions of the (global) shipping sector are projected to amount to 947 $MtCO_2$ in 2020. Thus, the relative share of the EU shipping sector's emissions on the global shipping sector's emissions would amount to ~30% in the case of the *EU-owned fleet*, to ~28% in the case of the *EU-operated fleet*, and to ~18% in the case of the *EU-registered fleet* in 2020 (see Table 2 for the absolute amount of BAU emissions per allocation way in 2020). We assume that these shares were in the same proportion in the base year of 1990,[15] and that, according to Buhaug et al. (2009), the BAU emissions of the shipping sector in that year amounted to 468 $MtCO_2$. Thus, we add 140 $MtCO_2$ in case of the *EU-owned fleet* to the regular base year emissions in 1990 (see Figure 2), 131 $MtCO_2$ in the case of *EU-operated fleet*, and 84 $MtCO_2$ in the case of *EU-registered fleet*. This gives us the new basis. To this new basis, we apply the relative emission reduction target of 20% (the reduction targets are calculated in Section 4.1).

4. Generating marginal abatement cost curves for the shipping sector in the 27 EU countries

4.1. MACCs and corresponding abatement cost functions for the shipping sector

We use MACCs in order to determine how much the shipping sector of the 27 EU countries (henceforth EU fleet) could contribute efficiently to a total given emission reduction target for all regulated sectors in the EU. Moreover, we use MACCs in order to determine if some countries could reduce emissions in the shipping sector more efficiently than other countries under the given emission reduction target for all sectors.

Eide et al. (2011) and Faber et al. (2011)/Wang et al. (2010)[16] present a methodology to generate MACCs for the shipping sector. This methodology includes, in general, three elements:

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[15] We have neither information about owner, operator, or flag state registration nor about the operational profiles of ships for the year 1990.

[16] Faber et al. (2011) is an updated version of Wang et al. (2010).

1. Projection of the fleet composition, i.e., the projection of the current fleet composition (ship-type/ship-age categories) to the reference year based on ship-type-specific growth and scrapping rates.
2. Determination of a business-as-usual (BAU) emission scenario, i.e., the determination of the fleet emissions in the reference year if no abatement measures are applied.
3. Calculation of project-level abatement costs (*AC*), i.e., the calculation of the abatement costs per measure applied to a specific ship-type/ship-age category. For example, the calculation approach presented in Eide et al. (2009) and applied in Eide et al. (2011) is based on a net present value analysis, which determines the abatement costs of a measure using the net present value of total costs (C_t) minus total benefits (B_t) of a measure, whereby i is the discount rate, divided by the total CO_2 emission reduction potential ($T \cdot CO_2^{red}$), see Equation 1:

$$AC = \frac{\sum_{t=1}^{T} \frac{C_t - B_t}{(1+i)^{t-1}}}{T \cdot CO_2^{red}} \quad \text{with } t=1,\ldots,T. \qquad (1)$$

By ordering the abatement costs of measures in an increasing order and then plotting them against the corresponding reduction potentials, the MACC is obtained.

In this paper, we use the reduction potentials and abatement costs per measure calculated in Heitmann and Peterson (2012) to generate MACCs of the EU shipping sector in 2020. They assume that ships start to apply abatement measures from 2020 onwards because they currently have little incentives to implement abatement measures.[17] The data on costs and reduction potential of 22 abatement measures is taken from Wang et al. (2010) and applied to the 14 major ship types. They work with two scenarios: high reduction potentials and low costs of abatement measures (*hrlc*) and low reduction potentials and high costs (*lrhc*). Thus, combining their reduction potential and abatements costs data with the three projected EU fleets (defined by the three allocation ways), we obtain 6 MACCs in total. The resulting MACCs are presented in Figures 3(a) and 3(b) and the maximum reduction potentials in Table 2.

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[17] The EEDI (Energy Efficiency Design Index) and the SEEMP (Ship Energy Efficiency Management Plan) are the only mandatory measures that currently exist (MEPC, 2011).

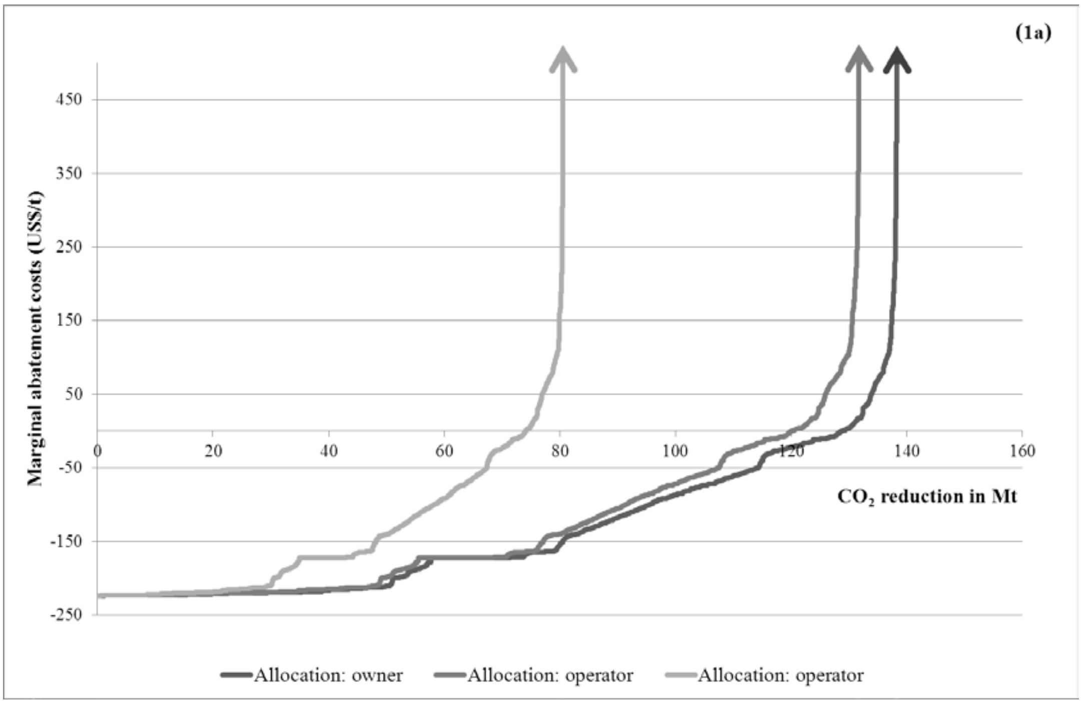

Figure 3(a): MACCs in 2020 according to the three allocation ways in the *hrlc* (high reduction potentials and low costs) scenario *Source*: Own calculations (prices are in 2007 US$).

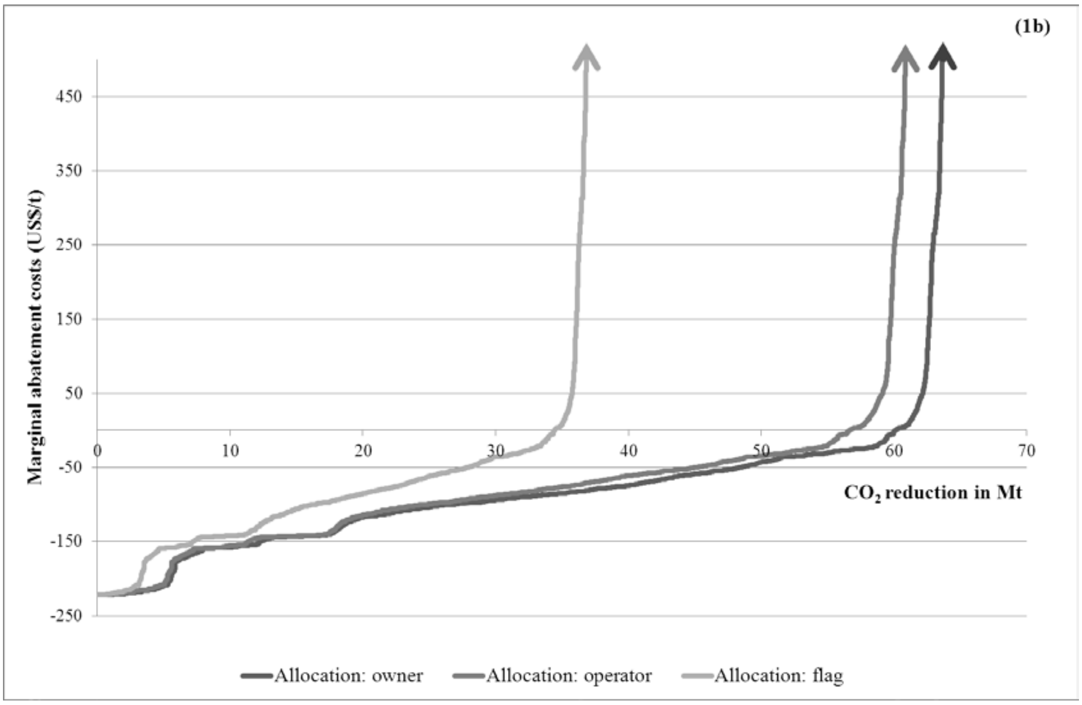

Figure 3(b): MACCs in 2020 according to the three allocation ways in the *lrhc* (low reduction potentials and high costs) scenario *Source*: Own calculations (prices are in 2007 US$).

Table 2: Maximum reduction potentials and BAU emissions in 2020 (in $MtCO_2$ emissions).

Allocation way		*Owner*	*Operator*	*Flag*
Reduction/costs scenarios	*hrlc*	139	133	81
	lrhc	64	61	37
BAU emissions of the EU fleet in Mt		286	276	173

Source: Own calculations.

The three MACCs differ in absolute terms of the maximum reduction potential. Looking at the reduction potential relative to the respective BAU emissions under the *hrlc* scenario (see Table 2) shows that all three are in a similar range: between 47% and 49% of BAU emissions could be abated under each allocation way. Moreover, the major share of the reduction potential is available at negative marginal abatement costs. This result is not specific to the MACCs generated here, but also to the MACCs presented in the shipping-specific literature, e.g., in Buhaug et al. (2009), Eide et al. (2011), Faber et al. (2011)/Wang et al. (2010), and Heitmann and Peterson (2012).

For the purpose of illustration, assuming, e.g., a carbon price in the range of 30–50 US$/t in 2020, the EU shipping sector could reduce its emissions, depending on the applied allocation way and reduction potentials/costs scenario (*hrlc and lrhc*), by 35–136 $MtCO_2$. However, the presented MACCs are based on a project-level cost analysis. This kind of costs analysis does not take into account potential barriers to implementation, which we discuss in Section 4.3.

4.2. MACC and corresponding abatement cost function for all other EU sectors

We use the computable general equilibrium (CGE) model DART to generate a regional MACC for all other production and consumption sectors, i.e., all sectors except for shipping and aviation (henceforth all other sectors (*AoS*)), in the EU27.[18]

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[18] The production sectors are represented by coal, refined oil, gas, chemical products, electricity, agriculture, crude oil, transport, energy intensive sectors, other light industries, other heavy industries, and services. The consumption sector is represented by a representative household per region.

The DART model is currently calibrated to the GTAP-8 database (Narayanan et al., 2012) and includes 14 world regions.[19] Europe is divided into the EU27 and Rest of Europe (Norway, Switzerland, and Island). The DART model is described in greater detail in Klepper et al. (2003). Figure 4 shows the generated MACC for *AoS* in the EU27 in 2020.

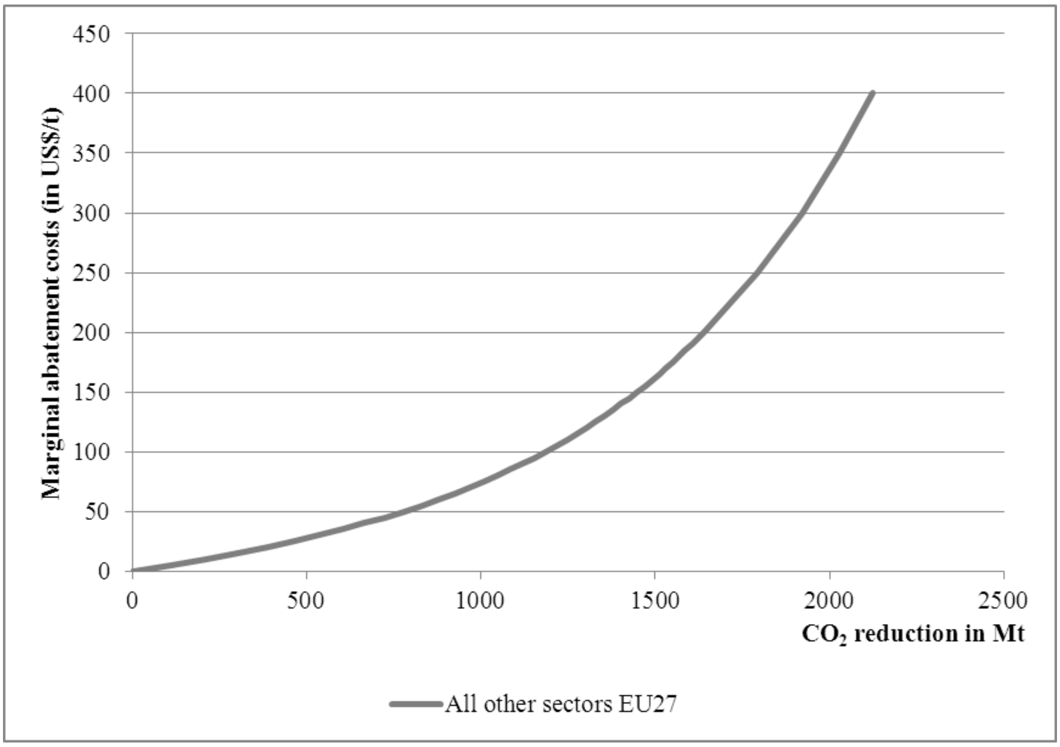

Figure 4: MACC for all other sectors of the EU27 in 2020. *Source*: Own presentation based on the CGE model DART (prices are in 2007 US$).

In order to determine how much *AoS* and the shipping sector could contribute to a given reduction target in 2020, we need to approximate marginal abatement cost functions. In doing this, we tested for several functional forms. Since it turns out in our scenario analysis (see Section 5.3.1) that optimal abatement outside the shipping sector is in a range of less than 1,500 $MtCO_2$, we decided to use the quadratic form because it fits the MACC best in this range. Equation 2 presents the approximated marginal abatement cost function for *AoS* ($MAC_{AoS}(R_{AoS})$).

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[19] The regions are the following: Japan, India, Canada, USA, EU27, Rest of Europe (non EU27), Former Soviet Union, Australia and New Zealand, Latin America, China, Pacific Asia, Middle East, North Africa, and Sub-Saharan Africa.

$$\mathrm{MAC}_{\mathrm{AoS}}(\mathrm{R}_{\mathrm{AoS}}) = 0.0182965 \cdot \mathrm{R}_{\mathrm{AoS}} + 0.0000578 \cdot R_{AoS}^2, \tag{2}$$

for $0 \leq R_{AoS} \leq 1500$,
with adjusted $R^2 = 0.999166$,
where R_{AoS} refers to emission reductions.

Ideally, emissions from the aviation sector should also be included in our analysis because, like emissions from the shipping sector, they are projected to increase in the coming decades.[20] Furthermore, the EU has started to regulate the aviation sector's emissions under the European Union Emission Trading Scheme (EU ETS), but emissions generated in 2012 are exempted in order to promote upcoming negotiations in the framework of the International Civil Aviation Organization to find a global solution (EC, 2012).[21] We exclude the aviation sector from our analysis because information needed to calculate a sector-specific MACC for the aviation sector is unavailable. This would include emission estimates based on activity data (as for the shipping sector presented in Buhaug et al., 2009),[22] projection of such emissions to 2020, and also data on reduction potentials and costs of abatement measures for specific types of aircraft. This is a limitation, but it is unlikely to affect our results significantly; the reduction potential in aviation is assumed to be small (see Anger and Köhler, 2010). Aviation is more likely being a buyer than seller of emission permits, for this reason we might underestimate the contribution of the shipping sector.

4.3. Combining both types of MACCs

The results of Section 4.1 showed that MACCs constructed with the above presented methodology can generate negative abatement costs. This is in contrast to model-derived MACCs (e.g., the CGE model DART in Section 4.2) that by construction only generate positive abatement costs. The underlying assumption is that rational

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[20] Gudmundsson, S.V., Anger, A. (2012) provide a meta-analysis of various studies projecting the aviation sector's emissions up to 2050 and find that the results vary significantly.

[21] All domestic and international flights that arrive at or depart from an airport located in the EU are subject to the EU ETS (Directive 2008/101/EC). There are some studies analyzing the effects of including the aviation sector's emissions in the EU ETS (Scheelhaase et al., 2010, Anger, 2010, Anger and Köhler, 2010).

[22] For example, the Annual European Union greenhouse gas inventory 1990 – 2010 and inventory report 2012 (2012) presents numbers for international bunker fuel emissions (aviation and shipping) that are mainly based on national fuel statistics.

individuals exploit abatement potential with negative abatement costs because they bring a net benefit even in the absence of climate policy (for more details, see, e.g., Heitmann and Peterson, 2012). In Section 5, we aim to combine both types of MACCs in order to determine how much the shipping sector could contribute efficiently to the EU's reduction commitment for 2020 and in order to determine the resulting abatement costs.[23] For this purpose, we make use of an approach presented in Hyman et al. (2002) and applied to the shipping sector by Heitmann and Peterson (2012). The approach assumes that all measures that reduce emissions at negative net costs are not economical when accounting for all relevant costs and to shift up the MACC so that it lies above the horizontal axis. This approach implicitly assumes that the barriers of implementation or extra costs are relevant for the implementation of all measures, also for the ones with positive abatement costs.

We tested, again, for several functional forms to approximate marginal abatement cost functions for the three EU fleets (*EU-owned fleet*, *EU-operated fleet*, and *EU-registered fleet*) under the *partial integration* approach and the *full integration* approach. We decided to analyze two functional forms in more depth under the *partial integration approach*, namely the exponential and the quadratic functional form. Both functional forms (Equations 3 and 4) fit the ranges of optimal abatement in the shipping sector best as derived in our scenario analysis in Section 5.3.1. The exponential functional form fits the MACC better for lower carbon prices (amount of reduction is small) than the quadratic one, but starts to deviate more from the MACC towards higher carbon prices (see Figures A1–A6 in the Appendix). It thus tends to underestimate abatement costs, whereas the quadratic functional form tends to overestimate abatement costs.[24] However, we decided to use the exponential form because it fits best under the *full integration approach* (Figures A7–A12) and therefore it fits in most scenarios better than the quadratic one.

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[23] The combination of both MACCs is based on the least cost theorem (see e.g. Perman et al., 1999). The shipping sector and *AoS* are required to jointly achieve a given target at least costs.

[24] When looking at how much the shipping sector could contribute efficiently to the joint target, both functional forms give rise to very similar values.

$$MAC_{ij}^{\exp}\left(R_{ij}\right) = \exp(a_{ij} + b_{ij}R_{ij}), \tag{3}$$

$$MAC_{ij}^{quad}\left(R_{ij}\right) = c_{ij}R_{ij}^{2}. \tag{4}$$

For both equations i refers to the different allocation ways – *owner* (i=1), *operator* (i=2), and *flag* (i=3) – and j refers to the two different scenarios considered – *hrlc* (j=1) and *lrhc* (j=2). Depending on the allocation rule and scenario considered under the *partial* or the *full* integration approach, the volume of emission reductions (R_{ij}) is exposed to different value restrictions (Table 3). The parameters (a_{ij},b_{ij}, and c_{ij}) used for calculation and the R^2 (adjusted R^2) are presented in Tables A1 and A2 in the Appendix.

Table 3: Value restrictions under the *partial* and the *full integration* approach

Integration approach	R_{ij}	*i=1 (owner)*	*i=2 (operator)*	*i=3 (flag)*
Partial integration	*j=1 (hrlc)*	[0,90]	[0,85]	[0,50]
	j=2 (lrhc)	[0,8]	[0,8]	[0,4.5]
Full integration	*j=1 (hrlc)*	[0,60]	[0,55]	[0,35]
	j=2 (lrhc)	[0,6.5]	[0,6.2]	[0,4]

Figures 5 and 6 present the graphical combination of both MACCs (*AoS* and shipping) assuming an exponential functional form for the shipping sector MACCs in the *hrlc* scenario and in the *lrhc* scenario under the *partial integration* approach (Figure 5) and under the *full integration* approach (Figure 6).

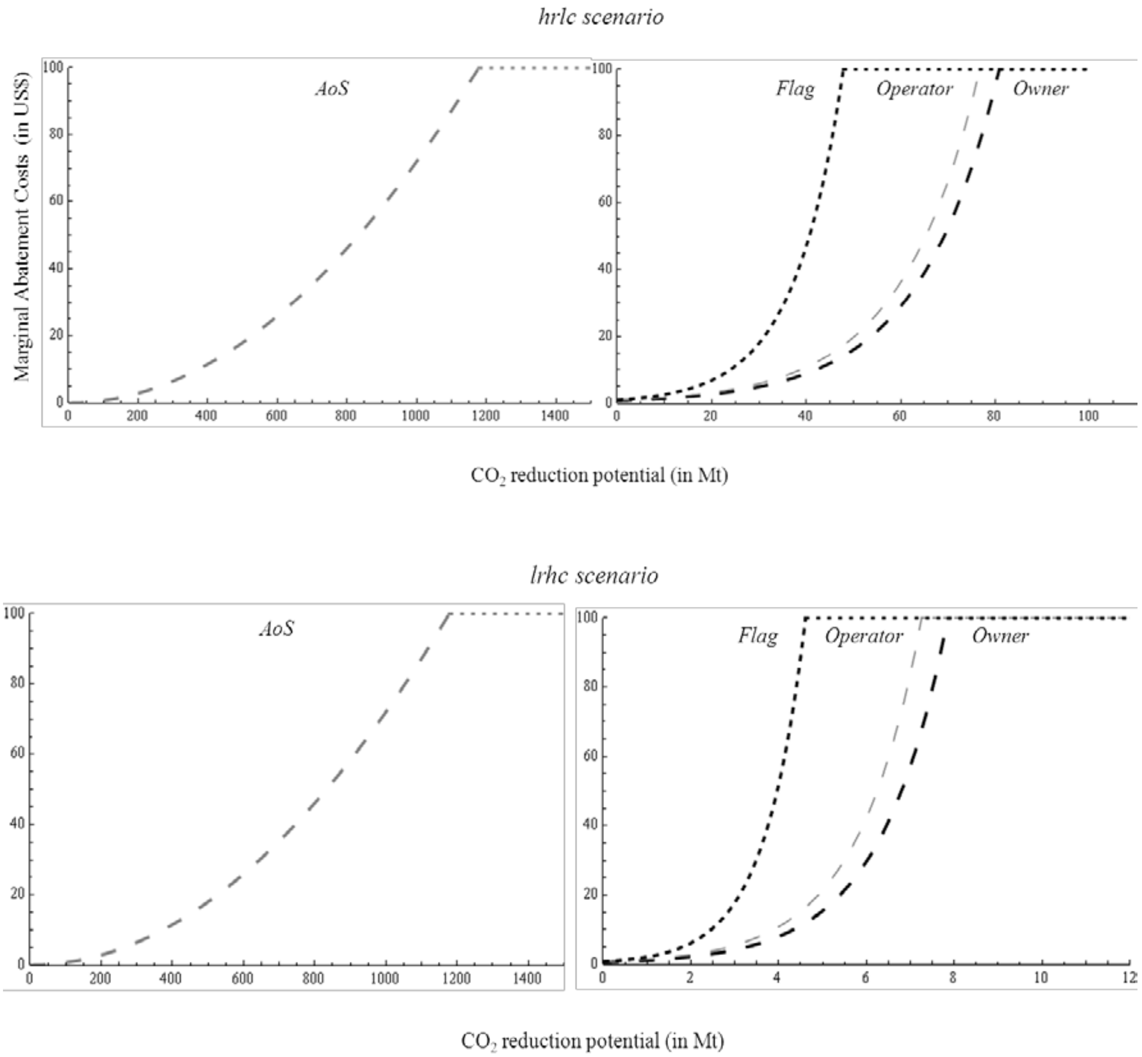
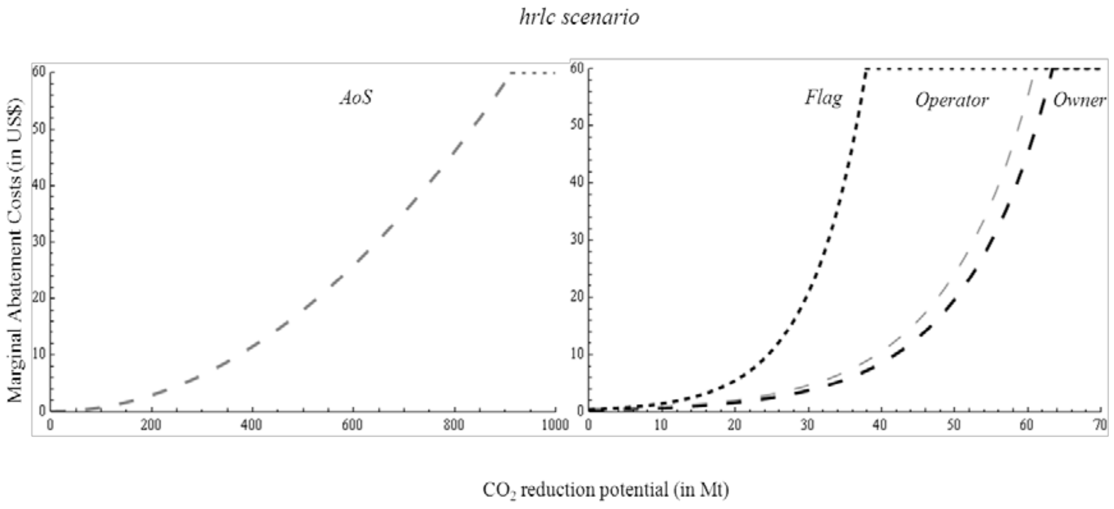


Figure 5: Combination of both MACCs under the *partial integration* approach (*hrlc* and *lrhc* scenario)



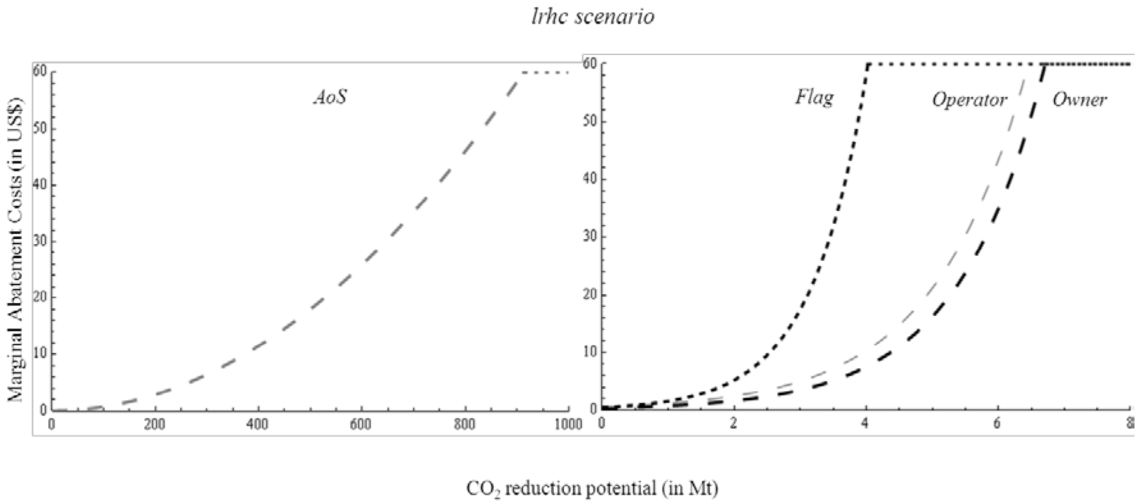


Figure 6: Combination of both MACCs under *full integration* approach (*hrlc* and *lrhc* scenario)

5. Analysis of policy scenarios

5.1. Determination of BAU emissions and emission targets

We start by describing scenarios for the BAU emissions of the shipping sector and all other production and consumption sectors (*AoS*) in the EU27 that use fossil fuels. This is necessary in order to determine the required emission reductions both sectors, shipping and *AoS*, have to achieve under the two reduction commitment scenarios (*partial and full integration approach*).

The projected BAU emissions of the EU27 (*AoS*), which result from fossil fuel use, amount to 4,249 MtCO_2 in 2020 according to the DART model. As mentioned before, this number includes CO_2 emissions of all production and consumption sectors of the EU27 economy, except the ones generated by shipping and aviation. The shipping sector's BAU emissions depend on the analyzed case (*owner*, *operator*, and *flag registration*) as presented in Section 3.2. Table 4 gives an overview of *AoS*' emissions resulting from fossil fuel use in the EU27 and the shipping sector's emissions according to the allocation ways applied in 2020.

Table 4: Unregulated BAU emissions of the shipping sector and all other sectors (*AoS*) in the EU27 in 2020

	EU AoS	EU shipping fleet		
		Owner	*Operator*	*Flag*
BAU emissions in Mt	4249	286	276	173

Source: Own calculations.

Because we are mainly interested in the abatement of CO_2 emissions resulting from fossil fuel use in the EU27, we need to derive a target for CO_2 emissions of the sectors covered in DART (*AoS*) plus the shipping sector. Therefore, we analyze only the share of CO_2 emissions in total GHG emissions.

We assume that the share of CO_2 emissions resulting from fossil fuel use in total GHG emissions stays constant over time, which was about 82% in 2010 according to the EEA (2012).[25] The emission targets of the two approaches *partial integration* and *full integration* are determined as follows: if we apply the *partial integration* approach (absolute target remains constant), we know from Section 3.1 that total allowable GHG emissions, including CO_2, in the EU27 are 4,450 MtCO_2-eq. in 2020. We multiply this number with the share of CO_2 emissions in total GHG emissions (82%) in order to determine the joint target for *AoS* and the shipping sector in 2020. This results in 3,649 MtCO_2 emissions from fossil fuel use to stay in line with meeting the absolute target in 2020.

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[25] This number excludes CO_2 emissions from LULUCF.

If we apply the *full integration* approach (the shipping sector's emissions are included in the base year emissions), the amount of total allowable GHG emissions by 2020 changes and thus does the joint target for *AoS* and the shipping sector as well. In the case of *owner* allocation, *AoS* and shipping are allowed to emit around 3,774 $MtCO_2$, in the case of *operator* allocation 3,767 $MtCO_2$, and in the case of *flag* allocation 3,730 $MtCO_2$. The difference between BAU emissions (sum of *AoS* and shipping emissions) and the allowed emissions gives the (joint) emission reduction target (Table 5).

Table 5: Joint emission reduction targets (in Mt CO_2) of the shipping sector and *AoS* in 2020

	Allocation way		
Integration approach	*Owner*	*Operator*	*Flag*
Partial integration	886	876	773
Full integration	761	758	692

Source: Own calculations.

5.2. Determination of policy scenarios

As mentioned in the Introduction, this analysis assesses, in a first step, how the EU reduction commitment changes if the shipping sector's emissions were included and, in a second step, the efficient contribution of *AoS* and the shipping sector to each assumed target and the magnitude of an increase in abatement costs under each assumed target. We define two policy scenarios that include the shipping sector and compare it to a policy scenario that mirrors the status quo, i.e., the shipping sector is not included in the EU reduction commitment. The scenarios are as follows:

1. Scenario: the shipping sector's emissions are included in the reduction commitment and the shipping sector and *AoS* are required to achieve the given target jointly. We define this scenario in the following as *S included in reduction effort*, whereby *S* refers to the shipping sector.

2. Scenario: the shipping sector's emissions are included in the reduction commitment, but the shipping sector is not required to achieve abatement, thus, *AoS* is required to achieve the given target alone. We define this scenario in the following as *S out of reduction effort*, whereby *S* refers, again, to the shipping sector.

3. Scenario: the shipping sector's emissions are not included in any reduction commitment. We define this scenario in the following as *status quo*.[26]

A comparison of the first two scenarios against the last one gives some insight into additional costs that the EU27 faces if the shipping sector's emissions were included according to one of the three allocation ways (*owner*, *operator*, and *flag registration*) in its reduction commitment. Moreover, it sheds light on the question if the shipping sector should be obliged or not to contribute to CO_2 emission abatement.

Moreover, we are interested in how the three ways of allocating emissions to the fleets of the 27 countries would affect the potential of a country fleet to reduce emissions efficiently. We do this by:

- first, determining how much emissions the fleets of the various EU countries reduce relative to their fleet-specific BAU emissions under a given emission reduction target for all sectors and
- second, comparing the resulting numbers to how much emissions the total EU fleet, which equals the sum of the individual country fleets, reduces relative to its fleet-specific BAU emissions under the same given reduction target for all sectors.

In order to keep the presentation and the discussion of this additional analysis of results simple, we analyze only the scenario, where the shipping sector's emissions are included in the reduction commitment and the shipping sector and *AoS* are required to achieve the given target jointly (*S included in reduction effort, full integration approach,* and *hrlc* scenario).

5.3. Results

5.3.1. EU27-level analysis

We start by presenting the results of scenario *S included in reduction effort* under the *partial* and the *full integration approach* (see Table 6 for a summary).

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[26] The difference between *AoS* BAU emissions (4,249 $MtCO_2$) and allowed emissions (3,649 $MtCO_2$), i.e., the allowed emissions resulting from fossil fuel use, in 2020 to stay in line with meeting the absolute target gives the reduction target for *AoS* in the scenario *status quo*: 600 $MtCO_2$.

Table 6: Resulting CO_2 prices (in US$) and efficient reductions in relative terms in 2020 for scenario *S included in reduction* effort

		Partial integration approach			***Full integration approach***		
Reduction potentials/costs scenario	Allocation way	CO_2 price (in US$)	a)R_S rel.to BAU emissions	a)R_S rel.to overall target	CO_2 price (in US$)	a)R_S rel.to BAU emissions	a)R_S rel.to overall target
hrlc	*Owner*	53.38	24.6%	7.94%	41.34	20.6%	7.74%
	Operator	52.72	24.0%	7.56%	41.28	20.5%	7.45%
	Flag	44.52	22.8%	5.10%	39.98	19.8%	4.96%
lrhc	*Owner*	60.73	2.5%	0.80%	46.72	2.2%	0.84%
	Operator	59.61	2.4%	0.74%	46.44	2.2%	0.80%
	Flag	48.26	2.3%	0.51%	39.98	2.1%	0.53%

a)R_s refers to emission reductions of the shipping sector.

Source: Own calculations.

The CO_2 prices are in a range between 45 and 61 US$/t under the *partial integration approach* and in a range between 40 and 47 US$/t under the *full integration approach*. The allocation rule *owner*, independent of the assumed reduction potentials/costs scenario and of the approach to include the shipping sector's emissions into the reduction commitment (*partial* and *full integration approach*), causes always the highest CO_2 prices and relative emission reductions, directly followed by the allocation way *operator*, and by far followed by the allocation way *flag*. This follows our projections on the joint emission reduction targets (see Table 5 in Section 5.1).

Although the difference between the two allocation ways *owner* and *operator* is almost negligible, this is not true for the difference between the two allocation rules and the allocation rule *flag*. The reason is that more emissions are allocated to the EU27 according to the allocation ways *owner* and *operator*. The *lrhc* scenario, which is characterized by a smaller reduction potential and higher costs per abatement measure than the *hrlc* scenario, always causes higher CO_2 prices. This is also the case for the *partial integration approach* (absolute target remains constant) compared to the *full integration approach* (relative target remains constant). The reason is that under the *partial integration approach* more emissions need to be abated (see Table 5, Section 5.1).

The emission reductions of the shipping sector relative to its BAU emissions is in a range between 20% to 25% in the *hrlc* scenario and significantly less, in the order of less than 3%, in the lrhc scenario. Compared to this, the emission reductions of *AoS* relative to its BAU emissions is between 16% and 21%, depending on the assumed reduction potentials/costs scenario and on the approach to include the shipping sector's emissions into the reduction commitment (*partial* and *full integration approach*).

Looking at Figure 7, which shows the efficient contribution (in %) of the shipping sector to the assumed targets under the *partial* and *full integration approach*, it is apparent that the efficient contribution of the shipping sector under the *full integration approach* (at most 7.74%) is almost the same (*hrlc* scenario) or even slightly higher (*lrhc* scenario) than under the *partial integration approach* (at most 7.94%), although absolute emission reduction is higher in the latter one. The reason for this is that the shipping sector provides a small but at the same time a relatively cheap abatement potential, at least in the beginning of the range optimal abatement, compared to *AoS*. Consequently, the relative contribution of the shipping sector is higher under the *full integration* approach because it requires less emission reductions in total.

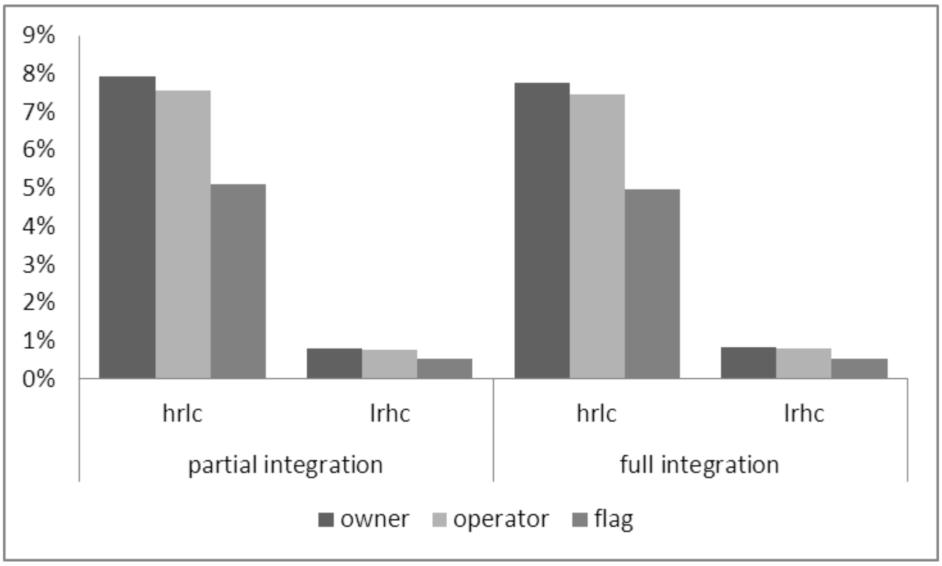

Figure 7: Efficient contribution (in %) of the shipping sector to the assumed targets under the *partial* and the *full integration* approach.
Source: Own calculations.

A comparison between scenario *S included in reduction efforts* (shipping sector is obliged to abate emissions) and scenario *S out of reduction efforts* (shipping sector is not obliged to abate emissions) shows that the EU27 could realize cost savings if scenario *S included in reduction efforts* is the preferred option, see Figure 8.

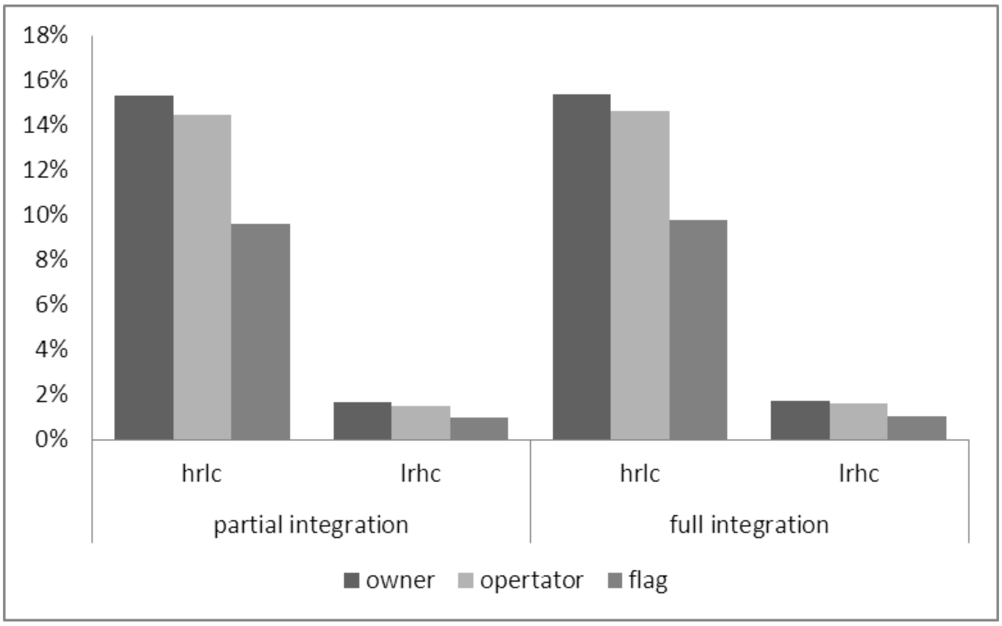

Figure 8: Abatement costs savings (in %) if the shipping sector would be included in reduction efforts under the *partial* and the *full integration* approach.
Source: Own calculations.

Cost savings are significant in the *hrlc* scenario, ranging between 8% and 16%. This is in particular the case, when we assume an exponential functional form instead of a quadratic one because the area under the marginal abatement cost function represents the abatement costs based on a specific emission reduction.[27] Cost savings are less pronounced in the *lrhc* scenario, ranging between 1.0% and 1.8%. The reason is that the shipping sector's reduction potential is much smaller than in the *hrlc* scenario. Thus, the amount of emission reduction that the shipping sector contributes additionally to the overall target, although it is relative cheap, has no significant effect on the cost savings.

A comparison of scenario *S included in reduction effort* and scenario *S out of reduction efforts* with scenario *status quo* shows that the CO_2 price and abatement costs increase significantly if the EU would include the shipping sector's emissions in its reduction commitment; see Table A3a–A4b in the Appendix and Figure 9, which shows the increase in the abatement costs between the scenario *S included in reduction efforts* and scenario *status quo* (the shipping sector's emissions are not included in the EU reduction commitment). The increase in abatement costs is in a range between 74% and 170% under the *partial integration approach* and between 30% and 82% under the *full*

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[27] See, e.g., Ellerman and Decaux (1998).

integration approach, depending on the reduction potentials/costs scenario assumed. The increase in abatement costs is particularly pronounced when applying the allocation way *owner* and the *partial integration approach* and by assuming the *lrhc* scenario (about 170%) because the amount of emission reduction is the highest, but the reduction potentials of measures are assumed to be low and costs are assumed to be high.

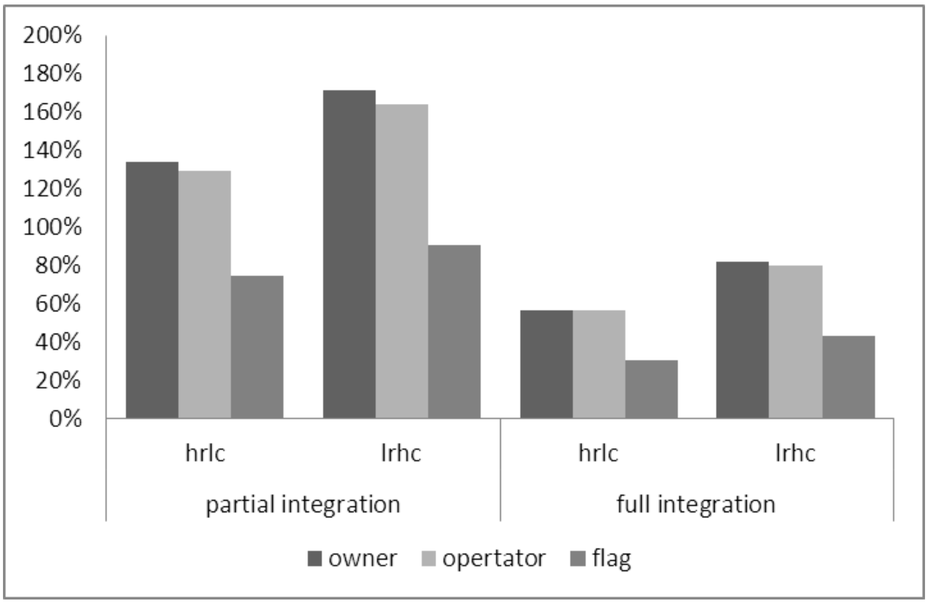

Figure 9: Increase in abatement costs (in %) if the shipping sector would be included in reduction efforts under the *partial* and the *full integration* approach compared to the status quo.
Source: Own calculations.

5.3.2. Shipping sector-specific country-level analysis

Moving from the regional to the country- level, the results for the scenario *S included in reduction effort* under the *full integration approach* assuming the *hrlc* scenario are summarized in Table 8. This table presents the ratio of how much emissions each individual country fleet reduces relative to its fleet-specific BAU emissions in relation to how much emissions the total EU fleet reduces relative to its fleet-specific BAU emissions under the given reduction target for all sectors, see Equation 5:

$$ratio_k = \frac{R_k^*}{E_{BAU_k}} \Bigg/ \frac{\sum_k R_k^*}{\sum_k E_{BAU_k}} \quad , \tag{5}$$

where *k* represents the individual 27 EU countries, R_k^* refers to the optimal emission reduction of country fleet *k* and E_{BAU_k} to the fleet-specific BAU emission reduction of country *k* in the scenario *S included in reduction effort* under the *full integration approach* assuming the *hrlc* scenario. Values larger than 100% indicate that the specific country fleet (defined by the three allocation ways) reduces its emissions more than the average EU fleet, i.e., the fleet consisting of the total ships that the 27 countries own, operate, or register under their flags together. Values smaller than 100% indicate that the specific country fleet reduces its emissions less than the average fleet.

Table 7: Ratio of country-specific emission reduction and EU fleet emission reduction in 2020

Allocation way					
Owner		*Operator*		*Flag*	
Country	ratio_k	Country	ratio_k	Country	ratio_k
Belgium	97.83%	Belgium	99.58%	Belgium	99.28%
Cyprus	99.14%	Cyprus	102.76%	Cyprus	99.27%
Denmark	100.50%	Denmark	101.55%	Denmark	98.26%
France	101.35%	France	104.09%	France	96.51%
Germany	100.89%	Germany	98.98%	Germany	105.73%
Greece	98.48%	Greece	98.21%	Greece	97.52%
Italy	96.78%	Italy	95.98%	Italy	96.66%
Netherlands	101.11%	Netherlands	100.98%	Malta	99.41%
Slovenia	101.60%	Slovenia	106.99%	Netherlands	98.29%
Spain	98.31%	Spain	96.76%	Spain	99.99%
Sweden	98.86%	Sweden	102.51%	Sweden	98.49%
UK	99.69%	UK	98.04%	UK	103.51%
EU27rest	100.45%	EU27rest	100.48%	EU27rest	100.66%

Source: Own calculations.

Looking at Table 7 shows that the way of allocating emissions to the individual countries affects their position of being a country that reduces its fleet-specific emissions relative to its fleet-specific BAU emissions more than the average EU fleet. For example, by allocating emissions according to the nationality of the *owner* of a ship, Table 7 shows that Denmark, France, Germany, the Netherlands, Slovenia, and the countries included in the EU27rest[28] reduce their emissions by more than the average, whereby Belgium, Cyprus, Greece, Italy, Spain, Sweden, and the United Kingdom (UK) reduce their emissions less than the average. The picture looks different by allocating emissions according to the nationality of the *operator* of a ship, e.g., Germany reduces its emissions less than the average EU fleet, whereas Sweden reduces its emissions more than the average EU fleet.

Moreover, the results show that the individual countries do not deviate significantly from the allocation-specific EU fleet average no matter which of the three allocation ways is applied. The reason for this is that the composition of fleets and of the efficient measures, i.e., the measures that are applied under the *full integration* approach and the *hrlc* scenario, is on average the same. This has implications for the policy design that is chosen in order to reduce the shipping sector's emissions, which we discuss in Section 6.

6. Discussion

Our results show that including the shipping sector's emissions into the EU27 reduction commitment for 2020 always, as a matter of course, increases the amount of required emission reductions and thus the abatement costs. This is particularly pronounced if we apply the allocation ways *owner* and *operator* and opt for the more ambitious approach (*partial integration approach*) to include the shipping sector's emissions into the reduction commitment.

We start to discuss our results by comparing the two approaches to include the shipping sector's emissions into the EU reduction commitment. The comparison shows that opting for the approach that keeps the relative target of 20% (*full integration approach*) should be the preferred option.

First, the approach also gives rise to significant emission reductions, but at the same time incurs less abatement costs (abatement costs increase non-linear).

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[28] The selection of countries is a mixture of the top 10 emitting country fleets in 2020 and two country fleets with little emissions in 2020. The EU27rest of the allocation ways *owner* and *operator* include Austria, Bulgaria, Czech Republic, Estonia, Finland, Hungary, Irish Republic, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, and Slovakia. The EU27rest of the allocation way *flag* includes Slovenia instead of Malta because Malta belongs in this case to the top 10 emitting country fleets in 2020.

Second, the approach seems to be politically more feasible. The reason is the following: as mentioned before, the EU committed itself to reduce its emissions in 2020 at least by 20% against 1990 levels or even up to 30% if other countries would also pursue more ambitious reduction targets (EC, 2008).[29] However, the commitment was based on a specific set of activities and sectors resulting in GHG emissions that excluded international bunker fuel emissions.[30] It can be assumed that the EU decided not to include international bunker fuel emissions into its reduction commitment because these emissions had been excluded from any commitment stated in the Kyoto Protocol during that time and thus were exempted from the national emissions regulated by the Kyoto Protocol. Instead the Kyoto Protocol's Article 2.2 requested that Annex I states should reduce emissions from international marine bunkers fuels by working through the IMO.[31]

Enlarging the set of regulated GHG emissions in 2020 should therefore demand a reassessment of the base year emissions by including the shipping sector's emissions. The other approach, i.e., the approach of including the shipping sector's emissions into the EU's emissions in 2020 and leaving the absolute emission target of 4.45 GtCO2-eq. constant (*partial integration approach*), would not only increase the required emission abatement in absolute terms, but also, in addition, give rise to much a sharper increase in abatement costs (assuming non-linear increasing abatement costs). Thus, the EU would actually reduce emissions by more than 20%.

Beyond that, we showed that the increase in abatement costs is significant under both approaches if the EU would include the shipping sector's emissions into its reduction commitment. However, the increase in abatement costs is higher if no reassessment of the base year emissions takes place.

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[29] The EU reconfirmed its reduction commitment in the process of associating with the Copenhagen Accord (EC, 2010). According to this reconfirmation developed countries should reduce their GHG emissions together by about 25% to 40% in 2020 compared to 1990 levels in order to stay in line with meeting the 2°C target.

[30] Total GHG emissions do not include emissions from international bunkers (EEA, 2012).

[31] The focus on the IMO as the responsible institution to regulate emissions from international shipping was also reinforced by the UNFCCC working group report of 2009 (UNFCCC, 2009). This report presented several options in the negotiation text for the Cop15 in Copenhagen on how to regulate the shipping sector's emissions. For example, according to one option, the IMO should set an emission reduction target for marine bunker fuels as equal to 20% below 2005 levels by 2020.

If the EU decides to include the shipping sector and the optimistic reduction potentials and costs scenario (*hrlc* scenario) can be assumed to be more realistic, then the shipping sector should definitely be included in the reduction efforts and not left outside any obligations as it is currently the case. The shipping sector could contribute efficiently to emission reductions (up to about 8%) and decrease abatement costs of achieving the given target (up to about 16%). Moreover, the burden of emission reduction for other EU sectors would be released and thus a fair burden sharing between a more complete set of sectors would be reached. If the pessimistic reduction potentials and costs scenario (*lrhc* scenario) can be assumed to be more realistic, then the shipping sector's inclusion into reduction efforts would yield only small contributions to efficient emission reduction (less than 1%) and small abatement cost savings (less than 2%). Almost all emission reductions would be burdened on the other EU sectors.

Comparing the three allocation ways (*owner*, *operator*, and *flag*) in the light of practicality, all three rules tend to be vulnerable to evasion (Faber and Rensma, 2008, Heitmann and Khalilian, 2012). This is conditioned by the global nature of the shipping sector. If the EU burdens its shipping sector with emission regulation, whereby the scope of the shipping sector refers to one of the three allocation ways, the shipping sector's affected stakeholders will search for ways to evade the regulation. Flagging out a ship is easily done and owners or operators will simply relocate their head offices countries where they would be exempt from such a regulation. As pointed out by Faber and Rensma (2008), this is in particular the case for the allocation way *owner* as ships are often owned by investment vehicles, e.g., Limited Partnerships (UK). The major share of these investment vehicles is currently based in OECD countries. However, they can easily relocate to other countries at little cost and thereby potentially evade the regulations.

So far, we have discussed the results only in the light of the optimal solution, which assumes that all sectors participate in a system that causes the marginal abatement costs of each sector to be equalized (e.g., market-based policy instruments). However, the debate in the IMO also highlights the option to regulate the shipping sector separately, e.g., by implementing market-based measures or command-and-control measures only for that sector (IMO, 2012). How the shipping sector's emissions should actually be regulated in order to contribute efficiently to a given emission reduction target depends on the structure of the reduction potential. The sectoral analysis of the shipping sector showed that all the country fleets reduce their BAU emissions by almost the same share (about 20%) by applying almost the same measures in the optimal scenario no matter which allocation way is chosen. Thus, regulating the emissions of the shipping sector by mandating the implementation of particular measures, i.e., the measures that are cost-effective under the optimal scenario, might be an effective policy instrument to reduce emissions in the shipping sector in the shot-run. In the long-run, however, the shipping sector's emissions should be regulated in a global agreement together with those of other transport modes. The reason for this is that a modal shift may occur and thus the shipping sector's emissions may be substituted by other unregulated transport modes' emissions that might be more emission-intensive and thus increase overall emissions.[32] For example, Faber et al. (2009) argue that this is likely the case for transport routes, where maritime transport competes with rail, road or aviation transport.

7. Summary and conclusions

While it is clear that the EU aims to include the shipping sector's emissions in its reduction commitment, it has not been analyzed so far how the inclusion would affect the EU reduction commitment for 2020 and the abatement costs. In this paper, we analyze these effects with the help of MACCs. Moreover, we determine if some country fleets could reduce emissions in the shipping sector relatively more efficiently than other country fleets under a given emission reduction target for all sectors. In order to do this, we first allocated the shipping sector's emissions to the EU27 based on the SBSTA rule No. 4: allocate emissions based on the nationality of (1) the ship owner, (2) the ship operator, or based on (3) the flag state registration. Second, we proposed two approaches to include the shipping sector's emissions into the EU27 reduction commitment for 2020: *partial integration approach*, which leaves the absolute target of 4.45 $GtCO_2$-eq. constant and adds shipping emissions on top of total emissions in 2020, and the *full integration approach*, which leaves the relative target of 20% reduction constant and reassesses the base year emissions in 1990 by including the shipping sector's emissions.

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[32] This issue is discussed in Buhaug et al. (2009) and in Faber et al. (2009).

The main findings are that the increase in the amount of required emission reductions and resulting abatement costs are in particular pronounced if we apply the allocation ways *owner* and *operator* and opt for the more ambitious approach (*partial integration approach*). Moreover, we find that the shipping sector could contribute efficiently to emission reductions (at most by 8.5%) if it was included in reduction efforts and decrease abatement costs of achieving the given target (at most by 16%). Moreover, the results show that the individual countries do not deviate significantly from the allocation-specific EU fleet average no matter which of the three allocation ways is applied. The reason for this is that the composition of the individual country fleets and of the efficient measures applied to them is on average the same.

Overall, we conclude that the EU27 should include the shipping sector's emissions in its reduction commitment if no global solution is achieved in the near future. Otherwise, these emissions are left outside any regulation and jeopardize the achievement of climate change goals, in particular, the 2°C target. Comparing the two integration approaches, the discussion in Section 5 shows that the relative target of 20% reduction in combination with a reassessment of the base year emissions in 1990 should be applied. Beyond that the shipping sector should also be included into abatement efforts. The reasons for this are that the shipping sector's emissions are substantial and thus a contribution to overall emission reductions, as other sectors of the economy are required to do, seems to be appropriate. At the same time, the shipping sector provides cost-effective abatement potential that should be exploited in order to alleviate the increase in abatement costs.

However, the practicality of including the shipping sector's emissions in the EU reduction commitment based on one of the allocation ways needs to be analyzed in greater detail. On the one hand, all three ways tend to be vulnerable to regulation evasion, thus making it harder to control the shipping sector's emissions effectively. On the other hand, the reassessment of the base year emissions is limited due to data availability. The approach of including the shipping sector's emissions into EU ETS by obliging all incoming and outgoing ships to surrender EU ETS allowances, independent of the nationality of the *owner*, *operator*, or *flag state registration*, would control emissions more effectively. However, the EU commission's moratorium on the aviation sector that excludes the aviation sector from surrendering EU ETS allowances in April

2013 for emissions generated in 2012 shows that regulating international mobile emitters by a regional policy instrument is a challenging task. Therefore, we conclude that regulating the emissions of the shipping sector by mandating the implementation of particular measures, i.e., the measures that are cost-effective under the optimal scenario, might be an effective policy instrument to reduce emissions in the shipping sector in the shot-run. In the long-run, however, emissions of the shipping sector should be included in a global market-based policy instrument with other sectors. But all these questions are deferred to future research. Overall, the IMO should foster to improve the data availability relating to emissions in order to reduce the level of uncertainty that is prevailing in all current studies.

A number of limitations are worth mentioning. Determining the emissions of the fleets in 1990 in order to reassess the base year emissions is challenging because we have neither information about ship owners, ship operators, or ships' flag state registration nor about the operational profiles of these ships for the year 1990. For this reason we have worked with the assumption that the projected relative shares of the EU shipping sector's emissions on the global shipping sector's emissions in 2020 were the same proportionately as in the base year of 1990. Moreover, including the aviation sector's emissions in the analysis is currently not possible because of data availability. Finally, we worked with data for only 14 ship types. These 14 ship types do not represent the whole world fleet, yet they represent a very large proportion of the transported tonnage globally.

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9. Appendix

Table A1: Estimates for marginal abatement cost functions assuming an exponential functional form under the *partial integration* approach

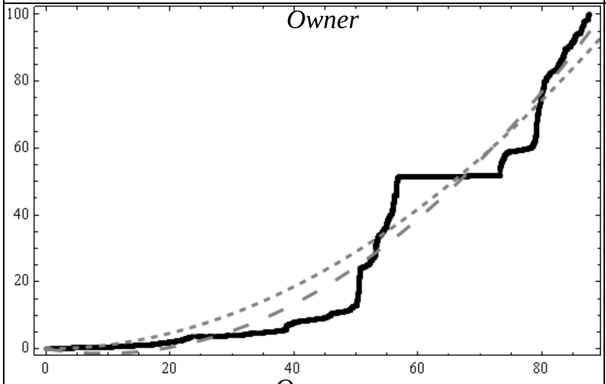
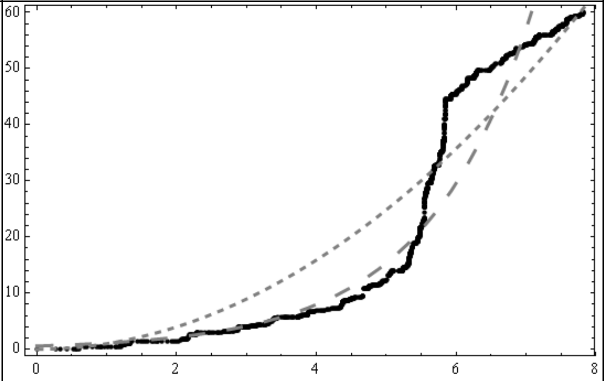
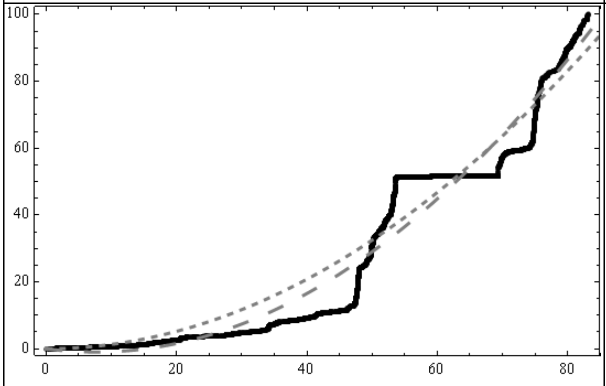
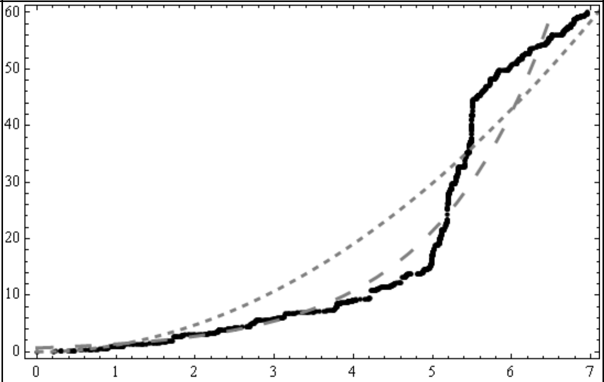
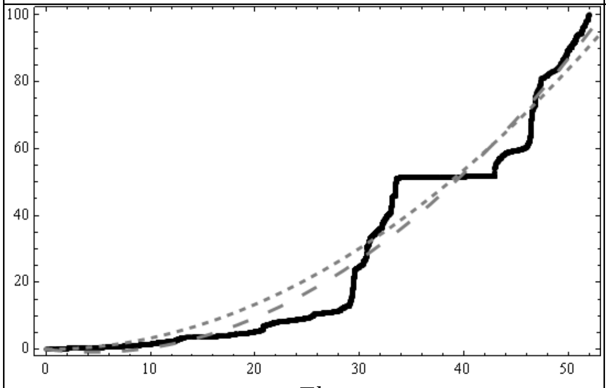
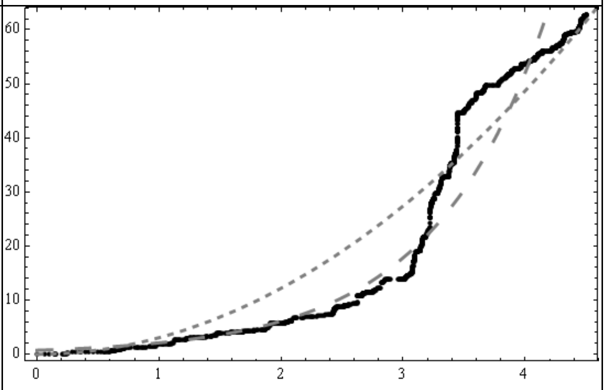
Allocation way	Reduction/costs scenario	Parameter values		R^2
		a	b	
Owner	*hrlc*	-0.18852	0.05926	0.903777
	lrhc	-0.54954	0.65629	0.933384
Operator	*hrlc*	-0.04894	0.06064	0.910114
	lrhc	-0.35586	0.68333	0.957638
Fleet	*hrlc*	0.00558	0.09607	0.909094
	lrhc	-0.33453	1.07121	0.952663

Source: Own calculations.

Table A2: Estimates for marginal abatement cost functions assuming an exponential functional form under the *full integration* approach

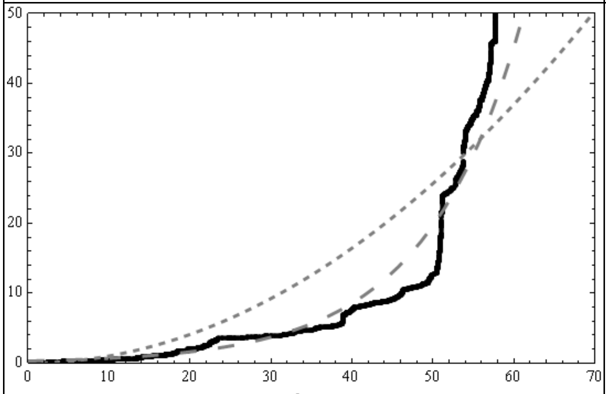
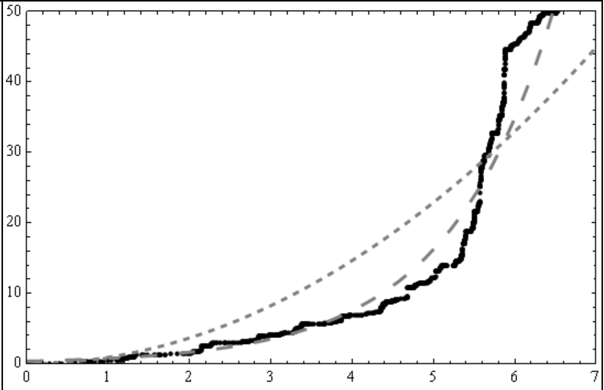
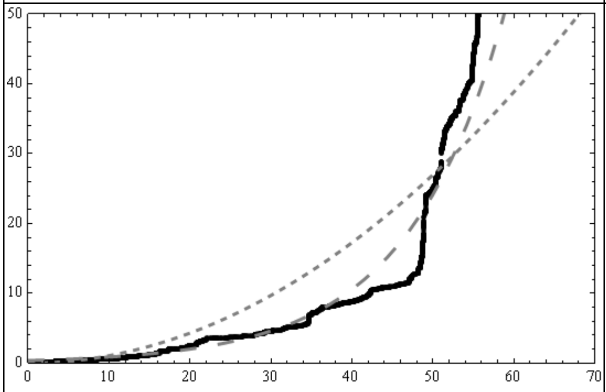
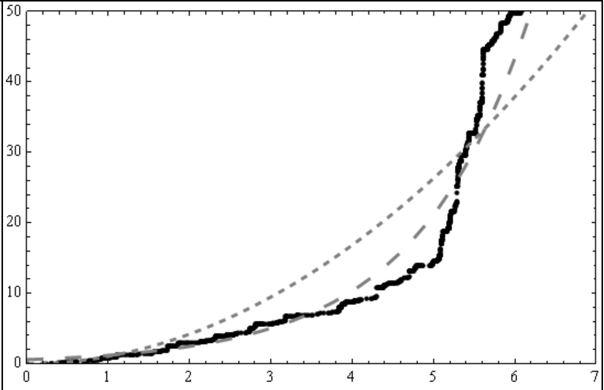
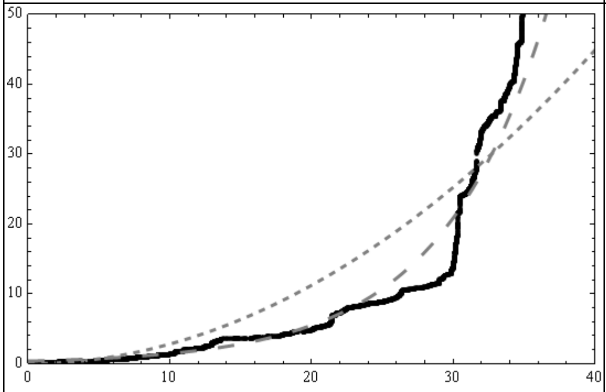
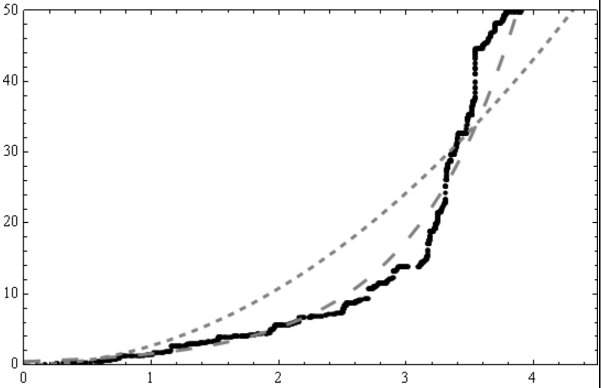
Allocation way	Reduction/costs scenario	Parameter values		R^2
		a	b	
Owner	*hrlc*	-1.18216	0.08321	0.956860
	lrhc	-1.04041	0.76531	0.958404
Operator	*hrlc*	-0.94782	0.08263	0.96646
	lrhc	-0.53262	0.71697	0.956814
Fleet	*hrlc*	-0.96219	0.13331	0.969958
	lrhc	-0.75045	1.20378	0.970225

Source: Own calculations.

hrlc scenario/partial integration approach	*lrhc scenario/partial integration approach*
 *Owner*	 *Owner*
 *Operator*	 *Operator*
 *Flag*	 *Flag*

[a] *The gray large-dashed line represents the fit of the exponential functional form, the gray short-dashed line represents the fit of the quadratic functional form, and the black dotted line represents the data plot.*

Figures A1–A6: Data and function plots of *owner*, *operator*, and *flag registration* under the *partial integration approach*[a]. *Source*: Own calculations.

hrlc scenario/full integration approach	*lrhc scenario/full integration approach*
 *Owner*	 *Owner*
 *Operator*	 *Operator*
 *Flag*	 *Flag*

[a] *The gray large-dashed line represents the fit of the exponential functional form, the gray short-dashed line represents the fit of the quadratic functional form, and the black dotted line represents the data plot.*

Figures A7–A12: Data and function plots of *owner*, *operator*, and *flag registration* under the *full integration approach*[a]. *Source*: Own calculations.

Table A3: Emissions, abatement costs, and CO_2 prices under the *partial integration* approach assuming an exponential functional form

Policy scenario	Reduction/ costs scenario	Allocation way	Business-as-usual emissions shipping and AoS (in Mt)		Emissions after efficient reduction (in Mt) in shipping sector	Emissions after efficient reduction (in Mt) in AoS	Abatement costs shipping (AC_S in billion 2007US$)	Abatement costs AoS (AC_{AoS} in billion 2007US$)	Abatement costs (AC_{AoS} + AC_S in billion 2007US$)	CO_2 price/ton (in 2007US$)= MAC_{AoS}	CO_2 price/ton (in 2007US$) =$MAC_{AoS}$=$MAC_S$
Joint target for AoS and shipping (scenario 1)	*hrlc*	*Owner*	286	4249	216	3433	0.89	16.54	17.43		53.38
		Operator	276	4249	210	3439	0.85	16.23	17.09		52.72
		Flag	173	4249	134	3515	0.45	12.53	12.98		44.52
	lrhc	*Owner*	286	4249	279	3370	0.09	20.15	20.24		60.73
		Operator	276	4249	269	3380	0.09	19.58	19.67		59.61
		Flag	173	4249	169	3480	0.04	14.18	14.22		48.26
AoS without shipping	*AoS (scenario 2)*	*Owner*		4249		3363		20.58		61.59	
		Operator		4249		3373		19.97		60.38	
		Flag		4249		3476		14.37		48.68	
	AoS (scenario 3)			4249		3649		7.46		31.79	

Source: Own calculations.

Table A4: Emissions, abatement costs, and CO_2 prices under the *full integration* approach assuming an exponential functional form

Policy scenario	Reduction/ costs scenario	Allocation way	Business-as-usual emissions shipping and AoS (in Mt)		Emissions after efficient reduction (in Mt) in shipping sector	Emissions after efficient reduction (in Mt) in AoS	Abatement costs shipping (AC_S in billion 2007US$)	Abatement costs AoS (AC_{AoS} in billion 2007US$)	Abatement costs (AC_{AoS} + AC_S in billion 2007US$)	CO_2 price/ton (in 2007US$)= MAC_{AoS}	CO_2 price/ton (in 2007US$) =$MAC_{AoS}$=$MAC_S$
Joint target for AoS and shipping (scenario 1)	*hrlc*	*Owner*	286	4249	227	3547	0.49	11.18	11.70		41.34
		Operator	276	4249	220	3547	0.49	11.15	11.65		41.28
		Flag	173	4249	139	3591	0.27	9.44	9.71		39.98
	lrhc	*Owner*	286	4249	280	3494	0.06	13.49	13.54		46.72
		Operator	276	4249	270	3497	0.06	13.36	13.43		46.44
		Flag	173	4249	169	3561	0.03	10.62	10.66		39.98
AoS without shipping	*AoS (scenario 2)*	*Owner*		4249		3488		13.79		49.01	
		Operator		4249		3491		13.65		48.15	
		Flag		4249		3557		10.77		40.34	
	AoS (scenario 3)			4249		3649		7.46		31.79	

Source: Own calculations