

# Essays on Economic Aspects of Regulating Maritime Transport

Inaugural-Dissertation

zur Erlangung des akademischen Grades eines Doktors  
der Wirtschafts- und Sozialwissenschaften  
der Wirtschafts- und Sozialwissenschaftlichen Fakultät  
der Christian-Albrechts-Universität zu Kiel

vorgelegt von

Diplom-Ökonomin, Nadine Heitmann  
aus Hannover, geb. 17.11.1979

Kiel, 2013

Gedruckt mit Genehmigung der  
Wirtschafts- und Sozialwissenschaftlichen Fakultät  
der Christian-Albrechts-Universität zu Kiel

Dekan: Prof. Horst Raff, Ph.D.

Erstberichterstatter: Prof. Dr. Katrin Rehdanz

Zweitberichterstatter: Prof. Dr. Carsten Schröder

Tag der Abgabe der Arbeit: 29. Januar 2013

Tag der mündlichen Prüfung: 24. Mai 2013

# Acknowledgements

I am sincerely grateful to my supervisor, Katrin Rehdanz. She supported and guided me through my dissertation. She always helped me to gather ideas and to improve my work. I am also very thankful to my second supervisor, Carsten Schröder.

I am thankful to my colleagues at the Kiel Institute for the World Economy, in particular Christine Bertram, Setareh Khalilian, Gernot Klepper, Daiju Narita, Sonja Peterson, Ulrich Schmidt, and Matthias Weitzel. I have enjoyed working and having discussions with them. I appreciate their support a lot. I am also thankful to Hendrik Goll for his research assistance and Paul Kramer for his scientific writing lessons. The Kiel Institute for the World Economy, in particular the Environment and Natural Resources Research Area, and the International Doctoral Programme in Quantitative Economics at the Kiel University provided an excellent research environment.

Moreover, I want to thank my fellow students and friends, Laura Birg, Wan-Hsin Liu, Markus Pape, and Matthias Raddant for vivid discussions and a great time in Kiel.

Above all, I am indebted to my family, in particular to Siegrun Heitmann and Anneliese Lichtenstein, and to my friends, in particular to Andreas Kräuter and Angelika Jürgens, for their encouragement, patience, support, and trust.

# Contents

<b>List of Abbreviations .....</b>	<b>IV</b>
<b>Figures and Tables.....</b>	<b>VII</b>
<b>Introduction.....</b>	<b>1</b>
<b>Part I: Price Discrimination.....</b>	<b>10</b>
<b>Paper I: Determining Optimal Transit Charges: The Kiel Canal in Germany .....</b>	<b>10</b>
1. Introduction.....	12
2. The Kiel Canal .....	15
2.1 History.....	15
2.2 Traffic data.....	16
2.3 Transit charge system .....	19
3. Method.....	20
4. Study design and data .....	22
5. Results.....	27
6. Discussion.....	32
7. Conclusion .....	35
8. References.....	38
9. Regulations .....	40
10. Appendix A.....	42
11. Appendix B.....	45
<b>Part II: Climate Change Policy .....</b>	<b>49</b>
<b>Paper I: Accounting for Carbon Dioxide Emissions from International Shipping: Burden Sharing under Different UNFCCC Allocation Options and Regime Scenarios .....</b>	<b>49</b>
1. Introduction.....	51
2. The shipping sector.....	53
2.1. Structure and emissions inventory of the shipping sector .....	53
2.2. Legal structures: IMO, UNCLOS and ownership of vessels.....	55

3. Options under the UNFCCC to allocate shipping emissions.....	56
4.1. Data set description and calculation approach of allocating CO <sub>2</sub> emissions.....	57
4.2. Results.....	59
4.3. Putting the results into perspective .....	61
5. Discussion of allocation results .....	64
5.1. Scenario description and evaluation criteria .....	64
5.2. Discussion.....	64
5.2.1. Environmental effectiveness.....	64
5.2.2. Legal effectiveness.....	66
5.2.3. Burden sharing.....	67
6. Conclusion .....	68
7. References.....	70
8. Appendix A.....	73
9. Appendix B.....	75

**Paper II: The Potential Contribution of the Shipping Sector to an Efficient Reduction of Global Carbon Dioxide Emissions..... 76**

1. Introduction.....	78
2. Generating a MACC for the shipping sector .....	80
2.1. Overview of MACC studies.....	80
2.2. Negative abatement costs.....	84
2.3. Generating MACCs and MAC functions.....	87
3. Combining the shipping MACC with a global MACC .....	93
3.1. Construction of a CGE-model-based global MACC .....	93
3.2. Discussion of combining both curves .....	94
4. Analysis of different emission reduction and climate policy scenarios.....	95
4.1. Description of scenarios.....	95
4.2. Results.....	98
5. Discussion.....	103

6. Conclusion .....	105
7. References.....	107
8. Appendix.....	111
<b>Paper III: Including Maritime Transport in the EU’s Climate Change Policy: Country-Based Allocation and Effects.....</b>	<b>117</b>
1. Introduction.....	120
2. Climate change policy .....	123
3. Allocation rules and effects of including the shipping sector’s emissions in the EU reduction commitment.....	125
3.1. Absolute versus relative target .....	125
3.2. Applying the UNFCCC allocation rule: the resulting emissions.....	127
4. Generating marginal abatement cost curves for the shipping sector in the 27 EU countries.....	130
4.1. MACCs and corresponding abatement cost functions for the shipping sector .....	130
4.2. MACC and corresponding abatement cost function for all other EU sectors .....	134
4.3. Combining both types of MACCs .....	136
5. Analysis of policy scenarios .....	140
5.1. Determination of BAU emissions and emission targets .....	140
5.2. Determination of policy scenarios .....	142
5.3. Results.....	143
5.3.1. EU27-level analysis .....	143
5.3.2. Shipping sector-specific country-level analysis.....	147
6. Discussion.....	149
7. Summary and conclusions .....	152
8. References.....	155
9. Appendix.....	160
<b>Eidesstattliche Erklärung.....</b>	<b>165</b>

# List of Abbreviations

AC	abatement costs
AE	auxiliary engine
AoS	all other sectors
BAU	business-as-usual
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
BMWi	Bundesministerium für Wirtschaft und Technologie
CATCH	cost of averting a tonne of CO <sub>2</sub> -eq. heating
CGE	computable general equilibrium
CO <sub>2</sub>	carbon dioxide
CP	Copenhagen Pledges
DART	Dynamic Applied Regional Trade
dwt	<i>dead weight tonnage</i>
EC	European Commission
ECCP	European Climate Change Programme
EEA	European Environment Agency
EEDI	Energy Efficiency Design Index
Elbe-LV	Elbe-Lotsverordnung
ETS	emission trading scheme
EU	European Union
EU ETS	European Union Emission Trading Scheme
g	gram
GHG	greenhouse gases
gt	gross tonnage
Gt	giga tonnes
GTAP	Global Trade Analysis Project
HFO	heavy fuel oil
hrlc	high reduction potential and low costs
IAM	integrated assessment models
ICAO	International Civil Aviation Organisation
ICCT	International Council on Clean Transportation

IEA	International Energy Agency
ILO	International Labour Organization
IMO	International Maritime Organization
IP	intersection point
IPCC	Intergovernmental Panel on Climate Change
ISL	Institut für Seeverkehrswirtschaft und Logistik Bremen
kn	knots
kW	kilowatt
kWh	kilowatt hour
lrhc	low reduction potential and high costs
LTV/LTO	Lotstarifverordnung
LULUCF	land use, land-use change and forestry
m	meter
MAC	marginal abatement costs
MACC	marginal abatement cost curve
MCR	maximum Continuous Rating
MDO	marine diesel oil
ME	main engine
MEPC	Marine Environment Protection Committee
MPP	multipurpose ship
Mt	million tonnes
nm	nautical miles
NOK	Nord-Ostsee-Kanal
NOKBefAbgV	Verordnung über die Befahrensabgaben auf dem Nord-Ostsee-Kanal
NOK-LV	Nord-Ostsee-Kanal-Lotsverordnung
NSR	Northern Sea Route
rp	reduction potential
OECD	Organization for Economic Cooperation and Development
SBSTA	Subsidiary Body for Scientific and Technological Advice
SeeAufgG	Seeaufgabengesetz
SeeLG	Seelotsgesetz



SEEMP	Ship Energy Efficiency Management Plan
SeeSchStrO	Seeschiffahrtsstraßen-Ordnung
SFOC	specific fuel oil consumption
SNAME	Society of Naval Architect and Naval Engineers
t	ton
T/C	time charter
TEU	twenty-foot equivalent unit
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USCAN	US Climate Action Network
WRE	Wigley, Richels, and Edmonds
WSD	Nord Wasser- und Schifffahrtsdirektion Nord
WTP	willingness-to-pay

# Figures and Tables

## Part I: Price Discrimination

### Paper I: Determining Optimal Transit Charges: The Kiel Canal in Germany

<b>Figure 1:</b>	Shipping routes and alternative passageways .....	12
<b>Figure 2:</b>	Traffic through the Kiel Canal (2005–2009) .....	17
<b>Table 1:</b>	Total traffic around Denmark and total traffic through the Kiel Canal (2005–2009). .....	17
<b>Figure 3:</b>	Types of ships using the Kiel Canal (2005–2009).....	19
<b>Table 2:</b>	Ship type specifications.....	24
<b>Table 3:</b>	Relevant length (in nm) between Helsinki and the three alternative ports at the North Sea.....	26
<b>Figure 4a:</b>	Cost differences and the actual Kiel Canal transit charge for the 1,400 TEU container on a voyage from Helsinki to Rotterdam (in thousand dollars) .....	28
<b>Figure 4b:</b>	Cost differences and the actual Kiel Canal transit charge for the 550 TEU container on a voyage from Helsinki to Rotterdam (in thousand dollars) .....	28
<b>Figure 4c:</b>	Cost differences and the actual Kiel Canal transit charge for the ship bulk carrier on a voyage from Helsinki to Rotterdam (in thousand dollars) .....	28
<b>Figure 4d:</b>	Cost differences and the actual Kiel Canal transit charge for the multipurpose ship on a voyage from Helsinki to Rotterdam (in thousand dollars) .....	28
<b>Figure 4e:</b>	Cost differences and the actual Kiel Canal transit charge for the 1,400 TEU container on a voyage from Helsinki to Hamburg (in thousand dollars) .....	29
<b>Figure 4f:</b>	Cost differences and the actual Kiel Canal transit charge for the 550 TEU container on a voyage from Helsinki to Hamburg (in thousand dollars) .....	29
<b>Figure 4g:</b>	Cost differences and the actual Kiel Canal transit charge for the ship bulk carrier on a voyage from Helsinki to Hamburg (in thousand dollars) .....	29

<b>Figure 4h:</b>	Cost differences and the actual Kiel Canal transit charge for the multipurpose ship on a voyage from Helsinki to Hamburg (in thousand dollars) .....	29
<b>Figure 4i:</b>	Cost differences and the actual Kiel Canal transit charge for the 1,400 TEU container on a voyage from Helsinki to Leith (in thousand dollars) .....	30
<b>Figure 4j:</b>	Cost differences and the actual Kiel Canal transit charge for the 550 TEU container on a voyage from Helsinki to Leith (in thousand dollars) .....	30
<b>Figure 4k:</b>	Cost differences and the actual Kiel Canal transit charge for the ship bulk carrier on a voyage from Helsinki to Leith (in thousand dollars).....	30
<b>Figure 4l:</b>	Cost differences and the actual Kiel Canal transit charge for the multipurpose ship on a voyage from Helsinki to Leith (in thousand dollars).....	30
<b>Table 3:</b>	Difference in revenues between the optimal and actual transit charge approach (in million dollars) .....	34
<b>Table B1:</b>	Difference in costs for the Helsinki–Rotterdam route (in \$).....	46
<b>Table B2:</b>	Difference in costs for the Helsinki–Hamburg route (in \$) .....	47
<b>Table B3:</b>	Difference in costs for the Helsinki–Leith route (in \$).....	48

## Part II: Climate Change Policy

### Paper I: Accounting for Carbon Dioxide Emissions from International Shipping: Burden Sharing under Different UNFCCC Allocation Options and Regime Scenarios

<b>Table 1:</b>	Presentation of top 5 countries by number and deadweight tonnage in registration of world fleet, ships of 300 gt and more .....	54
<b>Table 2:</b>	Presentation of top 5 countries by number and deadweight tonnage in control of world fleet, ships of 1000 gt and more .....	54
<b>Figure 1:</b>	Top 10 countries of allocated shipping emissions .....	60
<b>Figure 2:</b>	Comparison of allocation options on a regional scale .....	62
<b>Figure 3:</b>	Comparison of environmental effectiveness .....	65

<b>Table 3a:</b>	Representation of the top 10 trading countries defined by their relative share of world goods exports in 2007 .....	67
<b>Table 3b:</b>	Representation of the top 10 trading countries defined by their relative share of world goods imports in 2007 .....	67
<b>Table A1:</b>	Top 10 countries according to relative increase in total national emissions (in %) .....	73
<b>Table A2:</b>	Top 10 countries according to relative increase in total national emissions (in %) .....	73
<b>Table A3:</b>	Top 10 countries according to relative increase in total national emissions (in %) .....	74
<b>Table A4:</b>	Top 10 countries according to relative increase in total national emissions (in %) .....	74
<b>Table B1:</b>	Scenario description .....	75

## Paper II: The Potential Contribution of the Shipping Sector to an Efficient Reduction of Global Carbon Dioxide Emissions

<b>Table 1:</b>	Overview of expert-based MACCs: assumptions and results.....	81
<b>Table 2:</b>	Categories of measure types.....	82
<b>Figure 1:</b>	Actors in shipping and their control over factors determining a ship's CO <sub>2</sub> emissions.....	83
<b>Figure 2a and 2b:</b>	MACCs including negative abatement costs and MACCs relating to the three cases under the two reduction potentials and costs scenarios (2a: <i>hrlc</i> and 2b: <i>lrhc</i> ) .....	91
<b>Table 3:</b>	Maximum reduction potentials for the six cases in 2020.....	92
<b>Table 4:</b>	Emission targets, BAU emissions, and implied reduction targets .....	97
<b>Table 5:</b>	CO <sub>2</sub> prices, efficient reduction relative to BAU emissions and to overall target.....	99
<b>Figure 3a and 3b:</b>	Efficient contribution of shipping to the three overall reduction targets in the <i>hrlc</i> scenario (a) and the <i>lrhc</i> scenario (b).....	100

<b>Figure 4a and 4b:</b>	Comparison of efficient emission reductions relative to BAU emissions of AoS and S (a) in <i>hrhc</i> scenario and (b) in <i>lrhc</i> scenario.....	101
<b>Figure 5a and 5b:</b>	Relative global cost savings of the two policy scenarios: (a) <i>AoS</i> and S have a joint target versus <i>AoS</i> without S in the <i>hrhc</i> scenario and (b) <i>AoS</i> and S have a joint target versus <i>AoS</i> without S in the <i>lrhc</i> scenario.....	102
<b>Table A1:</b>	Parameter values and (adjusted) $R^2$ of approximated marginal abatement cost functions.....	111
<b>Figure A1–A3:</b>	show the approximated functions for the high reduction and low costs scenario ( <i>hrhc</i> ) .....	112
<b>Figures A4–A6:</b>	show the approximated functions for the high reduction and low costs scenario ( <i>lrhc</i> ) .....	112
<b>Figure A7:</b>	Comparison of functional fits with global ( <i>AoS</i> ) MACC.....	113
<b>Figure A8:</b>	Residuals plots .....	113
<b>Figure A9:</b>	Global ( <i>AoS</i> ) MACC and shipping MACCs .....	113
<b>Table A2:</b>	Emissions, abatement costs, and prices under the 2°C target .....	114
<b>Table A3:</b>	Emissions, abatement costs, and prices under the low Copenhagen Pledges target .....	115
<b>Table A4:</b>	Emissions, abatement costs, and prices under the high Copenhagen Pledges target .....	116

### Paper III: Including Maritime Transport in the EU’s Climate Change Policy: Country-Based Allocation and Effects

<b>Figure 1:</b>	<i>Partial integration</i> approach (absolute reduction target remains constant) .....	126
<b>Figure 2:</b>	<i>Full integration</i> approach (relative reduction target remains the same) .....	127
<b>Table 1:</b>	BAU emissions of the EU fleet in 2020 according to the three ways of allocating emissions: <i>owner</i> , <i>operator</i> , and <i>flag registration</i> .....	129
<b>Figure 3(a):</b>	MACCs in 2020 according to the three allocation ways in the <i>hrhc</i> ( <i>high reduction potentials and low costs</i> ) scenario .....	132

<b>Figure 3(b):</b>	MACCs in 2020 according to the three allocation ways in the <i>lrhc</i> ( <i>low reduction potentials and high costs</i> ) scenario .....	133
<b>Table 2:</b>	Maximum reduction potentials and BAU emissions in 2020 (in MtCO <sub>2</sub> emissions).....	133
<b>Figure 4:</b>	MACC for all other sectors of the EU27 in 2020 .....	135
<b>Table 3:</b>	Value restrictions under the <i>partial</i> and the <i>full integration</i> approach.....	138
<b>Figure 5:</b>	Combination of both MACCs under the <i>partial integration</i> approach ( <i>hrhc</i> and <i>lrhc</i> scenario) .....	139
<b>Figure 6:</b>	Combination of both MACCs under <i>full integration</i> approach ( <i>hrhc</i> and <i>lrhc</i> scenario).....	140
<b>Table 4:</b>	Unregulated BAU emissions of the shipping sector and all other sectors ( <i>AoS</i> ) in the EU27 in 2020.....	141
<b>Table 5:</b>	Joint emission reduction targets (in MtCO <sub>2</sub> ) of the shipping sector and <i>AoS</i> in 2020 .....	142
<b>Table 6:</b>	Resulting CO <sub>2</sub> prices (in US\$) and efficient reductions in relative terms in 2020 for scenario <i>S included in reduction effort</i> .....	144
<b>Figure 7:</b>	Efficient contribution (in %) of the shipping sector to the assumed targets under the <i>partial</i> and the <i>full integration</i> approach .....	145
<b>Figure 8:</b>	Abatement costs savings (in %) if the shipping sector would be included in reduction efforts under the <i>partial</i> and the <i>full integration</i> approach.....	146
<b>Figure 9:</b>	Increase in abatement costs (in %) if the shipping sector would be included in reduction efforts under the <i>partial</i> and the <i>full integration</i> approach compared to the status quo.....	147
<b>Table 7:</b>	Ratio of country-specific emission reduction and EU fleet emission reduction in 2020.....	148
<b>Table A1:</b>	Estimates for marginal abatement cost functions assuming an exponential functional form under the <i>partial integration</i> approach.....	160
<b>Table A2:</b>	Estimates for marginal abatement cost functions assuming an exponential functional form under the <i>full integration</i> approach.....	160

<b>Figures A1–A6:</b>	Data and function plots of owner, operator, and flag registration under the <i>partial integration</i> approach.....	161
<b>Figures A7–A12:</b>	Figures A1-A6: Data and function plots of owner, operator, and flag registration under the <i>full integration</i> approach .....	162
<b>Table A3:</b>	Emissions, abatement costs, and CO <sub>2</sub> prices under the <i>partial integration</i> approach assuming an exponential functional form.....	163
<b>Table A4:</b>	Emissions, abatement costs, and CO <sub>2</sub> prices under the <i>full integration</i> approach assuming an exponential functional form .....	164

# Introduction

The maritime transport sector (henceforth shipping sector) can be seen as the backbone of globalization since it transports 80% of the merchandise traded internationally (UNCTAD, 2008). It transported about 8.4 billion tons of merchandise throughout the world in 2010 (UNCTAD, 2011). Needless to say, the shipping sector is a global sector. Over 170 countries are engaged as maritime states.<sup>1</sup> Ships are globally mobile and can have multiple nationalities, i.e., ships can be owned and operated by different nationalities, and registered in different countries. Furthermore, ships are subject to multiple regulations, such as the United Nations Convention on the Law of the Sea (UNCLOS), the Conventions of the International Maritime Organization (IMO), the Conventions of the International Labour Organization (ILO), the laws of the flag states, and the laws of the coastal states (Stopford, 2009). Thus, regulating such a global sector is a challenging task.

The papers presented in this cumulative dissertation deal with economic aspects of regulating this global sector in two areas of interest. Thus, the dissertation is divided into two parts. Part I (first paper) deals with regulating the transit charges of an international waterway in the context of price discrimination. Part II (second, third, and fourth paper), which is the main emphasis of the dissertation, deals with regulating CO<sub>2</sub> emissions of the shipping sector in the context of climate change policy.

## *Part I*

Looking at the geographical aspect of maritime trade, we find that maritime trade is dominated by Asia, Europe, and North America. These three regions are interconnected by major shipping routes that are primarily used by container ships or other specialized ships. In addition, the three regions also serve as destinations for raw materials transported by bulk ships from other regions, such as Australia (Stopford, 2009).

Ships engaged in maritime trade have the choice of alternative shipping routes to sail from one port to another. Some shipping routes provide the opportunity to shorten the

---

<sup>1</sup> The International Maritime Organization, which is an agency of the United Nations concerned with safety, security, and environmental issues of international shipping, counts 170 Member States and three Associate Members (<http://www.imo.org/About/Membership/Pages/Default.aspx>).



distance by using passageways, such as the Panama Canal, the Suez Canal, or the Kiel Canal. In this context, questions arise that deal not only with the demand side of using such passageways, but also with the supply side of providing such passageways. Research focuses mostly on the competitiveness of certain shipping routes from an operator's point of view (Notteboom, 2012, Lasserre and Pelletier, 2011, Schøyen and Bråthen, 2011, Liu and Kronbak, 2010, Somanathan et al., 2009, 2007, Baird, 2006). Liu and Kronbak (2010), for example, deal with the economic potential of the Northern Sea Route (NSR) as an alternative transit route to the Suez Canal route. But there is also some research that focuses on the competitiveness of shipping routes from a canal authority's point of view (Hutchinson, 1912, Böhme and Sichelschmidt, 1997). Hutchinson (1912) deals with the Panama Canal. He investigates the US government's action to exclude coastwise shipping from paying charges and offset the decrease in revenue by increasing the charges for international shipping. His results indicate that the resulting loss will not be offset by such a policy. Böhme and Sichelschmidt (1997) deal with the factors that cause the Kiel Canal's balance sheet loss in order to determine how to lessen the loss. They find that the main way to lessen the loss is to reduce costs rather than to increase revenue. However, neither they nor anyone else provide an analysis of how to set optimal transit charges from a canal authority's point of view. This is what the first paper aims to do.

The paper presented in Part I (the first paper in the dissertation) is entitled "Determining optimal Transit Charges: The Kiel Canal in Germany." It was coauthored by Katrin Rehdanz and Ulrich Schmidt and deals with regulating the transit charges levied by an international waterway in the context of price discrimination, namely the Kiel Canal in Germany, which connects ports on the Baltic Sea with the rest of the world. The Kiel Canal is the most-used artificial waterway in the world, but despite this fact, it generates a balance sheet loss (WSD Nord, 2011). Its revenues, which are mainly generated by the transit charge, do not cover its operating expenses. This situation raises the question if and how the current charging system could be redesigned to make the canal generate a balance sheet profit. In this paper, the focus is solely on the canal's revenue. Because the canal is a monopoly that allows, in principle, for perfect price discrimination, the current charging system is contrasted with an optimal charging system based on the willingness-to-pay (WTP) approach. A general approach to

calculate optimal transit charges is devised and applied in a case study that includes four ship types on three routes. The findings of the case study indicate that, in principle, much higher revenues could be generated if the transit charges were based not only on ship size but also on fuel prices and a ship's departure and destination ports, as these affect a ship's costs in terms of fuel costs and required sailing time.

## *Part II*

Combating climate change is one of the major global challenges that mankind faces today and in the future. Deep cuts in greenhouse gas emissions, in particular in anthropogenic CO<sub>2</sub> emissions, are necessary in order to prevent climate change to unfold its dangerous impacts (IPCC, 2007, UNFCCC, 2010). Therefore, decarbonization policies urgently need to be aimed at the shipping sector for two reasons. First, the shipping sector relies on heavy fuel oil, which is emission-intensive, and, second, it is projected to grow in the coming decades, thus causing more emissions (Gilbert and Bows, 2012).

Nevertheless, environmental issues, e.g., issues related to the emissions caused by ships, did not receive much attention until fairly recently (Stopford, 2009). The reasons for this are pointed out by Gilbert and Bows (2012):

*“Treating climate change as a central environmental concern has come relatively late in the day for the shipping sector for a combination of reasons: more obvious local pollutants, its omissions from national inventories under the Kyoto Protocol, its importance in globalization and its reputation as the most energy efficient mode of freight transport.” (p. 613)*

The newly emerging concern to regulate the shipping sector's CO<sub>2</sub> emissions was spawned to a large extent by the Second IMO GHG Study 2009 (Buhaug et al., 2009) of the International Maritime Organization (IMO) on greenhouse gases (GHG) in the shipping sector. This study presented two important insights. First, the shipping sector generated about 3.3% of global GHG emissions in 2007, which is more than what was assumed before.<sup>2</sup> Second, the shipping sector's CO<sub>2</sub> emissions are projected to increase significantly in the coming decades if its CO<sub>2</sub> emissions remain unregulated (Buhaug et

---

<sup>2</sup> In addition, the shipping sector was one of the world's major CO<sub>2</sub> emitters in 2007 (evidenced by comparing the shipping sector's CO<sub>2</sub> emissions in 2007 (Buhaug et al., 2009) with data on CO<sub>2</sub> emissions from fuel combustion per country in 2007 (IEA, 2009).

al., 2009). The consequence would be that in the next decades the shipping sector's CO<sub>2</sub> emissions would constitute a considerable proportion of the maximum allowed emissions, i.e., the maximum emissions that are in line with the United Nations Framework Convention on Climate Change's (UNFCCC) 2°C target (UNEP, 2011). As a consequence other sectors would have to emit less to offset the increase in shipping CO<sub>2</sub> emissions.

These insights have sparked discussions on how to regulate the shipping sector's CO<sub>2</sub> emissions, which are continuing not only in the IMO, but also in the scientific community, and which center around the question whether this sector should be subject to an emission cap or whether it should be subject to some other means of reducing emissions (UNEP, 2011). However, a final decision has not been reached yet.

The literature related to shipping sector's CO<sub>2</sub> emissions can be split into two broad bodies of literature. The first discusses the pros and cons of various options to allocate shipping emissions to countries and on the effects of the various options on specific country groups. Research on this matter has been qualitative (Åhman, 2008, Kågeson, 2008, Zetterberg, 2008, Faber et al., 2007, Bode et al., 2002) and quantitative (Gilbert and Bows, 2012, Wang, 2010, Faber et al., 2009, den Elzen et al., 2007). Nevertheless, there are some options that have not yet been assessed by the existing quantitative literature. In order to obtain an overall picture, an analysis and comparison of all the options becomes necessary. This is what the second paper of the dissertation aims to do.

The second body of literature presents technical abatement potentials and the costs of different measures (Faber et al., 2011/Wang et al., 2010,<sup>3</sup> Eide et al. 2011, 2009, Longva et al., 2010, Buhaug et al., 2009, Faber et al., 2009). However, the literature on how much the shipping sector should contribute to global emission reductions from an efficiency point of view remains limited.<sup>4</sup> Further, whether CO<sub>2</sub> emissions should be regulated at all depends on the potential cost savings. This is what the third and fourth papers of the dissertation aim to determine. The third paper focuses on global climate change policy and the fourth on the European Union climate change policy.

---

<sup>3</sup> Note that Faber et al. (2011) is an updated version of Wang et al. (2010), but that only the later provides data that we make use of in this paper.

<sup>4</sup> Only Eide et al. (2009) derive a decision criterion for regulating CO<sub>2</sub> emissions in the shipping sector that is in line with the 2°C target.

The first paper presented in Part II (the second paper in the dissertation) is entitled “Accounting for Carbon Dioxide Emissions from International Shipping: Burden Sharing under Different UNFCCC Allocation Options and Regime Scenarios.” It was coauthored by Setareh Khalilian and frames the discussions about regulating CO<sub>2</sub> emissions within the framework of the UNFCCC. In this paper, the various options suggested by the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UNFCCC for allocating CO<sub>2</sub> emissions generated by the international shipping sector to individual countries are investigated. Economic and regulatory issues related to these options and the consequences of applying them are discussed. The various options are evaluated on the basis of environmental effectiveness, feasibility of legal implementation, and the fairness of burden sharing. The paper concludes that the international shipping sector’s emissions should be allocated on the basis of the operating company.

The second paper presented in Part II (the third paper in the dissertation) is entitled “The Potential Contribution of the Shipping Sector to an Efficient Reduction of Global Carbon Emissions.” It was coauthored by Sonja Peterson and analyzes how much the shipping sector could contribute to global CO<sub>2</sub> emission reductions from an efficiency point of view. To do this, a marginal abatement cost curve (MACC) for the shipping sector is generated that can be combined with a MACC for conventional CO<sub>2</sub> abatement in the production and consumption sectors around the world. These two MACCs are used to assess the following as regards the various global reduction targets: (a) what the maximum global cost savings would be that could be achieved by abating emissions in the shipping sector, (b) how much the shipping sector could contribute to abating emissions cost efficiently, and (c) what the potential additional costs of implementing a separate solution for the shipping sector would be. The focus is on the year 2020. The findings are that the shipping sector could always contribute to efficient global emission reductions and thus could always achieve global cost savings, but also that the size of the contribution and the size of cost savings depend heavily on the MACC case assumed, i.e., on how the existence of negative abatement costs is treated in a MACC, and on the reduction potentials and costs of measures assumed.

The third paper presented in Part II (the fourth paper in the dissertation) is entitled “Including Maritime Transport in the EU’s Climate Change Policy: Country-Based

Allocation and Effects”. This paper analyzes an option to include the shipping sector’s emissions in the EU’s greenhouse gas reduction commitment for 2020 that is based on the nationality of a ship, namely the nationality of the ship owner, the nationality of the ship operator, and the flag state registration. In doing so, emissions generated by ships owned, operated, or flagged by the 27 EU countries are allocated to the EU’s total GHG emissions. First, the effects on the reduction commitment caused by the three allocation ways are analyzed. Then, marginal abatement cost curves (MACCs) are used in order to determine how much the shipping sector of the 27 EU countries, defined by the three allocation ways, could contribute efficiently to a total given emission reduction target for all sectors in the EU. Moreover, MACCs are used in order to determine if some country fleets could reduce emissions in the shipping sector relatively more efficient than other countries under a given emission reduction target for all sectors. The findings indicate that the increase in the amount of required emission reductions and resulting abatement costs are in particular pronounced if the allocation ways owner and operator are applied and the more ambitious approach (partial integration approach) is chosen. Moreover, the findings indicate that the shipping sector could contribute efficiently to emission reductions (at most by 8.5%) if it was included in reduction efforts, and that the composition of both the individual country fleets and efficient measures applied to them is on average the same.

## References

- Åhman, M., 2008. Why International Transport Needs a Sectoral Approach. In Egenhofer C (ed.). *Beyond Bali – Strategic Issues for the Post-2010 Climate Change Regime*. Ch. 11, pp. 146–155. Brussels: Centre for European Policy Studies.
- Baird, A.J., 2006. Optimising the Container Transshipment Hub Location in Northern Europe. *Journal of Transport Geography* 14: 195–214.
- Bode, S., Isensee, J., Krause, K., Michaelowa, A., 2002. International Climate Policy: Analysis of Ecological, Technical and Economic Implications for International Maritime Transport. *Journal of Maritime Economics* 4 (2): 164–184.
- Böhme, H., Sichelschmidt, H., 1997. *Der Nord-Ostsee-Kanal in der Krise. Ein Plädoyer für eine Reform*. Kieler Diskussionsbeiträge 290. Kiel: Institut für Weltwirtschaft.
- Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Markowska, A.Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W–Q., Yoshida, K., 2009. *Second IMO GHG Study*. London: International Maritime Organization (IMO).
- den Elzen, M., Olivier, J., Berk, M., 2007. *An Analysis of Options for Including International Aviation and Marine Emissions in a post-2012 Climate Mitigation Regime*. MNP Report 500114007/2007. Bilthoven: Netherlands Environmental Assessment Agency.
- Eide, M.S., Endresen, Ø., Skjong, R., Longva, T., Alvik, S., 2009. Cost-effectiveness Assessment of CO<sub>2</sub> Reducing Measures in Shipping. *Maritime Policy and Management* 36 (4): 367–384.
- Eide, M.S., Longva, T., Hoffmann, P., Endresen, Ø., Dalsøren, S.B., 2011. *Future Cost Scenarios for Reduction of CO<sub>2</sub> Emissions*. *Maritime Policy and Management* 38 (1):11–37.
- Faber, J., Boon, B., Berk, M., den Elzen, M., Olivier, J., Lee, D., 2007. *Aviation and Maritime Transport in a post 2012 Climate Policy Regime*. Report 500102 008. Bilthoven: Netherlands Environmental Assessment Agency.  
<http://www.rivm.nl/bibliotheek/rapporten/500102008.pdf> (accessed 4/12/2010).
- Faber, J., Markowska, A., Nelissen, D., Davidson, M., Eyring, V., Cionni, I., Selstad, E., Kageson, P., Lee, D., Buhaug, Ø., Lindstad, H., Roche, P., Humpries, E., Graichen, J., Cames, M., Schwarz, W., 2009, *Technical Support for European Action to Reducing Greenhouse Gas Emissions from International Maritime Transport*. Delft: CE Delft.

[http://www.ce.nl/publicatie/technical\\_support\\_for\\_european\\_action\\_to\\_reducing\\_green\\_house\\_gas\\_emissions\\_from\\_international\\_maritime\\_transport/1005S](http://www.ce.nl/publicatie/technical_support_for_european_action_to_reducing_green_house_gas_emissions_from_international_maritime_transport/1005S)  
(accessed 04/12/2010).

Faber, J., Wang, H., Nelissen, D., Russel, B., St Amand, D., 2011. Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures. MEPC 62 INF 7.  
<http://www.imarest.org/LinkClick.aspx?fileticket=5kj0E0WMK8w%3D&tabid=878>  
(accessed 11/14/2011).

Gilbert, P., Bows, A., 2012. Exploring the Scope for Complementary Sub-global Policy to Mitigate CO<sub>2</sub> from Shipping. *Energy Policy* 50: 613–622.

Hutchinson, L., 1912. Panama Canal Tolls and the Theory of Monopoly Prices. *The Economic Journal* 22: 563–569.

IEA (International Energy Agency), 2009. CO<sub>2</sub> Emissions from Fuel Combustion, 2009 Edition. Paris: IEA.

IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC.

Kågeson, P., 2008. The Maritime Emissions Trading Scheme. Stockholm: Nature Associates.  
<http://www.natureassociates.se/pdf/METS%20final.pdf> (accessed 11/23/2009).

Lasserre, F. and Pelletier, S., 2011. Polar Super Seaways? Maritime Transport in the Arctic: An Analysis of Shipowners' Intentions. *Journal of Transport Geography* 19: 1465–1473.

Liu, M., Kronbak, J., 2010. The Potential Economic Viability of Using the Northern Sea Route (NSR) as an Alternative Route between Asia and Europe. *Journal of Transport Geography* 18: 434–444.

Longva, T., Eide, M.S., Skjong, R., 2010. Determining a Required Energy Efficiency Design Index Level for New Ships Based on a Cost-effectiveness Criterion. *Maritime Policy and Management* 37 (2): 129–143.

Notteboom, T.E., 2012. Towards a New Intermediate Hub Region in Container Shipping? Relay and Interlining via the Cape Route vs. the Suez Route. *Journal of Transport Geography* 22: 164–178.

Schøyen, H. and Bråthen, S., 2011. The Northern Sea Route versus the Suez Canal: Cases from Bulk Shipping. *Journal of Transport Geography* 19: 977–983.

Somanathan, S., Flynn, P.C., Szymanski, J.K., 2009. The Northwest Passage: A Simulation. *Transportation Research Part A* 43: 127–135.

Somanathan, S., Flynn, P.C., Szymanski, J.K., 2007. Feasibility of a Sea Route Through the Canadian Arctic. *Maritime Economics and Logistics*: 324–334.

Stopford, M., 2009. *Maritime Economics*, 3rd Edition. New York: Routledge.

UNCTAD (United Nations Conference on Trade and Development), 2008. *Review of Maritime Transport 2008*. New York and Geneva: UNCTAD.

UNCTAD, 2011. *Review of Maritime Transport 2010*. New York and Geneva: UNCTAD.

UNEP (United Nations Environment Programme), 2011. *Bridging the Emissions Gap*. UNEP.

[http://www.unep.org/pdf/UNEP\\_bridging\\_gap.pdf](http://www.unep.org/pdf/UNEP_bridging_gap.pdf)  
(accessed 06/05/12).

UNFCCC (United Nations Framework Convention on Climate Change), 2010. *Report of the Conference of the Parties on its Fifteenth Session, Held in Copenhagen from 7 to 19 December 2009. Part Two: Action Taken by the Conference of the Parties at its Fifteenth Session*. FCCC/CP/2009/11/Add.1. 30 March 2010.

Wang, H., 2010. Economic Costs of CO<sub>2</sub> Emissions Reduction for Non-Annex I Countries in International Shipping. *Energy for Sustainable Development* 14: 280–286.

Wang, H., Faber, J., Nelissen, D., Russel, B., St Amand, D., 2010. *Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures*. MEPC 61 INF 18.  
[http://www.cedelft.eu/publicatie/marginal\\_abatement\\_costs\\_and\\_cost-effectiveness\\_of\\_energy-efficiency\\_measures/1090](http://www.cedelft.eu/publicatie/marginal_abatement_costs_and_cost-effectiveness_of_energy-efficiency_measures/1090) (accessed 11/14/2011).

WSD Nord (Wasser- und Schifffahrtsdirektion Nord), 2011. *Einnahmen und Ausgaben der Jahre 2005–2010*. Kiel: WSD Nord.

Zetterberg, L., 2008. How to Integrate International Aviation and Shipping into a Global Emissions Trading System. In Egenhofer C (ed.). *Beyond Bali – Strategic Issues for the Post-2010 Climate Change Regime*. Ch. 12, pp. 156–162. Brussels: Centre for European Policy Studies.



Part I  
Price Discrimination

Paper I: Determining Optimal Transit Charges:  
The Kiel Canal in Germany

Heitmann, N., Rehdanz, K., Schmidt, U., 2013.  
Determining Optimal Transit Charges: The Kiel Canal in Germany,  
Journal of Transport Geography 26: 29–42.

# Determining Optimal Transit Charges: The Kiel Canal in Germany<sup>\*</sup>

Nadine Heitmann<sup>a</sup>, Katrin Rehdanz<sup>a,b</sup>, and Ulrich Schmidt<sup>a,b</sup>

<sup>a</sup> Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

<sup>b</sup> Department of Economics, Christian-Albrechts-University of Kiel, Wilhelm-Seelig-Platz 1,  
24118 Kiel, Germany

## Abstract

The Kiel Canal in Germany connects ports on the Baltic Sea with the rest of the world and is the most-used artificial waterway in the world. Despite this fact, it generates a balance sheet loss. Revenues, which are mainly generated by the transit charge, do not cover its operating expenses. This situation raises the question how the current charging system could be redesigned to make the canal generate a balance sheet profit.

In this paper, we focus solely on the canal's revenue. Because the canal is a monopoly that allows, in principle, for perfect price discrimination, we contrast the current charging system with an optimal charging system based on the willingness-to-pay (WTP) approach. We devise a general approach to calculate optimal transit charges and apply it in a case study that includes four ship types on three routes. The findings of the case study indicate that, in principle, much higher revenues could be generated if the transit charges were based not only on ship size but also on fuel prices and a ship's departure and destination ports, as these affect a ship's costs in terms of fuel costs and required sailing time.

**Keywords:** Optimal transit charge, Kiel Canal, shipping cost, Germany, price discrimination

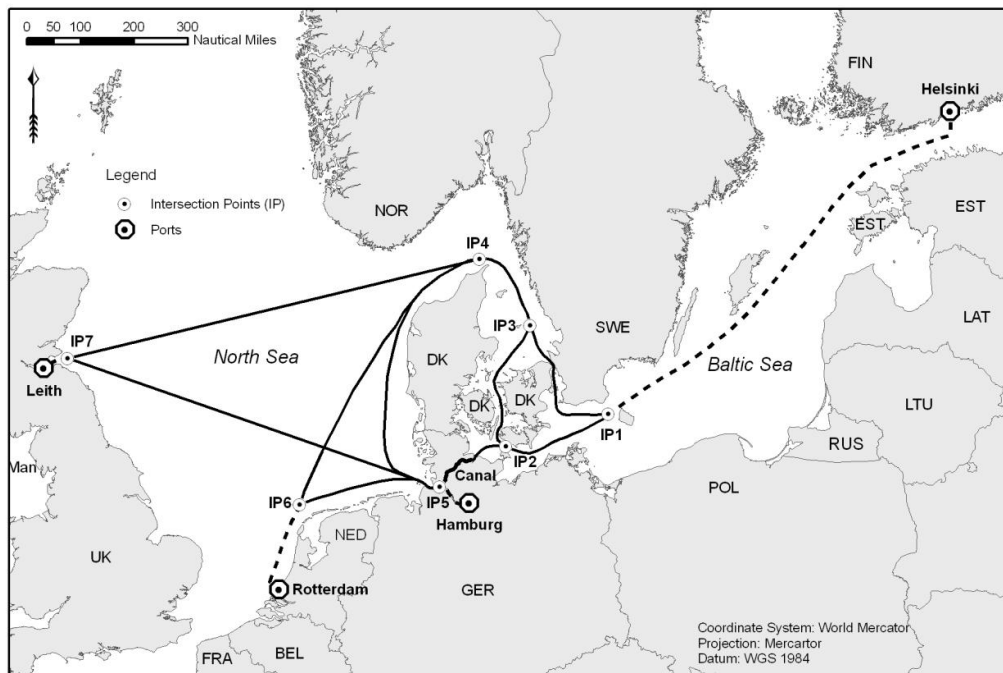
**JEL classification:** R48, L92

---

<sup>\*</sup> We would like to thank the editor and two anonymous referees for their helpful suggestions and comments. We would also like to thank the WSD Nord, particularly Daniela Nissen, Andrea Stölting, Christina Ruh, and Martin Abratis, for providing statistics on the Kiel Canal. Moreover, we would like to thank Markus Pape for programming advice and Hendrik Goll and Katja Dreßler for their research assistance. The German Research Foundation (DFG) provided welcome financial support through The Future Ocean Cluster of Excellence.

## 1. Introduction

Maritime transportation of goods is a costly business. Major determinants of the costs are fuel consumption and the time it takes a ship to sail from one port to another. Ships operating between ports of the Baltic Sea and the rest of the world, for example, have the choice of alternative passageways to leave or enter the Baltic Sea. They can use the Kiel Canal passageway, the most-used artificial waterway in the world<sup>1</sup> and, according to Knowles (2006a), one of the world's strategic ship canals, or one of the two natural passageways around Denmark: through the Great Belt passageway or through the Øresund passageway. Sailing through the Kiel Canal saves, on average, 250 nautical miles<sup>2</sup> and, depending on the type of ship, up to several hours.<sup>3</sup> Figure 1 shows the three alternative passageways for four ports in the region.<sup>4</sup>



**Figure 1:** Shipping routes and alternative passageways. *Source:* Own presentation based on ESRI Base Map; Shipping routes are based on Kerbaol and Hajduch (2009) and Helcom (2011).

<sup>1</sup> <http://www.kiel-canal.org/english.htm>.

<sup>2</sup> *ibid.*

<sup>3</sup> For example, a 1,400 TEU container ship on the route Helsinki-Rotterdam would save about 8.5 hours if the Kiel Canal were used instead of the Great Belt passageway.

<sup>4</sup> We define route as the connection between ports, and passageways as the alternative ways on that route.

The Kiel Canal is used by roughly the same number of ships as the Panama Canal and Suez Canal<sup>5</sup> taken together, but handles significantly less cargo tonnage. 43,378 ships transporting 99.78 million tonnes of cargo passed the Kiel Canal in 2007, (WSD Nord, 2011b).<sup>6</sup> In comparison, during the same year, 14,721 ships transporting 208.2 million tonnes of cargo passed through the Panama Canal (Panama Canal Authority, 2009), and 20,384 ships transporting 848.2 million tonnes of cargo passed through the Suez Canal.<sup>7</sup>

Despite the large amount of ship traffic the Kiel Canal handles, it nevertheless generates a balance sheet loss. Its revenues, which are mainly generated by the transit charge (charged by the Waterways and Shipping Authority North (WSD Nord)), do not cover its operating expenses. The transit charge is determined by the gross tonnage (gt) of a ship and includes up to four components, such as a transit toll, a pilotage due, a pilotage fee, and a helmsmen fee.<sup>8</sup> The last two components (pilotage fee and helmsmen fee) are passed on to the pilots and helmsmen for providing their services.<sup>9</sup> The pilotage due is used by the WSD Nord to maintain the pilotage facilities.<sup>10</sup> The WSD Nord relies mainly on the transit toll to cover expenses such as investments in extensions, operating and maintenance costs, and administrative costs.<sup>11</sup> Revenues in the period 2005–2010 covered only between 14% and 30% of expenses (WSD Nord, 2011a). The difference was covered by funds provided by the federal government. This loss and the current discussion on further widening and deepening of the Kiel Canal raise the question whether the current transit charges collected by the WSD Nord are too low and could be raised.

---

<sup>5</sup> The Panama Canal links the Pacific Ocean with the Caribbean. The Suez Canal links the Mediterranean with the Red Sea/Indian Ocean. Both canals provide the opportunity to significantly shorten the distance of shipping routes (Knowles, 2006a).

<sup>6</sup> This includes 39,239 cargo (bulker, tanker, etc.) and 4,139 non-cargo ships (fishing ships, service ships, etc.), but excludes 14,865 small boats (sailing boats etc.).

<sup>7</sup> <http://www.suezcanal.gov.eg/TRstat.aspx?reportId=3>.

<sup>8</sup> The German terms distinguish between fees that are regulated by public law and fees that are regulated by private law. The transit toll (Befahrensabgabe) and the pilotage due (Lotsenabgabe) are regulated by public law, whereas the pilotage fee (Lotsengeld) and the helmsmen fee (Kanalsteuergeld) are regulated by private law. We follow the official English translation of the WSD Nord to emphasize that differences in terms exist.

<sup>9</sup> Pilots and helmsmen are not employed by the WSD Nord. Pilots work freelance in accordance with §21 Seelotsgesetz (SeeLG, 2010) and helmsmen are organized in a registered association (<http://www.kanalsteuerer.de/index.html>).

<sup>10</sup> In accordance with Seelotsgesetz § 6 (SeeLG, 2010).

<sup>11</sup> In accordance with Seeaufgabengesetz §13 (SeeAufgG, 2008). Note that the WSD Nord collects additional revenues in the form of fines, grants, refundings, and other fees, but that these additional revenues are of minor importance.

The Kiel Canal is a monopoly that allows, in principle, for perfect price discrimination. Under perfect price discrimination, a monopolist charges according to the willingness-to-pay (WTP) of each customer (Besanko and Braeutigam, 2005). WTP is the maximum price the customer is willing to pay for a good, i.e., the customer is just indifferent between buying the good at his/her WTP and not buying the good at all. We define the WTP as the optimal price. Applied to the Kiel Canal, optimal pricing under perfect price discrimination implies charges that amount to the total cost savings a ship operator realizes when choosing the route via the Kiel Canal instead of the one around Denmark. These cost savings result mainly from reduced sailing time and reduced consumption of bunker fuel.

The first paper analyzing this topic with the theory of price discrimination was by Hutchinson (1912), who considered the Panama Canal. He investigated the US government's action to exclude coastwise shipping from paying charges and offset the decrease in revenue by increasing the charges for international shipping. His results indicate that the resulting loss would not be offset by such a policy. Despite Hutchinson's early analysis, the literature related to this field of research remains limited. Most of the literature studies the competitiveness of certain shipping routes from an operator's point of view (Notteboom, 2012, Lasserre and Pelletier, 2011, Schøyen and Bråthen, 2011, Liu and Kronbak, 2010, Somanathan et al., 2007, 2009). Liu and Kronbak (2010), for example, study the economic potential of the Northern Sea Route (NSR) as an alternative transit route to the Suez Canal route. Their results indicate that the ice-breaking fee is one of the main factors influencing the competitiveness of the NSR.

Two studies exist that look at the Kiel Canal. Baird (2006) analyzes transport-distance-associated costs for established and potential alternative hub locations to find the optimal hub location for northern Europe. Thereby, he includes the current Kiel Canal transit charge into his cost calculations. He finds that using established hub locations, including Rotterdam and Hamburg, to serve the Baltic Sea region via feeder shipping routed through the Kiel Canal, is more costly than using the alternative hub location Orkney, located in the north of Scotland, to serve the Baltic Sea region via feeder shipping routed around Denmark.

Böhme and Sichelschmidt (1997) analyze the factors that cause the Kiel Canal's balance sheet loss in order to determine how to decrease the loss. They find that the main way to leverage the loss is to reduce costs rather than to increase revenue. We build upon their results but also challenge them by analyzing the revenue part of the profit equation in more depth.

We contribute to the existing literature by taking the point of view of the canal authority to determine the optimal canal transit charges under perfect price discrimination. Charging the cost difference yields the maximum revenue for the canal authority.

The paper is structured as follows. Section 2 presents information on the Kiel Canal, including its history, traffic data, and transit charge system. Section 3 introduces a general approach to calculate optimal transit charges. Section 4 presents the design of a case study based on four ship types that typically use the Kiel Canal on three routes and the data used. Section 5 presents the results of the case study. Section 6 discusses the results. The final section, Section 7, concludes.

## **2. The Kiel Canal**

### ***2.1 History***

In the past, the route around Denmark was considered to be a time-consuming and difficult shipping route. At that time, the main trade routes were land routes between Italian ports and the North Sea and Baltic Sea ports. But after the discovery of America and the route to India, shipping to and from the North Sea ports gained momentum. Ships from America, India, and Africa started to transport goods to ports of the North Sea, since it was more cost effective than to transport goods over land. Due to an increased interest in trading with the states in the Baltic Sea region, there was a need for a short and safe waterway connecting the North Sea with the Baltic Sea. This need was originally fulfilled by the Eider Canal, which was opened in 1784.<sup>12</sup> It went from the Kiel Bay to Rendsburg, where it merged with the Eider, which finally provided access to the North Sea. However, by the middle of the 19th century, the Eider Canal was no

---

<sup>12</sup> The Eider Canal had a width of 29 m, a depth of 3 m, and could handle ships up to a maximum of 300 tons (<http://www.kiel-canal.de/kiel-canal/history/index.htm>).

longer able to handle the growing number and size of naval and merchant ships. Thus, construction work on the Kaiser-Wilhelm Canal was begun in 1887 and it was opened in 1895. It was declared, by the Treaty of Versailles, to be an international waterway in 1919 and since then has been known internationally as the Kiel Canal (Wulle, 1927).<sup>13</sup>

In the following years, the number and size of naval and merchant ships continued to grow and the volume of traffic thus increased considerably, by 66%, or from 19,960 to 33,158 ships, in the period 1896–1906 (Wulle, 1927). Therefore, in recent decades the canal has been widened and deepened several times.<sup>14</sup> The most recent planning phase to widen and deepen the canal and to build a new lock began in 2008, but construction work has not started yet.<sup>15</sup>

## ***2.2 Traffic data***

Today the Kiel Canal, which is approximately 99 km long, has a general width of 162 m (in places only 102.5 m) at the waterline, a general width of 90 m (in some places only 44 m) at the bottom, and a depth of 11 m. It is the most traveled artificial waterway in the world: 40,105 ships per year, on average, passed through it in the period 2005–2009 (WSD Nord, 2011b).<sup>16</sup> Traffic on the canal is predominantly transit traffic, i.e., it consists of ships passing completely through the canal in transit. Transit traffic amounted to approximately 30,500 ships per year, on average, in the period 2005–2009. Section traffic, i.e., traffic consisting of ships that leave from or call at a port in the canal, or travel from one port to another in the Canal, amounted to approximately 9,500 ships per year, on average, in the same period (Figure 2).

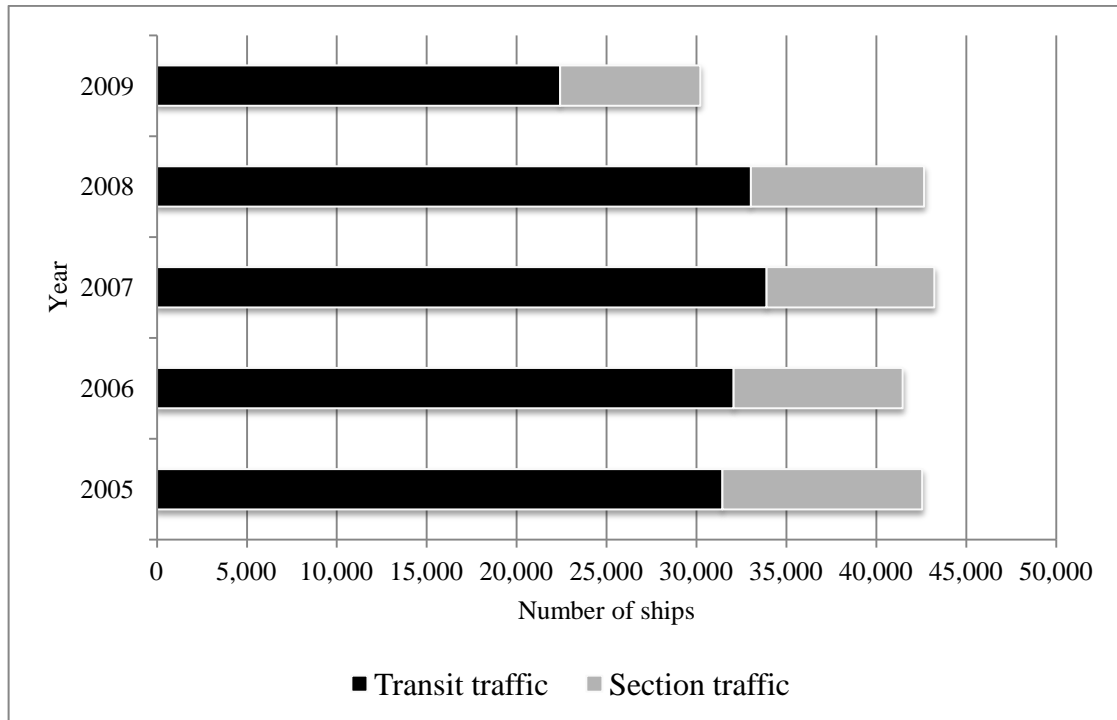
---

<sup>13</sup> The Kaiser-Wilhelm Canal was renamed the Nord-Ostsee-Kanal in 1948 (<http://www.kiel-canal.org/english.htm>).

<sup>14</sup> The first time construction work took place from 1907 to 1914. The second time it took place from 1965 to 2000 (<http://www.wsa-kiel.wsv.de/Kanal/index.html>).

<sup>15</sup> [http://www.wsa-kiel.wsv.de/ausbau\\_nok/](http://www.wsa-kiel.wsv.de/ausbau_nok/). It is planned to deepen the canal 1 m and to widen it from 44 m to 70 m at its current bottleneck (Oststrecke) so that ships of a maximum allowed length of 280 m, a beam of 40 m, and a draught of 9.5 m are able to use the canal after the construction work has finished.

<sup>16</sup> Small boats are omitted, although their share in total traffic is not negligible. For example, in 2008, an average of 117 merchant and non-cargo ships and about 43 small boats used the canal per day (transit and section traffic) (WSD Nord, 2011b). In addition, cruise ships are less common on the Kiel Canal, e.g., 119 canal transits of cruise ships were counted in 2010.



**Figure 2:** Traffic through the Kiel Canal (2005–2009). *Source:* Own presentation based on data from WSD Nord (2011b).

For comparison, total traffic around Denmark amounted to 54,492 ships per year, on average, for the same period (2005–2009), see Table 1.

**Table 1:** Total traffic around Denmark and total traffic through the Kiel Canal (2005–2009).

Year	Denmark	Kiel Canal	Total overall	% Kiel Canal
2005	39,521	42,552	82,073	52
2006	52,075	41,472	93,547	44
2007	59,721	43,378	103,099	42
2008	58,402	42,811	101,213	42
2009	62,743	30,314	93,057	33
Ø 2005-2009	54,492	40,105	94,598	42

*Source:* Own presentation based on data from WSD Nord (2011b).

The reasons for traveling around Denmark are manifold. Ships may be simply too large to use the Kiel Canal.<sup>17</sup> The maximum allowed length and beam of ships using the

<sup>17</sup> Note that ships traveling around Denmark can travel either through the Great Belt or through the Øresund. The Great Belt has a height constraint for shipping of 65 m and a draught constraint of 17 m whereas the Øresund Bridge has a clearance of 57 m (55 m above high water mark) and a draught



canal is 235 m and 32 m, respectively (WSD Nord, 2001).<sup>18</sup> But more importantly, a significant number of ships make weekly round trips from and to ports on a fixed schedule and a fixed route and thus are not free to choose between different routes. Another reason is that the demand for maritime transportation decreased sharply during the recession in 2009 and led to overcapacities in the market. Ship operators reacted by laying-up ships, reducing services, or by slow steaming, which reduces fuel consumption and overcapacity (UNCTAD, 2011). As a consequence, maritime transportation became so cheap that the passageways around Denmark become more attractive economically. The volume of traffic (transit and section) through the canal decreased by 29% between 2008 and 2009 (see Table 1). This decrease was more pronounced in transit traffic than in section traffic (Bösl, 2010).

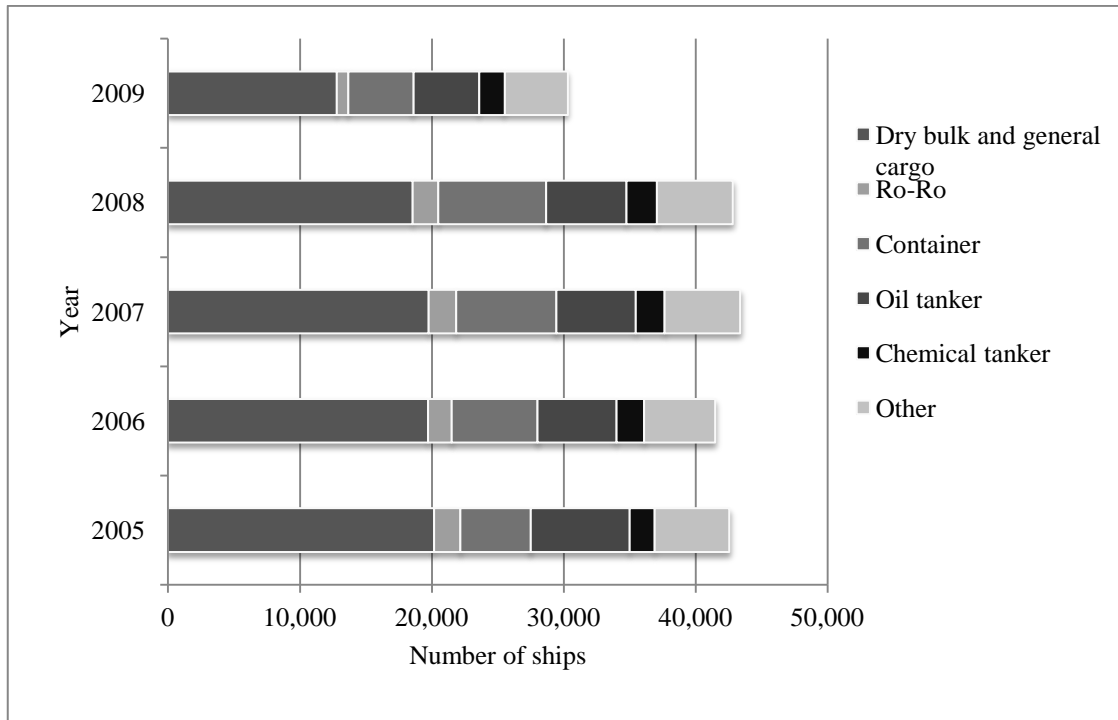
Analyzing traffic through the Kiel Canal by ship type reveals that the canal is mainly used by merchant ships.<sup>19</sup> Figure 3 shows that general cargo ships (including dry bulk carriers) clearly make up the largest portion of the merchant ships (45%) using the canal, followed by container ships (16%), and oil tankers (15%). Non-cargo ships, e.g., such as fishing, naval, or service ships, account only for approximately 10 percent of total ship traffic. Most of the ships using the canal have a tonnage of 2,501–6,000 gt. Ships smaller than 700 gt or larger than 10,000 gt are much less common on the canal (WSD Nord, 2011b). PLANCO (Meesenburg et al., 2010) estimates that about 50,000 merchant ships will transit the Kiel Canal per year by 2025, with an increase in general cargo ships (including dry bulk carrier) and container ships.

---

constraint of 8.4 m whilst Øresund's Drogden channel between Amager and Saltholm has no height constraint but a draught constraint of 8 m over the Øresund Tunnel (Helcom, 2009, Knowles, 2000, Knowles, 2006b).

<sup>18</sup> Ships with a length and beam larger than 235 m and 32 m, respectively, could be classified as medium-sized or large-sized ships. For example, a Panamax bulk carrier (60,000–79,999 dwt) has a beam of 32 m and a Sub-Panamax (container with 2,000–2,999 TEU) has a beam of 31 m (Stopford, 2009). Helcom (2009) provides numbers for ships passing the Skaw (Denmark) according to their draught. The majority of ships (where the draught is known) has a draught of less than 7 m. Thus, the number of larger ships in total traffic between the Baltic Sea and North Sea could be assumed to be small compared to small or small middle-sized ships.

<sup>19</sup> Here the term “merchant ships” includes general cargo ships (including dry bulk carrier), ro-ro ships, container ships, passenger ships, crude oil tankers, gas tankers, chemical tankers, and other tankers.



**Figure 3:** Types of ships using the Kiel Canal (2005–2009). *Source:* Own presentation based on data from WSD Nord (2011b).

### 2.3 Transit charge system

The transit charge to travel through the canal includes, as mentioned in the introduction, up to four components: a transit toll, a pilotage due, a pilotage fee, and a helmsmen fee.<sup>20</sup> These are charged according to a ship's characteristics, e.g., its length, width, and draught and the classification of its cargo (whether or not it is classified as dangerous or environmentally hazardous goods).<sup>21</sup> The amount that has to be paid for each component depends on a ship's gross tonnage. Sport boats, unmotorized boats, and ships with a gross tonnage of 300 or less pay the transit toll only. All other ships, excluding the service ships of the WSD Nord, are obliged to pay the transit toll and the pilotage due<sup>22</sup>. Pilotage and helmsmen fees are charged if a ship exceeds predefined dimensions.<sup>23</sup> There are, however, several exceptions, and discounts exist. For example, a feeder ship that travels the canal on a regular basis per year is eligible for a discount of up to 50%

<sup>20</sup> NOKBefAbgV (2003), LTV (2010), Kanalsteuertarifverordnung (2010).

<sup>21</sup> Ships are classified according to six different traffic groups (so-called Verkehrsgruppen 1–6). This classification helps the canal's traffic controllers plan traffic through the canal to avoid collisions and to determine the transit charges.

<sup>22</sup> Pilotage dues are charged to provide pilotage facilities in a pilotage district (SeeLG, 2010 and LTV, 2010).

<sup>23</sup> See §42 Abs.5 SeeSchStrO (SeeSchStrO, 2006, NOK-LV, 2003, Bekanntmachung WSD Nord: Annahmepflicht Kanalsteurer).

on the transit toll.<sup>24</sup> Note also that in addition to the transit charge for the Kiel Canal, a pilotage due and a pilotage fee for the Kiel Bay (before entering/after leaving the canal) and the Elbe estuary (after entering/before leaving the canal) might be due (NOK-LV, 2003).

Pilotage dues and pilotage fees for the Kiel Canal are adjusted on a regular basis, e.g., the last two adjustments were in 2010 and 2011 (LTV, 2011, 2010). In contrast, transit tolls and helmsmen fees are adjusted much less frequently, e.g., the last two transit toll adjustments were made in 1996 and 2003 (NOKBefAbgV, 2003, 1996) and the last two helmsmen fee adjustments were made in 2004 and 2010 (Kanalsteuer-tarifverordnung, 2010, 2004).

### 3. Method

Sailing a specific route incurs costs in terms of required time, fuel consumption, and charges. A ship traveling from a Baltic Sea port to a North Sea port, or vice versa, can use one of three passageways on its route: the Kiel Canal, the Øresund, or the Great Belt passageway. The costs incurred by using a particular passageway differ for several reasons, e.g., navigational conditions (such as length, possible speed, or canal transit with reduced speed) that affect mainly the duration of a trip and a ship's fuel consumption. Thus, a ship operator would choose the passageway that incurs the least cost. From the point of view of the canal authority, the difference in costs between the passageways is the amount that would make a ship operator indifferent between using the Kiel Canal or one of the two passageways around Denmark. The difference in costs is the ship operator's WTP. Thus, we define the difference in costs as the optimal transit charge.

In order to calculate the optimal transit charge, the canal authority needs to determine the total costs associated with each of the three passageways.<sup>25</sup> Total costs of running a ship can be divided into five cost categories: (1) capital costs, (2) operating costs, (3) periodic maintenance costs, (4) voyage costs, and (5) cargo-handling costs (Stopford, 2009). Capital costs include interest and capital payments when debt financed, or dividend payments when equity financed. Operating costs include factors necessary for

---

<sup>24</sup> NOKBefAbgV (2003).

<sup>25</sup> Note that when calculating the optimal transit charge, the actual Kiel Canal transit charge is not part of the total costs per route when the Kiel Canal passageway is used.

the day-to-day running of a ship. It does not matter whether the ship is actually on a voyage. These factors include costs for manning, stores and consumables, maintenance and repairs, insurance, and general costs like registration fees. Periodic maintenance costs include interim dry-docking and major survey costs. Voyage costs include the fuel consumption of a ship whether it is at sea, in estuary (with possible speed restriction), in canal or in port. In addition, they include charges as well. Cargo-handling costs include loading and discharging costs, and any claims that may arise (Stopford, 2009).

To simplify calculations, the canal authority could assume that costs associated with port stopovers are generally the same, no matter which passageway is actually chosen. Thus, a part of the voyage costs (port costs including port charges and fuel consumption in port) and cargo-handling costs could be excluded from calculations. Then, total cost differences per route associated with one of the three passageways only include the remaining four cost components: (1) capital costs, (2) operating costs, (3) periodic maintenance costs, and (4) the remaining part of the voyage costs, in particular fuel costs and charges for entering a pilotage district. Capital costs, operating costs, and periodic maintenance costs could be taken together and defined as costs for providing a ship. Because it would be difficult for the canal authority to gather information on capital costs, operating costs, and periodic maintenance costs per ship, it could use time charter rates as a proxy for these costs. According to Baird (2006), time charter rates are a representative measure of the costs of providing a ship. Time charter rates are often based on a fixed per-day basis (\$/day). Thus, the canal authority needs to consider only the charter rate payment and the voyage costs of a ship on a specific route in their calculations.<sup>26</sup>

The charter rate payment depends on the charter rate per hour ( $char/24$ ) and the duration (*in hours*) of sailing a specific route ( $D_{ij,z}$ ). The voyage costs include bunker fuel costs per route ( $FuelC_{ij,z}$ ) and, if applicable, charges for entering a pilotage district ( $k$ ). The total costs per route ( $C_{ij,z}$ ) for a ship on a voyage from port  $i$  on the Baltic Sea to a port  $j$  on the North Sea via passageway  $z$ , with  $z = Kiel Canal, the Øresund or the Great Belt passageway$  can, therefore, be written as:

---

<sup>26</sup> We had preliminary communication with one operator and the Waterways and Shipping Authority North in order to identify the factors that operators take into account when selecting one of the three passageways.

$$C_{ij,z} = (\text{char} / 24) \cdot D_{ij,z} + \text{Fuel}C_{ij,z} + k \quad (1)$$

Knowing the total costs per route, the canal authority can calculate the difference in costs ( $C_{dif}$ ) between the alternative passageways to obtain the optimal transit charge ( $k_{tr}^*$ ):

$$k_{tr}^* = C_{dif} \quad (2)$$

More detailed information on the modeling approach is provided in Appendix A.

Given the geographical scope of our analysis, certain ports and route sections can be clustered to simplify the calculations, e.g., all ships coming from a port on the eastern Baltic Sea need to pass Bornholm before they enter one of the three passageways and, therefore, these ports can be clustered. For this reason, we define intersection points to calculate, for each route, the differences in costs associated with each of the three different passageways (Kiel Canal, the Great Belt, or the Øresund). The advantage of doing this is that instead of calculating the costs for the total length of the route three times for each of the different passageways and subtracting the three sets of costs from each other, only the costs for the diverging sections of the routes, i.e., the costs associated with each of the passageways, need to be calculated (see Figure 1, black lines).

The intersection point for all ships departing from or heading for one of the major ports on the eastern Baltic Sea (west of Bornholm, Denmark) is IP1 (see Figure 1 above). The intersection point for all ships departing from or heading for a North Sea port between Rotterdam and LeHavre (west of Eierland, Netherlands) is IP6.<sup>27</sup> The intersection point for all ships departing from or heading for the North Sea port of Hamburg is IP5. Other intersection points are defined for other routes such that the points are as close as possible to the ports, e.g., IP7 for Leith.

#### 4. Study design and data

The purpose of the study is to determine the optimal transit charge for specific ship types on specific routes and compare it to the actual transit charge in order to determine

---

<sup>27</sup> The intersection point would be further northwest for those ships required to use the deep water route.

whether the optimal transit charge system could increase the canal authority's revenues to mitigate its current balance sheet loss. We selected the following ships for our analysis: a 550 TEU container ship, a 1,400 TEU container ship, a handymax bulk carrier, and a container-oriented multipurpose ship (MPP ship). Our reasons for selecting these types of ships are as follows. Container ships regularly use the canal. Typical container ships traveling through the Kiel Canal had a capacity of 508, 658, or 822 TEU in 2004 (Kågeson et al., 2009). Following the general trend to larger ships, ships (feeder ship segment) with a capacity of 1,200–1,700 TEU are common on the canal as well (Bösl, 2010). We selected the bulk carrier to include a ship that belongs to the group of large ships (20,000–30,000 gt) that can use the canal but are nevertheless not frequent users (~1% of total ship traffic in the period 2005–2009; WSD Nord, 2011c). Further, we selected the MPP ship in order to account for possible differences in cost per ship types, since the MPP ship is comparable in size to the container ships. We selected the following three routes for our analysis: (1) the route between the Baltic Sea port of Helsinki (Finland) and the North Sea port of Rotterdam (Netherlands), (2) the route between Helsinki and the North Sea port of Leith (UK), and (3) the route between Helsinki and the North Sea port of Hamburg (Germany). Helsinki is exemplary for all ports in the eastern part of the Baltic Sea located to the east of IP1 (see Figure 1). Rotterdam is exemplary for all ports in the southwestern part of the North Sea located to the west of IP6. Leith is exemplary for ports in the northwestern part of the North Sea. Hamburg has a unique position as it is located next to the Kiel Canal. The data we use in our case study to calculate the actual and optimal transit charge come from different sources. The ship type specifications we used are presented in Table 2. Specifications for gt, dwt, TEU capacity, sizes, and SFOC of main and the auxiliary engines are based on Buhaug et al. (2009) and represent world fleet average values for specific ship types.<sup>28</sup> Values for beam, design draught, and speed were taken from Stopford (2009).<sup>29,30</sup>

---

<sup>28</sup> The respective ship categories in Buhaug et al. 2009 are Container 0–999 TEU, Container 1,000–1,999 TEU, Bulk 35,000–59,999 dwt, General Cargo 5,000–9,999 dwt, 100+ TEU, and General Cargo 10,000+ dwt, 100+ TEU. We use the average value for the MPP ship, which falls between two size classes of one category.

<sup>29</sup> The respective ship types in Stopford (2009) are Feedermax and Handy for container ships, Handymax for bulk carriers (including length), and Grand total for the MPP ship (including only speed).

<sup>30</sup> Stopford (2009) bases his values on the Containership Register 2006, Clarkson Research Services Ltd and Bulk Carrier Register 2006, Clarkson Research Services Ltd.

**Table 2:** Ship type specifications. *Source:* Own presentation based on Buhaug et al. (2009), Stopford (2009).

Characteristics	Ship category			
	Container vessel	Container vessel	Bulk carrier	General cargo
Type of ship	Handy	Feedermax	Handymax	Multipurpose (MPP)
Length (m)	160	135	182	130
Beam (m)	26	21	31	23
Design draught (m)	9.7	7.7	11.4	8.5
Allowed draught (m)	9.5	9.5	8.4	9.5
Actual draught (m)	$d_{\min} < d_{ac} < d_{al}$	$d_{\min} < d_{ac} < d_{al}$	$d_{\min} < d_{ac} < d_{al}$	$d_{\min} < d_{ac} < d_{al}$
Gross tonnage (gt)	16,438	6,967	27,596	10,468
Deadweight (dwt)			45,000	12,500
Container capacity (TEU)	1,400	550		600
Main engine (kW)	12,364	5,703	8,209	5,801
Engine type	2-stroke slow-speed	4-stroke medium/high-speed	2-stroke slow-speed	4-stroke medium/high-speed
Auxiliary engine (kW)	985	600	533	628
Engine type	4-stroke medium/high-speed	4-stroke medium/high-speed	4-stroke medium/high-speed	4-stroke medium/high-speed
Design speed (kn) at 90% MCR	19	16.8	14.4	15
Allowed max speed Kiel Canal (kn)	8.1	8.1	6.5	8.1
SFOC (g/kWh) main engine	165–175	180–195	170–180	175–185
SFOC (g/kWh) auxiliary engines	220	230	230	230
Type of bunker fuel ME/AE	HFO/MDO	HFO/MDO	HFO/MDO	HFO/MDO

<sup>a</sup> The allowed draught ( $d_{al}$ ) of a ship using the Kiel Canal is determined by its size dimensions: length and beam.<sup>31</sup> Its actual draught ( $d_{ac}$ ) depends on the load it is carrying and, thus, can range from the minimum draught ( $d_{\min}$ ), if not laden at all, to the design draught. We assume that ships are not fully laden and that they do not exceed the allowed draught.

<sup>b</sup> Depending on a ship's classification into one of the six traffic groups (see Section 2), its allowed speed is 6.5 or 8.1 kn.<sup>32</sup>

Data on time charter (T/C) rates for the bulk carrier (45,000 dwt) and the two container ships (550 TEU and 1,400 TEU) are taken from Fearnleys Monthly Report (Fearnresearch 2005–2009) and cover the period January 2005 to December 2009. These T/C rates are charged in dollars per day for a period of 12 months T/C. Since rates vary between months, the canal authority would need to know the month the ship was chartered to calculate the optimal transit charge exactly. For simplification, we use

<sup>31</sup> § 42 Abs. 1 Nr. 1 und Abs. 6 SeeSchStrO: Zulassung zum Befahren des Nord-Ostsee-Kanals; Bekanntmachung der Waterways and Shipping Authority North.

<sup>32</sup> In accordance with § 26 Abs. 3 SeeSchStrO: Höchstgeschwindigkeit; Bekanntmachung der WSD Nord.

the average over the last 12 months. For example, if a ship travels through the Kiel Canal in July 2008, we use the average T/C rate for the period August 2007 to July 2008. The T/C rates used for the 1,400 TEU container are calculated as the average of the rates for a 550 TEU and a 1,700 TEU container taken from the Fearnleys Monthly Report for the period January 2005 to December 2009 (Fearnresearch, 2005–2009). The T/C rates used for the MPP ship are taken from Gardiner (2010), but are available on an annual basis only.

Data on monthly bunker prices (heavy fuel oil and marine diesel oil) for the period 2005–2009 are taken from the Shipping Statistics Yearbook (ISL Bremen, 2009, 2008). Actual transit charges (in euros) for the Kiel Canal are those discussed above and are determined according to various regulations. The following regulations determine whether a ship is obliged or not to take helmsmen and pilots on board: Seeschiffahrtsstraßen-Ordnung (SeeSchStrO, 2006), NOK-Lotsverordnung (NOK-LV, 2003), and Elbe-Lotsverordnung (Elbe-LV, 2003). The Kanalsteuertarifverordnung (2004) is used to determine the helmsmen fee in the years 2005–2009. The Lotstarifverordnung (LTO, 2008, 2006, 2005, LTV, 2009) is used to determine the pilotage fee in the years 2005–2009, whereas the Lotstarifverordnung (LTO, 2006, 2001, LTV, 2009) is used to determine the pilotage due in the years 2005–2009. The Verordnung über die Befahrensabgaben auf dem Nord-Ostsee-Kanal (NOKBefAbgV, 2003) is used to determine the transit toll in the years 2005–2009.

Data on monthly dollar-euro exchange rates for the period 2005–2009 are taken from the Deutsche Bundesbank.

Shipping route length is also important in determining the costs of shipping. Table 3 presents an overview over the length of the three possible routes when using each of the three passageways, i.e., the Kiel Canal, the Great Belt, and the Øresund.<sup>33</sup> For our calculations, we assume that all ships operate without intermediate stops, i.e., ships that operate on a fixed route with multiple stops and fixed schedule around Denmark are excluded.

Total shipping *route length* is measured for each of the three routes when using each of the passageways (see Figure 1). We are, however, primarily interested in the length

---

<sup>33</sup> The Øresund passageway is restricted to ships with a draught of 8 m or less (Helcom, 2009). If a ship's draught exceeds 8 m, it would have to travel through the Great Belt passageway, thus having to travel a greater distance.



of those sections of the route that are coterminous with each of the passageways (black line), as, for example, the section of the Helsinki-Rotterdam route between Helsinki and IP1 and between Rotterdam and IP6 is a constant (dotted line) regardless of which passageway is used. We define the length of the sections that are coterminous with each of the passageways as *relevant length* (see Table 3).

According to our calculations, by using the Kiel Canal on the Helsinki-Hamburg route, for example, more than 400 nm could be saved (668.6–225.8 nm) compared to the Helsinki-Leith route, where less than 150 nm would be saved (833.9–689.1 nm).

**Table 3:** Relevant length (in nm) between Helsinki and the three alternative ports at the North Sea.

Route	Passageway	Route length	Relevant length	Nmsaved by using Kiel Canal
Helsinki-Rotterdam	Kiel Canal	941.1	398.9	n.a.
	Øresund	1103.2	561.1	162.1
	Great Belt	1211.0	668.8	269.9
Helsinki-Hamburg	Kiel Canal	703.3	225.8	n.a.
	Øresund	1038.4	560.9	335.0
	Great Belt	1146.2	668.6	442.8
Helsinki-Leith	Kiel Canal	1161.4	689.1	n.a.
	Øresund	1198.3	726.1	37.0
	Great Belt	1306.1	833.9	144.8

*Source:* Own calculations based on ESRI Base Map.

While most of our model parameters, such as bunker price and route lengths, are observable and discrete, other parameters, such as travel time, may vary from voyage to voyage, and are thus unobservable. In order to take this into account, we make assumptions about the distribution of these unobservable parameters, namely the actual speed of the ship at sea, the canal waiting time, and the SFOC.

Based on the model devised by Somanathan et al. (2009), we use a triangular distribution with parameters  $a = 0.85$  and  $b = c = 1$  for speed at sea. This is to account for varying navigational conditions at sea, such as wind and the resulting waves. For the

canal waiting time (in minutes) at the two locks of the Kiel Canal, which is included in the variable duration ( $D$ ) (see Section 3, Equation 1), we assume waiting times to be exponentially distributed with parameters  $\lambda = 18, 12, 15$  and  $12$ , for the four different ships entering the canal at the Kiel-Holtenau lock, and  $\lambda = 6, 6, 9$  and  $6$ , for the four ships exiting the canal at the Brunsbüttel lock. The variation in the parameters is due to the different ship sizes. The exponential distribution is chosen to reproduce potentially long delays in times of heavy traffic and moderate average latencies. To account for differences in types of main engine, we assume a uniform distribution of SFOC over the interval given in Buhaug et al. (2009) (see Table 2).<sup>34</sup>

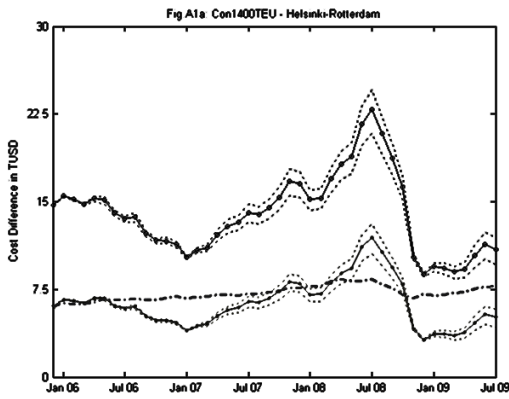
## 5. Results

Figures 4a–4l show the results of our case study based on the mean values of our simulation runs with 95% confidence bounds for the various ship types. These figures show the difference in total costs for the two passageways around Denmark (black dotted line for Great Belt and grey crossed line for Øresund) compared to the total costs of the Kiel Canal passageway (without transit charge). The Kiel Canal functions as the benchmark (normalized to 0).<sup>35</sup> A positive cost difference shows that it is more costly for a particular ship type to travel around Denmark than to travel via the Kiel Canal, whereas a negative cost difference shows that it is less costly. This cost difference is, according to our definition, the optimal transit charge. Calculating the actual Kiel Canal transit charge (light dashed line) for each particular ship type makes it possible to compare it to the optimal transit charge (cost differences in total costs excluding actual Kiel Canal transit charge) at a glance.

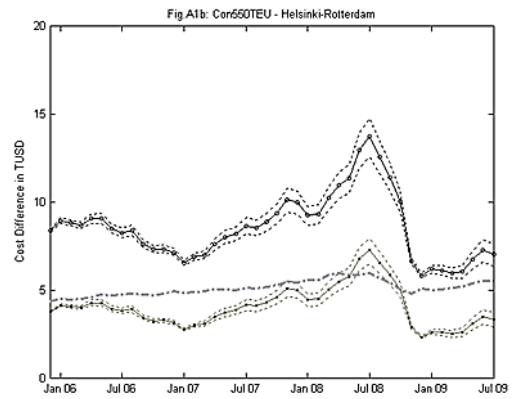
---

<sup>34</sup> Since the transformation of this variable is linear throughout the model, the point estimate is the same as it would be for a deterministic value equaling the mean of this random variable. However, for interval estimations, this assumption is useful.

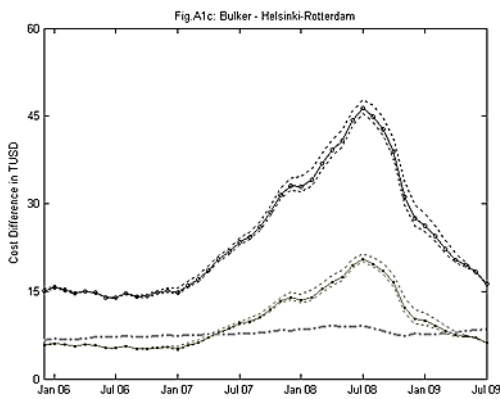
<sup>35</sup> Note that for the ship types 1,400 TEU container, 550 TEU container, and bulk carrier the results are based on monthly data (December 2005–July 2009). For the MPP ship, the results are based on yearly data (2005–2009) due to limited data availability.



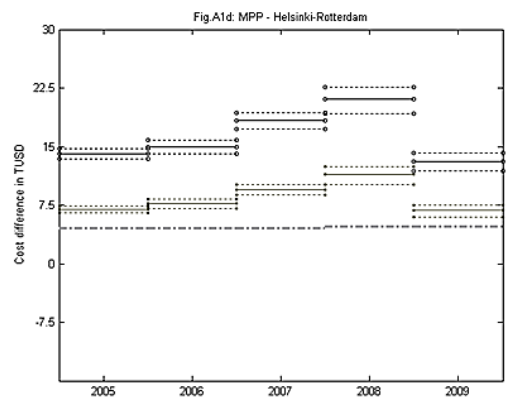
**Figure 4a:** Cost differences and the actual Kiel Canal transit charge for the 1,400 TEU container on a voyage from Helsinki to Rotterdam (in thousand dollars). *Source:* Own calculations.



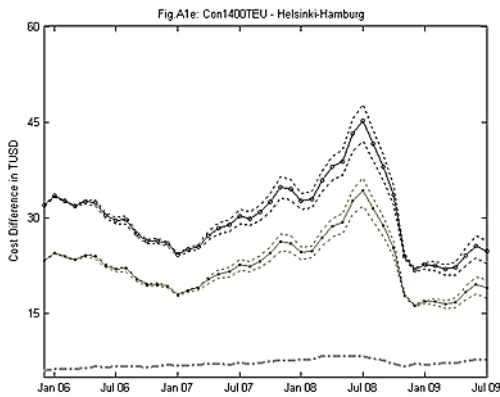
**Figure 4b:** Cost differences and the actual Kiel Canal transit charge for the 550 TEU container on a voyage from Helsinki to Rotterdam (in thousand dollars). *Source:* Own calculations.



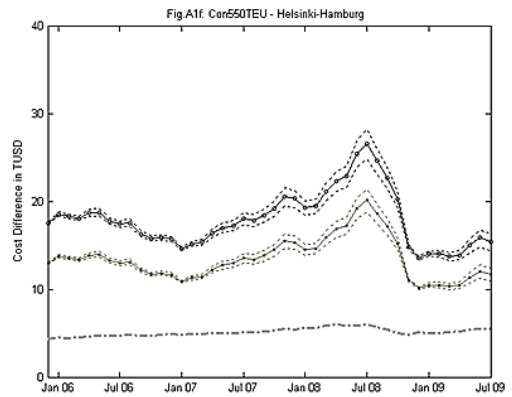
**Figure 4c:** Cost differences and the actual Kiel Canal transit charge for the ship bulk carrier on a voyage from Helsinki to Rotterdam (in thousand dollars). *Source:* Own calculations.



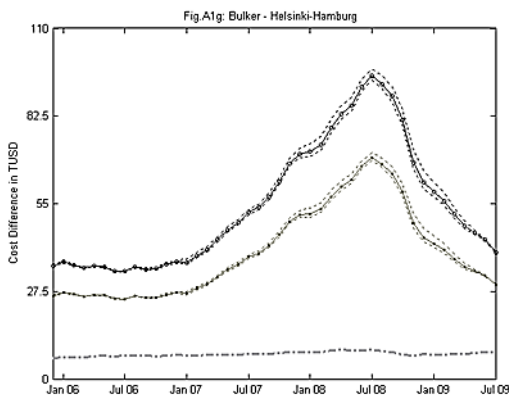
**Figure 4d:** Cost differences and the actual Kiel Canal transit charge for the multipurpose ship on a voyage from Helsinki to Rotterdam (in thousand dollars). *Source:* Own calculations.



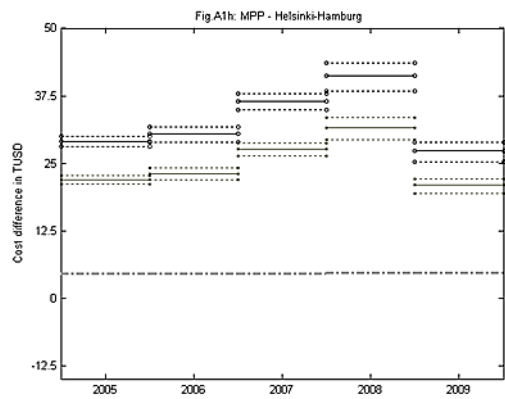
**Figure 4e:** Cost differences and the actual Kiel Canal transit charge for the 1,400 TEU container on a voyage from Helsinki to Hamburg (in thousand dollars). *Source:* Own calculations.



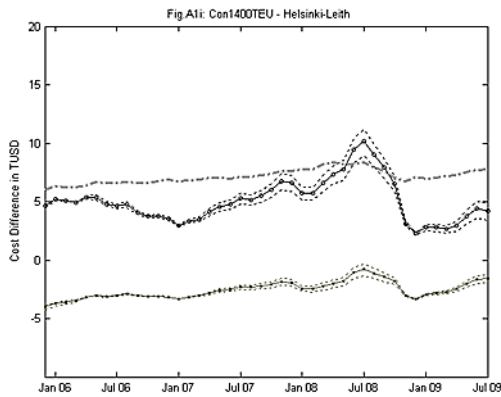
**Figure 4f:** Cost differences and the actual Kiel Canal transit charge for the 550 TEU container on a voyage from Helsinki to Hamburg (in thousand dollars). *Source:* Own calculations.



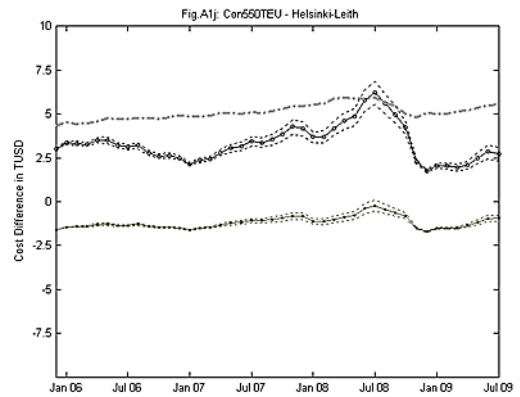
**Figure 4g:** Cost differences and the actual Kiel Canal transit charge for the ship bulk carrier on a voyage from Helsinki to Hamburg (in thousand dollars). *Source:* Own calculations.



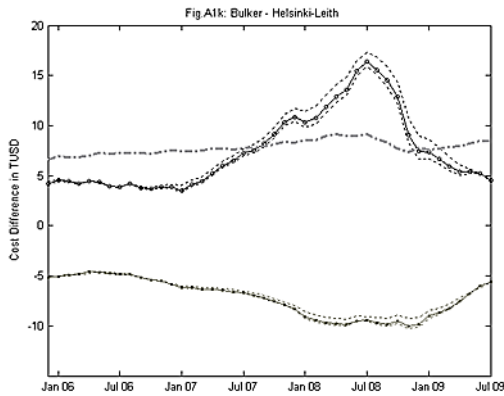
**Figure 4h:** Cost differences and the actual Kiel Canal transit charge for the multipurpose ship on a voyage from Helsinki to Hamburg (in thousand dollars). *Source:* Own calculations.



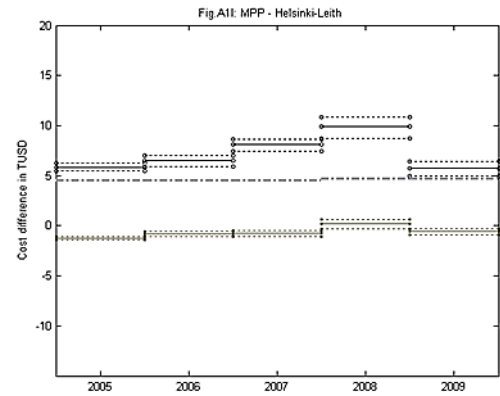
**Figure 4i:** Cost differences and the actual Kiel Canal transit charge for the 1,400 TEU container on a voyage from Helsinki to Leith (in thousand dollars). *Source:* Own calculations.



**Figure 4j:** Cost differences and the actual Kiel Canal transit charge for the 550 TEU container on a voyage from Helsinki to Leith (in thousand dollars). *Source:* Own calculations.



**Figure 4k:** Cost differences and the actual Kiel Canal transit charge for the ship bulk carrier on a voyage from Helsinki to Leith (in thousand dollars). *Source:* Own calculations.



**Figure 4l:** Cost differences and the actual Kiel Canal transit charge for the multipurpose ship on a voyage from Helsinki to Leith (in thousand dollars). *Source:* Own calculations.

In general, the Great Belt is the most expensive passageway. The cost difference for this passageway is considerably larger than for the Øresund passageway (costs of the Kiel Canal serve as the benchmark). Comparing the cost difference to the actual Kiel Canal transit charge shows that in most cases the actual transit charge is lower than the optimal one. Most notably so for the Helsinki–Hamburg route, where the cost difference peaks in the middle of 2008 at approximately \$95,000. One exception is the Helsinki–

Leith route, for which the optimal transit charge is lower or close to the actual transit charge in some months.

The results for the Øresund passageway are different. Here, for all ship types on the Helsinki-Rotterdam route the optimal transit charges is close to the actual transit charge. For the Helsinki–Leith route, the optimal transit charge is lower than the actual transit charge. In almost all cases, it is even below zero. This is particularly pronounced in the case of the bulk carrier, where it is approximately \$11,000 below the benchmark. The only exception where the actual Kiel Canal transit charge is considerably lower than the optimal charge is on the Helsinki–Hamburg route.

However, looking at the different ship types shows the following. The differences in costs between the bulk carrier and the 1,400 TEU container, and the MPP ship were nearly the same in the beginning of the time period analyzed (e.g., approximately 15,000 euros for ships on the Helsinki–Rotterdam route using the Great Belt passageway, and, approximately 6,000 euros for ships using the Øresund passageway). Cost differences for the bulk carrier started to increase faster than the cost differences for the other two ship types in 2007. This is particularly the case for the Helsinki–Hamburg route. The 550 TEU container had the lowest level of cost differences for both passageways.

In addition to analyzing the impact of ship type and route on the optimal transit charge, we also analyzed the differences in charter costs, fuel costs, and charge costs, including the actual Kiel Canal transit charge. We did this for all ship types on all three routes and all three passageways. This approach sheds light on the cost level of the individual cost components in total cost differences and how they vary within the time period analyzed. Moreover, it shows how varying charter and fuel costs could impact the economics of passageways when charges are held constant. The results are as follows (for more details on individual numbers see Appendix B):

On the route Helsinki–Rotterdam it is more often economical for the two container ships to travel the Øresund passageway than to use the Kiel Canal, although the passageway around Denmark incurs higher charter and fuel costs. The reason for this is that the sum of the charges (Kiel Bay, Kiel Canal, and Elbe) outweighs the sum of the higher charter and fuel costs. This is particularly pronounced in times of low charter rates and low bunker prices. It is more often economical for the bulk carrier and the

MPP ship to travel through the Kiel Canal than to travel around Denmark via the Øresund passageway. The opposite is true for the Great Belt passageway, i.e., it is always more economical to travel through the Kiel Canal. Using the Great Belt passageway incurs higher charter and fuel costs that are not offset by the sum of charge costs.

On the route Helsinki–Hamburg it is more economical for all ship types to travel through the Kiel Canal than through the Øresund or the Great Belt passageway. Using the Øresund or the Great Belt passageway saves charge costs but incurs considerably higher charter and fuel costs. Therefore, the fuel and charter costs savings achieved by using the Kiel Canal offset the charge costs.

On the route Helsinki–Leith it is more economical to travel around Denmark than to use the Kiel Canal. The only exception is the MPP ship using the Great Belt passageway, where in three out of five years it is more economical to use the Kiel Canal. Using the Øresund passageway incurs higher fuel costs but saves charter and charge costs. Using the Great Belt passageway incurs higher fuel and charter costs but saves charge costs. Therefore, the fuel and charter costs savings achieved by using the Kiel Canal are usually not high enough to offset the higher charge costs associated with this passageway.

The results of our simulation indicate that the actual Kiel Canal transit charge is not optimal. However, it is not possible to state that it is in general too low or too high. This depends on route and ship type. Results vary significantly for all routes, all passageways, and all ship types. In some cases, the actual transit charge is close to the optimal transit charge, whereas in other cases it is considerably far away from it.

## **6. Discussion**

As mentioned above, the Kiel Canal generates a balance sheet loss. To get an idea about whether and by how much this loss could be reduced by an optimal transit charge system, we calculate the difference in revenues compared to the approach using the actual transit charge. We base our calculation on the four ship types and the three routes in our case study. To do so, we first evaluate the importance of individual elements (port, passageway, and ship type) that determine the costs.

A comparison of the three ports on the North Sea in the light of cargo flows with the Baltic Sea region shows that Hamburg is the most important port, at least in container/feeder shipping (Notteboom, 2010, Lorenz, 2006). According to Kågeson et al. (2008), the majority of container/feeder shipping that travels through the Kiel Canal goes to Hamburg and Bremerhaven, and a minority goes to UK ports, Rotterdam, and Antwerp.

Comparing the two passageways around Denmark, the Øresund passageway is shorter and is used more frequently than the Great Belt passageway, but it has a draught constraint of 8 m maximum. For this reason, it is used particularly by ships with a draught of less than 7 m (Helcom, 2009). The Kiel Canal has a similar draught constraint of 7.0–9.5 m, depending on the beam and the length of a ship. This implies that larger ships that cannot use the Øresund passageway might also be too large to use the Kiel Canal. For example, if the bulk carrier referred to above were fully laden, its actual draught would exceed the allowed draught of both the Øresund (8 m) and the Kiel Canal (8.4 m) (see Section 4.1). Thus, as long as the Kiel Canal is not deepened, such ships can only use the Great Belt passageway. For other ships, including the 1,400 TEU container in our case study, which might be too large for the Øresund passageway but not for the Kiel Canal, the Great Belt passageway would serve as the substitute to the Kiel Canal.

Statistics provided by the WSD Nord about ship transits per year differentiate either between ship types or size classes (in gt). There are no statistics available about how many ships of a specific ship type in a specific size class pass through the Kiel Canal per year. Statistics are only available for size classes. Thus, we take the number of ships in a particular size class to which our ships in the case study belong and multiply this number by the optimal and the actual Kiel Canal transit charge to determine the difference in revenues. For example, the 550 TEU container ship belongs to the size class 6,000–8,000 gt. 3,633 ships of this size class passed the Kiel Canal, on average, counting both directions, in the time period (2005–2009) (WSD Nord, 2011c).

As discussed above, the three ports, Hamburg, Rotterdam, and Leith are not equally important for maritime transportation in the Baltic Sea (northern Europe) region. Thus, we assume that most of the ships in a particular size class generally have Hamburg as their destination or departure port, e.g., 70% go to or depart from Hamburg and 30% go



to or depart from Rotterdam. We assume that 100% of ships similar to the 550 TEU container go to or depart from Hamburg because within the time period analyzed, the Øresund passageway was often the more economical choice for ships going to Rotterdam (see Section 4). Thus, we assume that these types of ships only used the Kiel Canal if their destination or departure port was Hamburg. For simplicity, we do not consider Leith, since, for the majority of the ship types studied, it is not economical to travel through the Kiel Canal (see Section 4). Furthermore, we assume that ships in the size class (in gt) similar to the 550 TEU container have an actual draught of less than 8m, i.e., they are allowed to travel through both the Øresund and the Kiel Canal. We assume an actual draught of more than 8m for the majority of ships in the size classes similar to the 1,400 TEU container, the MPP ship, and the bulk carrier; i.e., these ships are not allowed to use the Øresund but to use the Kiel Canal or the Great Belt instead. We assume an actual draught of less than 8 m only for a minority of these ships, e.g., when a bulk carrier is in ballast.

The results of our calculation are shown in table 4. Evidently, under the assumptions made, the optimal transit charge approach yields higher revenues than the actual transit charge approach. Differences in revenues are in a range of up to several million dollars.

**Table 4:** Difference in revenues between the optimal and actual transit charge approach (in million dollars).

Year	Con550TEU	Con1400TEU	Bulker	MPP
2005	26.4	8.4	5.0	10.3
2006	29.3	9.2	6.5	11.6
2007	34.6	12.2	14.8	9.4
2008	44.7	17.7	22.3	24.5
2009	15.5	8.2	6.8	11.7

*Source:* Own calculations.

However, differences are smaller if fewer ships with an actual draught of more than 8m are assumed to travel to Hamburg. For example, if we assume that only 50% of the ships travel to Hamburg and 50% to Rotterdam (instead of 70% and 30%), the differences in revenues would range from \$0.4 to \$21.4 million compared to \$5 to \$24.5 million (Table 4, columns 3–5).

## 7. Conclusion

In this paper, we propose an optimal transit charge system that is based on the maximal WTP of customers. The WTP amounts to the cost savings that ship operators could achieve by choosing the Kiel Canal passageway instead of the passageways around Denmark. We conduct a case study based on four ship types and three routes to compare the optimal transit charge system with the actual Kiel Canal transit charge system, which is based on the gross tonnage (gt) of a ship.

The main findings of our case study are that the optimal transit charge is considerably higher than the actual transit charge for all four ship types and both passageways on the route Hamburg–Helsinki (whereby Helsinki is exemplary for all ports east of IP1, see Figure 1). However, the picture is more heterogeneous for the routes Rotterdam–Helsinki and Leith–Helsinki (whereby Rotterdam is exemplary for all ports west of IP6, see Figure 1). In both cases the optimal transit charge is either higher, close to, or lower than the actual transit charge, depending on the passageway used. Moreover, the discussion in Section 5 shows that if the majority of ships go to or depart from Hamburg, the optimal transit charge system would achieve higher revenues than the actual transit charge system, even though the optimal transit charge would be lower than the actual transit charge for some ship types and routes.

Thus, we conclude that under an optimal transit charge system, the canal authority could set higher charges for ships going to or coming from Hamburg and lower charges for ships that are currently not using the Kiel Canal because it would not be profitable to do so, e.g., ships traveling to ports near Rotterdam if they use the Øresund passageway. However, setting higher charges might prove difficult. On the one hand, political acceptance might be low and, on the other hand, the legal practicality needs to be proved. But it needs to be noted that transit through the Kiel Canal is highly subsidized at present, because the difference between revenues and expenses of the Kiel Canal is covered by funds provided by the German federal government. Without these funds, operating the Kiel Canal would not be possible and ships would have to travel around Denmark. Reducing this imbalance should be in the interest of the Kiel Canal authority as well as the taxpayers.

In order to discuss the practicability of the proposed transit charge system, the following points need to be highlighted. To determine the WTP, the canal authority would

theoretically require complete knowledge about a ship's departure and destination, cost structure, and operating conditions. Such knowledge is generally not available to the canal authority. Therefore, it would have to rely on information it can actually obtain. The canal authority could ascertain the departure and destination port of a ship in the course of ascertaining its size dimensions, which is already done in order to classify ships for the purpose of traffic control. We propose using charter rate payments and fuel costs per ship type on a particular route as WTP indicators. However, charter rates and bunker prices vary over time and would require the transit charge to vary too. We thus propose adjusting charges regularly after a given time period in order to account for such fluctuations. While some components of the charge could be adjusted on an annual basis, it would be preferable to adjust other components, like bunker prices, on a monthly basis. At present, some components of the current charge have not been adjusted for several years.

It is important to point out that a number of limitations apply. The case study is based on specific ship types on specific routes and the results might change by employing other ship types or routes. For example, taking Gothenburg or any other port in the Baltic Sea west of IP1 (Figure 1) would change the results. However, the major share of the volume transported via Kiel Canal comes from the states located to the east of intersection point 1, such as Finland or Russia (WSD Nord, 2006). Time charter rates are often only available for ships of a certain size, particularly for large ships, but the Kiel Canal is mostly used by small and lower-middle-sized ships. Further, some of the ships might operate on a fixed route and a fixed schedule, so that they cannot choose between alternative passageways.

It would be interesting to know whether considering external costs would change the results. For example, additional costs caused by CO<sub>2</sub> emission regulation in the shipping sector could change the results because ship operators might decide to travel the less CO<sub>2</sub>-intensive passageway. Furthermore, the marginal costs of providing canal services, in particular, the costs of repairing marginal damages to the canal must also be taken into account when determining optimal transit charges, i.e., optimal charges amount to the maximum of marginal costs and WTP. We assume for convenience that WTP always exceeds marginal costs such that the latter can be ignored when calculating optimal charges. This assumption simply means that it is economical for all ship types

to use the canal, i.e., that the marginal costs of canal passage are less than the total cost savings for a given ship. All these additional aspects are deferred for future research.

## 8. References

- Baird, A.J., 2006. Optimising the Container Transshipment Hub Location in Northern Europe. *Journal of Transport Geography* 14: 195–214.
- Besanko, D. and Braeutigam, R., 2005. *Microeconomics: An Integrated Approach*, 2<sup>nd</sup> edition, John Wiley & Sons.
- Böhme, H., Sichelschmidt, H., 1997. *Der Nord-Ostsee-Kanal in der Krise. Ein Plädoyer für eine Reform*. Kieler Diskussionsbeiträge 290. Kiel: Institut für Weltwirtschaft.
- Bösl, U., 2010. *Die Meeresautobahn Nord-Ostsee-Kanal im Jahr der Wirtschaftskrise. Jahresbericht 2009*. Kiel: Wasser- und Schifffahrtsdirektion Nord.
- Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Markowska, A.Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W-Q., Yoshida, K., 2009. *Second IMO GHG Study*. London: International Maritime Organization (IMO).
- Corbett, J.J., Wang, H., Winebrake, J.J., 2009. The Effectiveness and Costs of Speed Reductions on Emissions from International Shipping. *Transport Research Part D* 14: 593–598.
- Fearnresearch 2005–2009. *Fearnleys Monthly Report*. January 2005 to July 2009. Oslo.
- Gardiner, N., 2010. *Multipurpose Shipping Market in Focus*. Briefing Report. Drewry, London
- Helcom, 2011. *Helcom Map and Data Service*.  
<http://maps.helcom.fi/website/mapservice/index.html> (accessed 05/02/2011).
- Helcom, 2009. *Overview of the Shipping Traffic in the Baltic Sea*.  
[http://www.helcom.fi/stc/files/shipping/Overview%20of%20ships%20traffic\\_updateApril2009.pdf](http://www.helcom.fi/stc/files/shipping/Overview%20of%20ships%20traffic_updateApril2009.pdf). (accessed 04/19/2011).
- Holst, B., 2008. *Grundlagen der Schifffahrt*. In Winter, C. (ed.), *Grundlagen der Schiffsfinanzierung*, 3rd Edition. Ch. 3, pp. 47–128. Frankfurt am Main: Frankfurt School Verlag.
- Hutchinson, L., 1912. Panama Canal Tolls and the Theory of Monopoly Prices. *The Economic Journal* 22 (1912): 563–569.
- ISL (Institut für Seeverkehrswirtschaft und Logistik Bremen), 2009. *Shipping Statistics Yearbook 2009*. Bremen: ISL

- ISL Bremen, 2008. Shipping Statistics Yearbook 2008. Bremen: ISL
- Kågeson, P., Bahlke, C., Hader, A., Hübscher, A., 2008. Market Based Instruments for Abatement of Emissions from Shipping. A Pilot Project for the Baltic Sea. Dessau-Roßlau, Germany: Umweltbundesamt.
- Kerbaol, V., Hajduch, G., 2009. ESA Map Reveals European Shipping Routes like Never Before. Shipping Route Map.  
[http://www.esa.int/esaEO/SEMBDI0OWUF\\_index\\_1.html](http://www.esa.int/esaEO/SEMBDI0OWUF_index_1.html) (accessed 04/19/2011).
- Knowles, R.D., 2006a. Transport Shaping Space: Differential Collapse in Time-space. *Journal of Transport Geography* 14: 407–425.
- Knowles, R. D., 2006b. Transport Impacts of the Øresund (Copenhagen to Malmö) Fixed Link. *Geography* 91(3): 227–240.
- Knowles, R. D., 2000. The Great Belt Fixed Link and Denmark's Transition from Inter-island Sea to Land Transport. *Geography* 85(4): 345–354.
- Lasserre, F. and Pelletier, S., 2011. Polar Super Seaways? Maritime Transport in the Arctic: An Analysis of Shipowners' Intentions. *Journal of Transport Geography* 19: 1465–1473.
- Liu, M., Kronbak, J., 2010. The Potential Economic Viability of Using the Northern Sea Route (NSR) as an Alternative Route between Asia and Europe. *Journal of Transport Geography* 18: 434–444.
- Lorenz, H., 2006. Port Congestion. A Challenge to the Future of Shortsea Shipping. In *Shortsea Shipping on the Baltic Sea. Prospects and Challenges*. Publications from the Centre for Maritime Studies University of Turku. Turku, Finland: University of Turku.
- Meesenburg, S., Abratis, M., Bröcker, M., 2010. Planung mit Tiefgang. Jahresbericht 2009. Kiel: Wasser- und Schifffahrtsdirektion Nord.
- Notteboom, T.E., 2012. Towards a New Intermediate Hub Region in Container Shipping? Relay and Interlining via the Cape Route vs. the Suez route. *Journal of Transport Geography* 22: 164–178.
- Notteboom, T.E., 2010. Concentration and the Formation of Multi-port Gateway Regions in the European Container Port System: an Update. *Journal of Transport Geography* 18 : 567–583.
- Panama Canal Authority, 2009. Panama Canal Traffic – Fiscal Years 2007 through 2009.  
<http://www.pancanal.com/eng/maritime/reports/table01.pdf> (accessed 03/23/2011).

Schøyen, H. and Bråthen, S., 2011. The Northern Sea Route versus the Suez Canal: Cases from Bulk Shipping. *Journal of Transport Geography* 19: 977–983.

Somanathan, S., Flynn, P.C., Szymanski, J.K., 2009. The Northwest Passage: A Simulation. *Transportation Research Part A* 43: 127–135.

Somanathan, S., Flynn, P.C., Szymanski, J.K., 2007. Feasibility of a Sea Route through the Canadian Arctic. *Maritime Economics and Logistics* 9: 324–334.

Stopford, M. 2009. *Maritime Economics*, 3rd Edition. New York: Routledge

UNCTAD (United Nations Conference on Trade and Development) 2011. *Review of Maritime Transport 2010*. New York and Geneva: UNCTAD.

WSD Nord (Wasser- und Schifffahrtsdirektion Nord), 2011a. *Einnahmen und Ausgaben der Jahre 2005–2010*. Kiel: Wasser- und Schifffahrtsdirektion Nord.

WSD Nord, 2011b. *Verkehrsdaten der Jahre 2005–2009*. Kiel: Wasser- und Schifffahrtsdirektion Nord.

WSD Nord, 2011c. *Schiffsverkehr nach Größenklassen – Durchgangsverkehr der Jahre 2005–2009*. Kiel: Wasser- und Schifffahrtsdirektion Nord.

WSD Nord, 2006. *Nord-Ostsee-Kanal. Jahresbericht für die Jahre 2004 und 2005*. Kiel: Wasser- und Schifffahrtsdirektion Nord.

WSD Nord, 2001. *Der Nord-Ostsee-Kanal. Eine dem internationalen Seeverkehr dienende Bundeswasserstraße von Weltgeltung*. Kiel: Wasser- und Schifffahrtsdirektion Nord.

Wulle, K., 1927. *Der dreißigjährige Kaiser-Wilhelm-Kanal. Seine Vorgeschichte, Entwicklung und Bedeutung*. Sonderabdruck aus der "Zeitschrift für Bauwesen" 4–6: 1–10.

## **9. Regulations**

Elbe-LV, 2003. *Verordnung über die Verwaltung und Ordnung des Seelotsreviers Elbe (Elbe-Lotsverordnung - Elbe-LV) vom 8. April 2003*.

Kanalsteuertarifverordnung, 2010. *Verordnung über die Entgelte der Kanalsteuerer auf dem Nord-Ostsee-Kanal. Gültig ab 1. November 2010*.

Kanalsteuertarifverordnung, 2004. *Verordnung über die Entgelte der Steuerer auf dem Nord-Ostsee-Kanal. Gültig ab 1. September 2004*.

LTO (Lotstarifordnung), 2008. Tarifordnung für die Seelotsreviere. Gültig ab 1. Januar 2008.

LTO, 2006. Tarifordnung für die Seelotsreviere. Gültig ab 1. Januar 2006.

LTO, 2005. Tarifordnung für die Seelotsreviere. Gültig ab 1. Januar 2005.

LTO, 2001. Verordnung über die Tarifordnung für die Seelotsreviere (Lotstarifverordnung - LTV). Gültig ab dem 15. März 2001.

LTV (Lotstarifverordnung), 2011. Verordnung über die Tarifordnung für die Seelotsreviere in der Fassung der ersten Verordnung zur Änderung der Lotstarifordnung gültig ab dem 1. Januar 2011.

LTV, 2010. Verordnung über die Tarifordnung für die Seelotsreviere in der Fassung der ersten Verordnung zur Änderung der Lotstarifordnung. Gültig ab dem 1. April 2010.

LTV, 2009. Verordnung über die Tarifordnung für die Seelotsreviere. Gültig ab dem 1. Februar 2009.

NOKBefAbgV, 2003. Verordnung über die Befahrensabgaben auf dem Nord-Ostsee-Kanal. Gültig ab 1. Juni 2003. Bundesanzeiger, Ausgabe 100 vom 30. Mai 2003: 11853.

NOKBefAbgV, 1996. Verordnung über die Befahrensabgaben auf dem Nord-Ostsee-Kanal. Gültig ab 1. Oktober 1996. Bundesanzeiger, Ausgabe 184 vom 26. September 1996, Seite 11119.

NOK-LV, 2003. Verordnung über die Verwaltung und Ordnung der Seelotsreviere Nord-Ostsee-Kanal I und Nord-Ostsee-Kanal II/Kieler Förde/Trave/Flensburger Förde (NOK-Lotsverordnung – NOK-LV) vom 08. April 2003.

SeeAufgG , 2008. Gesetz über die Aufgaben des Bundes auf dem Gebiet der Seeschifffahrt (Seeaufgabengesetz - SeeAufgG) in der Fassung der Bekanntmachung vom 26. Juli 2002 (BGBl. I S. 2876). Zuletzt geändert durch Artikel 4 des Gesetzes vom 2. Juni 2008 (BGBl. 2008 II S. 520).

SeeLG, 2010. Gesetz über das Seelotswesen (Seelotsgesetz - SeeLG) in der Fassung der Bekanntmachung vom 13. September 1984 (BGBl. I S. 1213). Zuletzt geändert durch Artikel 105 des Gesetzes vom 8. Dezember 2010 (BGBl. I S. 1864).

SeeSchStrO, 2006. Seeschiffahrtsstraßen-Ordnung (SeeSchStrO) in der Fassung der Bekanntmachung vom 22. Oktober 1998 (BGBl. 1998 I S. 3209). Zuletzt geändert durch die Achte Schiffssicherheitsanpassungsverordnung vom 28. Juni 2006 (BGBl. 2006 I S. 1417).



## 10. Appendix A

The Appendix provides more detailed information on the methodological approach, and in particular, on Eq. (1).

The total costs per route ( $C_{ij,z}$ ) for a ship on a voyage from port  $i$  on the Baltic Sea to a port  $j$  on the North Sea via passageway  $z$ , with  $z = \text{Kiel Canal, the Øresund or the Great Belt passageway}$ , is determined by

$$C_{ij,z} = P_{char,ij,z} + VC_{ij,z} \quad (\text{A1})$$

where  $P_{char,ij,z}$  denotes the charter rate payment per route and  $VC_{ij,z}$  denotes the voyage costs per route. The charter rate payment depends on the charter rate ( $char$ ), which approximately represents capital and operational costs (plus a benefit for the owner for providing the ship), and on the duration ( $D$ ) of the voyage. The duration (*in hours*) of sailing a specific route  $D_{ij,z}$  depends on the length (*in nm*) of the route and the speed (*in kn*) of a ship. In addition, if a ship uses the Kiel Canal, it also depends on the lock time ( $d_{lock}$ ) and the waiting time before entering the lock ( $d_{waiting}$ ):

$$D_{ij,z} = nm_{ij,z} / kn_{ij,z} + d_{lock} + d_{waiting}. \quad (\text{A2})$$

Bunker costs ( $FuelC$ ) are a function of a ship's fuel consumption and the bunker price.

$$FuelC_{ij,z} = fc_{ij,z} \cdot P_{bunker}. \quad (\text{A3})$$

The fuel consumption (*ton/h*) of a ship's main engine is determined by

$$fc = fc^* (s / s^*)^\beta \quad (\text{A4})$$

where  $fc^*$  is defined as design fuel consumption (*in ton/h*),  $s$  as speed (*in kn*),  $s^*$  as design speed (*in kn*) (Stopford, 2009). The exponent  $\beta$  indicates the type of engine. According to Stopford (2009),  $\beta = 3$  for diesel engines.

In general, ships are designed to fulfill a predetermined transport performance/demand per period of time. To do so, they have to operate at a specific speed. Thus, ships are designed to operate at a specific speed, called the design speed  $s^*$ . After determining the

design speed, the engine (and the hull) is designed to provide the required speed. The relationship between engine size ( $E_{size}$ ) and speed ( $s$ ) is approximately given by  $E_{size} \approx s^3$  (Holst, 2008; Corbett et al. 2009).

In general, the design fuel consumption per hour is determined by

$$fc^* = E_{size} \cdot F_{load}^* \cdot SFOC / 10^6 \quad (A5)$$

where  $E_{size}$  is the engine size (in kW),  $F_{load}^*$  is the design engine load factor (in % Maximum Continuous Rating (MCR)), and  $SFOC$  is the related specific fuel oil consumption (in g/kWh) (Buhaug et al., 2009).

A ship generally has a main engine that provides motive power and more than one auxiliary engine that provide power for other necessary services on board.<sup>36</sup> Thus, the fuel consumption of the main engine ( $fc_{ME,ij,z}$ ) and the fuel consumption of the auxiliary engines ( $fc_{AE,ij,z}$ ) need to be differentiated. The fuel consumption per route ( $fc_{ij,z}$ ), taking the different route sections into account, is then given by

$$fc_{ij,z} = fc_{ME,ij,z} + fc_{AE,ij,z} \quad (A6)$$

Because fuel consumption varies along a shipping route due to differences in navigational conditions, a shipping route can be divided into four different sections: at sea, in speed restricted estuary/pilotage district, in port and in canal. Depending on the section, traveling speeds differ and waiting times might occur.

The fuel consumption of the main engine is given by

$$fc_{ME,ij,z} = d_s \cdot fc_{ME}^* \cdot (s_s / s^*)^\beta + d_e \cdot fc_{ME}^* \cdot (s_e / s^*)^\beta + d_c \cdot fc_{ME}^* \cdot (s_c / s^*)^\beta \quad (A7)$$

where  $fc_{ME}^*$  is defined as design fuel consumption per hour and  $d_s$  as the time spent sailing at sea,  $d_e$  as the time spent sailing in estuary (pilotage district), and  $d_c$  as the time spent sailing on the canal.

The fuel consumption of the auxiliary engines is given by

$$\sum_{r=1}^n fc_{AE_r,ij,z} = (E_{size_r} \cdot F_{load_r} \cdot SFOC_r / 10^6) \cdot d_{AE_r} \quad (A8)$$

---

<sup>36</sup> Ships are equipped with several auxiliary engines, with generators (small diesel engines) for producing electricity as the most important auxiliary engine. Ships usually have at least three of these generators, which operate by turns, to guarantee failure-free operation (Buhaug et al., 2009).

where  $r=1, \dots, n$  denotes the number of auxiliary engines and  $d_{AE_r}$  the duration of their operating time. The number of auxiliary engines in operation and the actual time they spend in operation depends on the type of ship.<sup>37</sup> If the main engine and the auxiliary engines would require a different type of bunker fuel, than the bunker costs are given by

$$FuelC_{ij,z} = fc_{ME,ij,z} \cdot p_{bunker_v} + fc_{AE,ij,z} \cdot p_{bunker_w} \quad (A9)$$

where  $v$  and  $w$  denote different types of bunker fuel.

---

<sup>37</sup> Ships usually have one generator in operation, i.e., the others are put on hold, i.e., they are available for maintenance or are on standby (Buhaug et al., 2009). In some cases, ships are additionally equipped with a shaft generator for generating electricity, which reduces the need to operate generators at sea.

## **11. Appendix B**

Tables B1 to B3 show the cost differences in total costs, including the actual Kiel Canal transit charge, for all ship types on all three routes and all three passageways. It presents the highest cost difference (highest  $\Delta$ ), the lowest cost difference (smallest  $\Delta$ ), and the median cost difference (median  $\Delta$ ) in the time period December 2005–July 2005 and 2005–2009 for the MPP ship. In addition, the numbers in brackets show how many times (months or years for the MPP) a positive cost difference occurs during the time period analyzed. Moreover, the total cost differences of the highest and the lowest values are divided into charter costs, fuel cost, and charge costs.

**Table B1:** Difference in costs for the Helsinki–Rotterdam route (in \$).

Passage-ways compared	Type of ship	Difference in total costs ( $\Delta$ )		Difference composed of		
		median $\Delta$ ( $\geq 0$ )	highest $\Delta$ lowest $\Delta$	charter costs $\Delta$	fuel costs $\Delta$	charge costs $\Delta$
Øresund-Kiel Canal	Container 550 TEU	-976 (4/44)	-2,752 -22	1,671 1,800	2,472 5,008	-6,895 -6,830
	Container 1400 TEU	-696 (15/44)	-3,928 13	1,939 3,478	4,391 5,193	-10,258 -8,658
	Bulker	313 (23/44)	11,423 308	14,309 8,500	11,896 4,747	-14,782 -12,939
	MPP	1,282 (4/5)	3,469 -98	3,100 2,000	12,159 8,029	-11,790 -10,127
Great Belt-Kiel Canal	Container 550 TEU	3,569 (44/44)	7,758 739	4,309 3,843	11,534 3,791	-8,085 -6,895
	Container 1400 TEU	6,967 (44/44)	14,607 1,681	6,296 5,253	20,339 6,686	-12,028 -10,258
	Bulker	13,424 (44/44)	37,175 6,700	33,777 10,001	18,180 8,358	-14,782 -11,659
	MPP	8,588 (5/5)	13,149 6,241	6,521 4,207	18,418 12,161	-11,790 -10,127

Source: Own calculations.

**Table B2:** Difference in costs for the Helsinki–Hamburg route (in \$).

Passage-ways compared	Type of ship	Difference in total costs ( $\Delta$ )		Difference composed of		
		median $\Delta$ ( $\geq 0$ )	highest $\Delta$ lowest $\Delta$	charter costs $\Delta$	fuel costs $\Delta$	charge costs $\Delta$
Øresund-Kiel Canal	Container 550 TEU	8,000 (44/44)	14,237 5,046	5,789 5,162	13,969 4,592	-5,521 -4,708
	Container 1400 TEU	15,446 (44/44)	25,943 9,091	8,699 7,257	24,563 8,076	-7,319 -6,242
	Bulker	27,748 (44/44)	60,364 17,915	45,582 13,498	21,992 10,110	-7,210 -5,693
	MPP	16,693 (5/5)	23,615 14,038	8,588 5,541	22,201 14,659	-7,174 -6,162
Great Belt-Kiel Canal	Container 550 TEU	12,874 (44/44)	20,687 8,538	8,226 7,335	17,982 5,911	-5,521 -4,708
	Container 1400 TEU	23,059 (44/44)	36,900 14,700	12,671 10,571	31,548 10,371	-7,319 -6,242
	Bulker	40,769 (44/44)	86,150 26,580	65,075 19,270	28,285 13,003	-7,210 -5,693
	MPP	23,999 (5/5)	33,295 20,378	12,009 7,748	28,460 18,792	-7,174 -6,162

Source: Own calculations.

**Table B3:** Difference in costs for the Helsinki–Leith route (in \$).

Passage-ways compared	Type of ship	Difference in total costs ( $\Delta$ )		Difference composed of		
		median $\Delta$ ( $\geq 0$ )	highest $\Delta$ lowest $\Delta$	charter costs $\Delta$	fuel costs $\Delta$	charge costs $\Delta$
Øresund-Kiel Canal	Container 550 TEU	-6,271 (0/44)	-6,889 -5,851	-938 -923	2,010 1,902	-7,961 -6,830
	Container 1400 TEU	-9,702 (0/44)	-10,448 -8,804	-1,911 -2,128	1,721 3,485	-10,258 -10,161
	Bulker	-14,641 (0/44)	-18,909 -11,607	-7,648 -2,574	3,504 2,247	-14,765 -11,280
	MPP	-7,616 (0/5)	-7,774 -7,204	-873 -852	4,889 3,096	-11,790 -9,448
Great Belt-Kiel Canal	Container 550 TEU	-1,695 (1/44)	-3,314 -70	1,321 1,474	2,260 6,134	-6,895 -7,678
	Container 1400 TEU	-1,952 (4/44)	-4,838 313	1,402 1,620	4,018 9,653	-10,258 -10,960
	Bulker	1,833 (15/44)	7,252 239	11,157 6,693	10,878 6,357	-14,783 -12,811
	MPP	101 (3/5)	1,906 101	2,548 2,489	11,148 7,060	-11,790 -9,448

Source: Own calculations.

## Part II

### Climate Change Policy

#### Paper I: Accounting for Carbon Dioxide Emissions from International Shipping: Burden Sharing under Different UNFCCC Allocation Options and Regime Scenarios

Heitmann, N., Khalilian, S., 2011.

Accounting for carbon dioxide emissions from international shipping: Burden sharing under different UNFCCC allocation options and regime scenarios,

Marine Policy 35: 682–691.



# Accounting for Carbon Dioxide Emissions from International Shipping: Burden Sharing under Different UNFCCC Allocation Options and Regime Scenarios<sup>\*</sup>

Nadine Heitmann<sup>a</sup> and Setareh Khalilian<sup>a</sup>

<sup>a</sup> Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

## Abstract

CO<sub>2</sub> emissions from international shipping, which are currently unregulated, are predicted to rise dramatically if no regulations are implemented. International bunker fuel emissions have been excluded from the Kyoto Protocol; the UNFCCC conference in Copenhagen also failed to bring about clear directions on how to proceed with these emissions.

In this paper, the various options suggested by the Subsidiary Body for Scientific and Technological Advice of the UNFCCC for allocating CO<sub>2</sub> emissions from international shipping to individual countries are investigated. This is followed by a discussion of the economic and regulatory issues related to these options and the consequences of applying them. Then, the various options are evaluated on the basis of environmental effectiveness, possibility of legal implementation, and fairness of burden sharing. The evaluation shows that there is no single allocation option that can be regarded as environmentally effective, legally effective and allowing for fair burden sharing. Nevertheless, it is concluded that an allocation of international shipping emissions should be conducted on the basis of the operating company.

**Keywords:** climate change, international shipping, CO<sub>2</sub> emissions, International Maritime Organization

**JEL classification:** Q52, Q54, Q56

---

<sup>\*</sup> We would like to thank Katrin Rehdanz, Sonja Peterson, and Gernot Klepper for their helpful suggestions and comments. Moreover, we would like to thank Markus Schwedeler and Markus Spreyer for their research assistance and Amy Louisa Cowan for providing linguistic assistance. The DFG provided financial support-through the Excellence Initiative Future Ocean. The usual caveats apply.

## 1. Introduction

In 2007, 3.3% of the world's total anthropogenic CO<sub>2</sub> emissions were caused by global shipping, with the international shipping sector accounting for the major share of 2.7% [1].<sup>1</sup> The International Maritime Organization (IMO) estimates that these emissions, if not curbed, could grow significantly until 2050—amounting to 12–18% of the total allowable CO<sub>2</sub> emissions under the WRE [2] 450 ppm stabilisation scenario [1].

To date, the major share of these global shipping emissions is unregulated. International bunker fuel emissions have been excluded from the Kyoto Protocol. In contrast to emissions from domestic shipping, which amount to less than 0.6%, emissions from international shipping are not assigned to national emissions inventories. Therefore they remain unaffected by the Kyoto regulations. The UNFCCC conference in Copenhagen in 2009 also failed to give directions on how to proceed with emissions from international shipping. As a consequence, IMO and International Civil Aviation Organisation (ICAO) will continue to discuss regulating emissions in their respective sectors yet without formal guidance.

The present lack of regulation can be traced to the truly global nature of the shipping sector. In 2005, the world merchant fleet counted 90,662 million ships of 100 gross tonnes (gt) and more, transporting 7 billion tons of cargo between 160 countries [3, 4]. A significant part of the emissions caused by international shipping therefore takes place on the high seas outside of the jurisdiction of any country. Here only the United Nations Convention on the Law of the Sea (UNCLOS) and ratified IMO conventions apply. Moreover, regulating shipping emissions is difficult due to the multiple nationalities involved in shipping. Often ships are registered in one country – their flag state – but their owners may be citizens of another country while the operating company is based in a third country. Regulating this global business therefore needs a global inclusive approach that limits free-riding.

Abatement cost studies analysing potential technological and operational measures for reducing CO<sub>2</sub> emissions and their costs show that many cost-effective abatement

---

<sup>1</sup> In accordance with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (<http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html>), [1] define international shipping as shipping activities that cross borders, whereas domestic shipping is defined as local shipping activities without the crossing of borders. Both shipping definitions exclude fishing and military vessels. The term global shipping includes international and domestic shipping as well as fishing vessels but excludes military vessels.

measures are available to the shipping sector [1, 5–7]. They show that their implementation is beneficial even in the absence of a CO<sub>2</sub> regulation. Thus, integrating CO<sub>2</sub> emissions of the shipping sector into a UNFCCC climate regime or regulating these emissions within a sectoral approach based on IMO regulations could be economically beneficial. This makes a strong case for regulating shipping emissions because it is a cost-effective way of reducing emissions in general.

There are essentially two ways in which emissions from international shipping can be regulated: a UNFCCC-based versus a sectoral approach. If regulation based on the UNFCCC framework is chosen, emissions would have to be allocated to individual countries, adding to their total national emissions. Individual countries would then decide how to reduce their total national emissions, probably opting for cost-effective sectors and measures. Hence, regulation of the shipping sector may or may not be the consequence, depending on what national policy makers consider the most efficient method. Alternatively, a sectoral approach could be aimed for, which would focus only on the shipping sector's emissions and allocate them within the shipping sector. A global approach should be pursued to avoid free-riding, as shipping regulations introduced in some countries could easily be avoided if other non-committed countries lack regulation. From an economic perspective, an allocation to total national emissions combined with a global carbon price – e.g., within an international emissions trading system – would be most efficient. For this reason the focus is on regulations based on the UNFCCC framework.

For both options, however, an allocation of emissions to individual countries is necessary—even if a global scheme is set up in the sectoral approach. Governments will want to know the quantitative and financial effects of regulations on their industries before they agree to an international scheme. Additionally, their support and policing is necessary for the effective implementation and enforcement of regulations. Hence, the question of how to allocate shipping emissions to individual countries is relevant for every option. So far, research on this matter has been mostly qualitative [8–12] and few quantitative assessments exist [7, 13].

The analysis in this paper is a quantitative assessment, adding to the existing literature by analysing the UNFCCC options that have not yet been assessed and comparing them with those that have, e.g. by [13, 7]. This quantitative assessment differs from

previous studies because it is based on country-level data allowing a more detailed investigation into the effect of different allocation rules. Furthermore, the literature is extended by adding further allocation options proposed by the UNFCCC, such as proportional allocations based on national emissions, nationality of the ship owner and nationality of the operator. Furthermore, more recent and more detailed data are applied and a calculation approach is used, which enables a more sophisticated allocation based on flag state registry. Also updated data for an allocation based on the sale of bunker fuels is applied.

## **2. The shipping sector**

### ***2.1. Structure and emissions inventory of the shipping sector***

The maritime transport industry carries over 80% of the world's merchandise trade by volume and exhibits an estimated annual growth rate of 3.1% on average over the last three decades [14], which has accelerated to 6.5% on average per year in the period 2004–2008 [3].<sup>2</sup> In 2007, the world fleet consisted of slightly more than 100,000 ships of 100 gt and above [1]. Thereof, 44,971 ships belonged to the world merchant fleet (cargo ships) with over 1 billion deadweight tonnage (dwt), representing 89% of world total tonnage [1, 3]. Tankers, bulk carriers, and container ships represent the largest share of total world fleet in terms of dwt [3], in terms of fuel consumption and consequently in terms of emissions [1].

The structure of the shipping sector is complex due to multiple ownership natures of vessels. A ship can be owned by a company based in one country, whose owners are citizens of another country; it can be registered in another country (its flag state) and be operated by a company that is based in yet another country. Hence, multiple jurisdictions may apply in addition to the UNCLOS framework and IMO conventions. However, the country of registration, the flag state, is most relevant because it has the obligation to comply with international agreements.

---

<sup>2</sup> In 2008, growth in international seaborne trade decreased and growth in world merchandise exports decreased by 4 percentage points from 6% in 2007 to 2% in 2008 due to the economic downturn [14].

The difference between registration and ownership (control) of fleets becomes evident when comparing Tables 1 and 2.<sup>3</sup>

**Table 1:** Presentation of top 5 countries by number and deadweight tonnage in registration of world fleet, ships of 300 gt and more.

country	number of ships	country	deadweight tonnage (in 1000)
Panama	6 380	Panama	250 287
Japan	2 528	Liberia	114 975
China	2 428	Greece	61 141
Liberia	2 067	Hong Kong	59 554
Indonesia	1 878	Marshall Islands	58 368

Source: [3].

**Table 2:** Presentation of top 5 countries by number and deadweight tonnage in control of world fleet, ships of 1000 gt and more.

country	number of ships	country	deadweight tonnage (in 1000)
Japan	3 433	Greece	175 711
Germany	3 189	Japan	160 722
Greece	3 087	Germany	94 513
China	2 975	China	83 064
Norway	1 400	Norway	45 118

Source: [3].

It is clear that non-Annex I countries like Panama and Liberia are used as registration countries whereas actual control of the fleet mostly lies in developed countries like Greece, Japan, Germany and Norway, with the exception of China.

Establishing emission inventories for the shipping sector is a challenging task, inter alia due to limited data availability [15, 16]. The main reason for limited data availability is that ships are neither obliged to report their route of navigation nor their consumption of fuel during their voyages. In addition, ships vary greatly in their emission intensities caused by different factors such as size, age, purpose, condition and operation - in particular speed. This makes a general analysis of average fuel consumption and emissions per ship type difficult [1].

<sup>3</sup> Note that due to availability of data table 1 refers to ships of 300 gt and more while table 2 refers to ships of 1000 gt and more. While the difference in total ships is substantial when comparing number of ships (44,553 versus 34,915), the difference in dwt is much smaller (1.0796 billion versus 1.0719 billion) [3].

In recent years different approaches to estimating overall global shipping emissions have been presented in the literature [1, 7, 17–21].

[1] predicts that without any policy measures international shipping emissions will lie between 6% and 22% (925–1058 Mt of CO<sub>2</sub> emissions) higher in 2020 than emissions in 2007. By 2050 emissions are predicted to even lie between 119% and 204% (1903–2648 Mt of CO<sub>2</sub> emissions) higher than in 2007.

## ***2.2. Legal structures: IMO, UNCLOS and ownership of vessels***

Ships are mobile emitters, and, if engaged in international trade, cross different jurisdictions. The United Nations Convention on the Law of the Sea (UNCLOS) applies in international waters, called the High Seas, but in the exclusive economic zone, i.e., the coastal area, national jurisdiction applies. UNCLOS provides ships with the right of “innocent passage” through national territorial waters and economic zones, meaning that national or regional laws and regulations do not apply to the design, construction or equipment of foreign ships wanting to pass through—“unless they are giving effect to generally accepted international rules or standards” [22]. Therefore, national or regional laws, e.g. within the EU, cannot affect ships registered in a foreign country. Moreover, UNCLOS only regulates affairs between states; its regulations do not directly apply to ship owners or operators [1].

Ships are regulated by the laws of their country of registration. The process of “flagging out a ship”, i.e., registering it in a country other than the owner’s office location, is predominantly used to avoid regulation at home. From Table 1 above it becomes apparent that a large part of the fleet is registered in “open registry” countries, i.e., countries that have open or easy access to their flag. Under this system of “open flag” more than two thirds (68.3% in 2008) of ship tonnage are flying a “flag of convenience”, a trend which is increasing [3].

The IMO has 168 Member States representing almost 99% of the world tonnage and provides the legislative framework for international shipping with 50 conventions and protocols. Once a convention is agreed upon, the member states are asked to ratify it, thereby agreeing to implement it as part of their national legislation. Consequently, flag states must enforce this legislation upon their flag ships. Once IMO legislation has entered into force, it is considered to be a generally accepted international rule and

thereby overrides the UNCLOS right of innocent passage. Hence countries that have ratified it can apply it to all ships landing in their ports regardless of their flag.

In addition, the IMO principle of equal treatment of ships must be resolved with the UNFCCC principle of “common but differentiated responsibilities” that governs climate negotiations and ensures differentiation between contributions of developed and developing countries—this principle is a matter of continued disagreement at climate conferences and developing countries have argued that any IMO convention on curbing shipping emissions should only apply to developed countries in accordance with the spirit of the Kyoto Protocol [1]. Yet, three quarters of all merchant vessels, by dead-weight, engaged in international shipping are registered in countries that have no binding emission reduction targets under the Kyoto Protocol.<sup>4</sup>

The UNFCCC working group report of 2009 has also touched upon the regulation of shipping emissions by presenting several options in their negotiation text for the Cop15 in Copenhagen [23], but no agreement was made. Hence, the UNFCCC has yet to provide the input the IMO was hoping for.

### **3. Options under the UNFCCC to allocate shipping emissions**

In its 1996 National Communication by the Subsidiary Body for Scientific and Technological Advice (SBSTA) [24], the UNFCCC proposes eight possible allocation options for shipping emissions:

1. No allocation
2. Allocation to Parties in proportion to their national emissions
3. Allocation to Parties according to the country where the bunker fuel is sold
4. Allocation to Parties according to the nationality of the transporting company, or to the country where the vessel is registered, or to the country of the operator
5. Allocation to Parties according to the country of departure or destination of a vessel. Alternatively the emissions related to the journey of a vessel could be shared between the country of departure and the country of arrival

---

<sup>4</sup> If ownership is considered, instead of registration, then, of the total merchant fleet, 68% of dwt is controlled by OECD countries and 95% of dwt is controlled by only 35 countries [3].

6. Allocation to Parties according to the country of departure or destination of passenger or cargo. Alternatively, the emissions related to the journey of passengers or cargo could be shared by the country of departure and the country of arrival
7. Allocation to Parties according to the country that owns the cargo or origin of the passengers
8. Allocation to the Party of emissions generated in its national space

Options 2, 7 and 8 have already been dismissed by the SBSTA. [13] and [7] have assessed options 3 (IEA data from 2000), 5, 6 and parts of 4 (*flag state*). This paper adds option 2 because its general approach can provide a benchmark for comparison with other options, despite the fact that the SBSTA has dismissed it. Further, also an updated version of 3 (IEA data from 2007) and a complete analysis of option 4 (*flag state/operator/owner*) with new data and a different calculation method are added.

## **4. Calculation of emissions allocation to national inventories**

### ***4.1. Data set description and calculation approach of allocating CO<sub>2</sub> emissions***

The analysis is based on different statistical databases for 2007. Data from the International Energy Agency [25] on CO<sub>2</sub> emissions from fuel combustion and the World Bank [26] on country specific per capita CO<sub>2</sub> emissions are used as databases for determining a country's national CO<sub>2</sub> emissions inventory—in the following denoted as total national emissions.<sup>5</sup> For attributing the share of emissions from international marine bunker fuel sold to a country (allocation option 3 (*fuel sold*)), data from the IEA on CO<sub>2</sub> emissions from international marine bunker fuel sold is used [25]. For allocation options 2 (*proportional*) and 4 (*flag state/operator/owner*), additional data from the second IMO GHG study [1] is employed. In this study, a CO<sub>2</sub> emissions inventory for the shipping sector is established for the year 2007 by estimating fuel consumption based

---

<sup>5</sup> For the year 2007 the data sets only contain data on a country's total CO<sub>2</sub> emissions from fuel combustion and not for a country's GHG emissions. The latter is only available in the IEA statistics for the year 2005. Nevertheless, they are chosen as databases for determining a country's national emissions total because all datasets used on shipping emissions are based on the year 2007 too.



on activity data.<sup>6</sup> This data set covers all ships larger than 100 gt (in total 100,243 ships), excluding military vessels, and contains information for different ship categories on size, number of ships, annual average fuel consumption, and used fuel type. Emissions per category are calculated based on conversion factors:  $\epsilon = 3.13$  for heavy fuel oil (HFO) or  $\epsilon = 3.19$  marine diesel oil (MDO).<sup>7</sup>

Information on the nationality of the transporting country (*ownership*)<sup>8</sup>, country of registration (*flag state*), and country of ship operator (*operator*) was provided by the Institute of Shipping Economics and Logistics for 2007 [27]. By employing this data the analysis is limited to ships of 1,000 gt and more, which amounts to 32,292 for the two categories flag state and owner and 33,088 for the category operator.<sup>9</sup> These ships are predominately cargo ships most often used on the high seas.

The emission calculation for allocation option 2 (*proportional*) is straightforward: According to [1], international shipping emitted 870 Mt of CO<sub>2</sub> emissions and caused 2.7% of the world's CO<sub>2</sub> emissions in 2007. Consequently, 2.7% are added to all total national emissions, irrespective of whether a country is land-locked or sold international marine bunker fuel [24].<sup>10</sup>

For allocation option 3 (*fuel sold*) emissions from 2007 international marine bunker fuel sales are allocated to the respective countries.

To investigate allocation option 4 (*flag state/operator/owner*), emissions must be attributed to the individual countries' fleet. This can be done in terms of flag state registry (option 4a), operating company (option 4b), and ownership (option 4c). To gain

---

<sup>6</sup> The applied activity-based model cannot differentiate between international and domestic shipping, since some types of ships can be used in both international and domestic shipping. To differentiate between them, domestic fuel consumption based on fuel statistics is subtracted from the calculated global fuel consumption based on activity data [1]. To date, domestic shipping emissions are included in the national GHG emissions inventory reports of the UNFCCC Parties.

<sup>7</sup> The emission factors employed in [1] are in line with the 2006 IPCC Guidelines on National Greenhouse Gas Inventories (<http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.html>). Since some types of ships are able to use both types of bunker fuel, a conversion factor of  $\epsilon = 3.16$  is assumed for those ships.

<sup>8</sup> Lloyd's Register is followed by defining "ownership" as the "true nationality" of the controlling interest behind the fleet. In this case "true nationality" means where the benefits of the operation of the ships finally go to. So for example, if the owner of a ship is Greek and based in New York but remits the profits back to his home country Greece, then the "true nationality" would be Greece.

<sup>9</sup> Information on ship ownership and flag state registration is based on July 2007 data and information on operator is based on January 2008 data. Although [27] includes only around 1/3 of the ships (mainly cargo ships) that are included in [1] more than 70% of the world fleet's total fuel consumption is covered.

<sup>10</sup> As it is worked with a different database compared to [1] to determine a country's total national emissions, the relative share of international shipping of worldwide CO<sub>2</sub> emissions differs from the 2.7% mentioned in the second IMO GHG study. In the case of IEA data on CO<sub>2</sub> emissions from fuel combustion in 2007 [25] a share of around 3% is obtained.

insight into the country specific distribution of overall emissions, data on annual average fuel consumption per ship type derived from the activity-based approach by [1] is combined with data on ship ownership, flag, and operator taken from the Institute of Shipping Economics and Logistics [27].

To calculate the total emissions for a country's fleet, information on annual average fuel consumption per ship type is used and multiplied by the corresponding emission factors. The resulting emissions per ship type are then multiplied by the number of ships that each country owns, operates, or has registered in that category. The emissions  $E$  for a country  $i$ 's fleet are thus given by

$$E_i = \varepsilon \sum_j q_{ij} c_j(d_{ij}),$$

where  $\varepsilon$  represents the corresponding emissions factor,  $q$  the number of ships of country  $i$  in category  $j$ ,  $c_j(d_{ij})$  the specific fuel consumption value that gives yearly average fuel consumption depending on the ship size  $d$ .

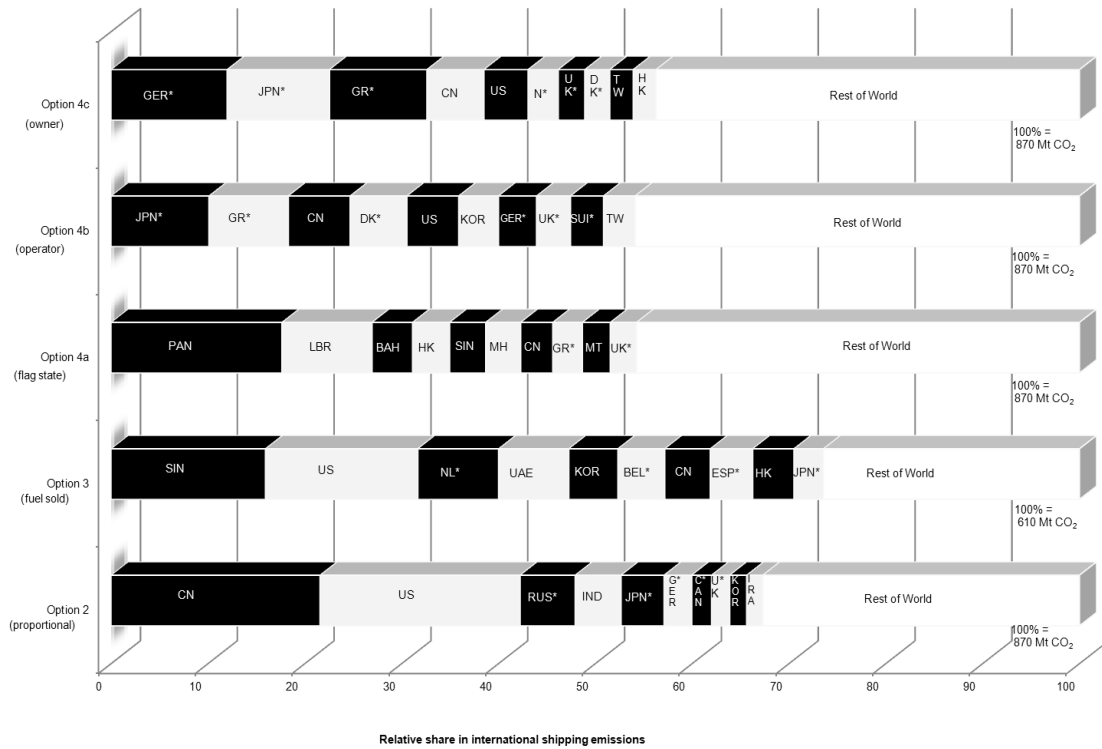
Note that due to the unavailability of ship movement data, the above calculation assumes equal activity for ships in the same category and does not represent the actual miles that a country's fleet in a specific category travelled annually. It merely represents the share of a country's fleet in a specific category in comparison. This assumption is made due to limited data availability.<sup>11</sup> Furthermore, 2007 was a good year for international seaborne trade in terms of ton-miles [14]. It can therefore be assumed that (almost) full employment of merchant ships existed, i.e. it can be reasoned that all registered ships were in use during the year 2007, which, in turn, supports our assumption of equal activity.

## 4.2. Results

The results of allocation options 2 (*proportional*), 3 (*fuel sold*), and 4a (*flag state*), 4b (*operator*), and 4c (*owner*) are presented in figure 1.

---

<sup>11</sup> Lloyd's Register maintains data on ship movements [7] but the authors have no access due to financial constraints.



**Figure 1:** Top 10 countries of allocated shipping emissions. The figure shows the top 10 countries according to relative share in total international shipping emissions per allocation option in comparison to the rest of the world. (a) Note that option 3 is based on 610 Mt of CO<sub>2</sub> emissions instead of 870 Mt of CO<sub>2</sub> emissions. This is because IEA statistics use a different methodology than [1] to account for international shipping emissions [1]. (b) Further, since two different climate regime scenarios are going to be analysed in Section 5.1, countries that have agreed to emission reduction targets under the Kyoto Protocol have been marked with an asterisk. *Source:* Own calculations based on IEA [26], Buhaug et al. [1], and ISL [3].

The results show that all option 4 cases would allocate roughly 50% of the emissions to the top ten countries and the other 50% to the rest of the world. This is considerably lower than allocation options 3 and 2 (70% and 65% respectively). However, the distribution of emissions varies significantly among options. Option 4c (*owner*) would allocate the highest CO<sub>2</sub> shares to Germany, Japan and Greece – all three have agreed to emission reduction targets under the Kyoto Protocol – followed by China and the US. Option 4b (*operator*) allocates the highest share to Japan, Greece and China, followed by Denmark and the US. The third case of option 4, allocation according to *flag state*, is not as balanced because Panama and Liberia alone would have to account for roughly 25% of all emissions—whilst both countries have small economies and a small amount

of total national emissions overall. In this scenario, only two out of the top ten countries have agreed to emission reduction targets under Kyoto.

The results for taking into account not only the increase in absolute emissions but also the relative increase in total national emissions is shown in the Appendix A (Tables A1–A4): the highest relative increase in total national emissions would fall on countries known for commonly “flagging out” ships and some large European shipping nations such as Denmark, Greece or Norway.

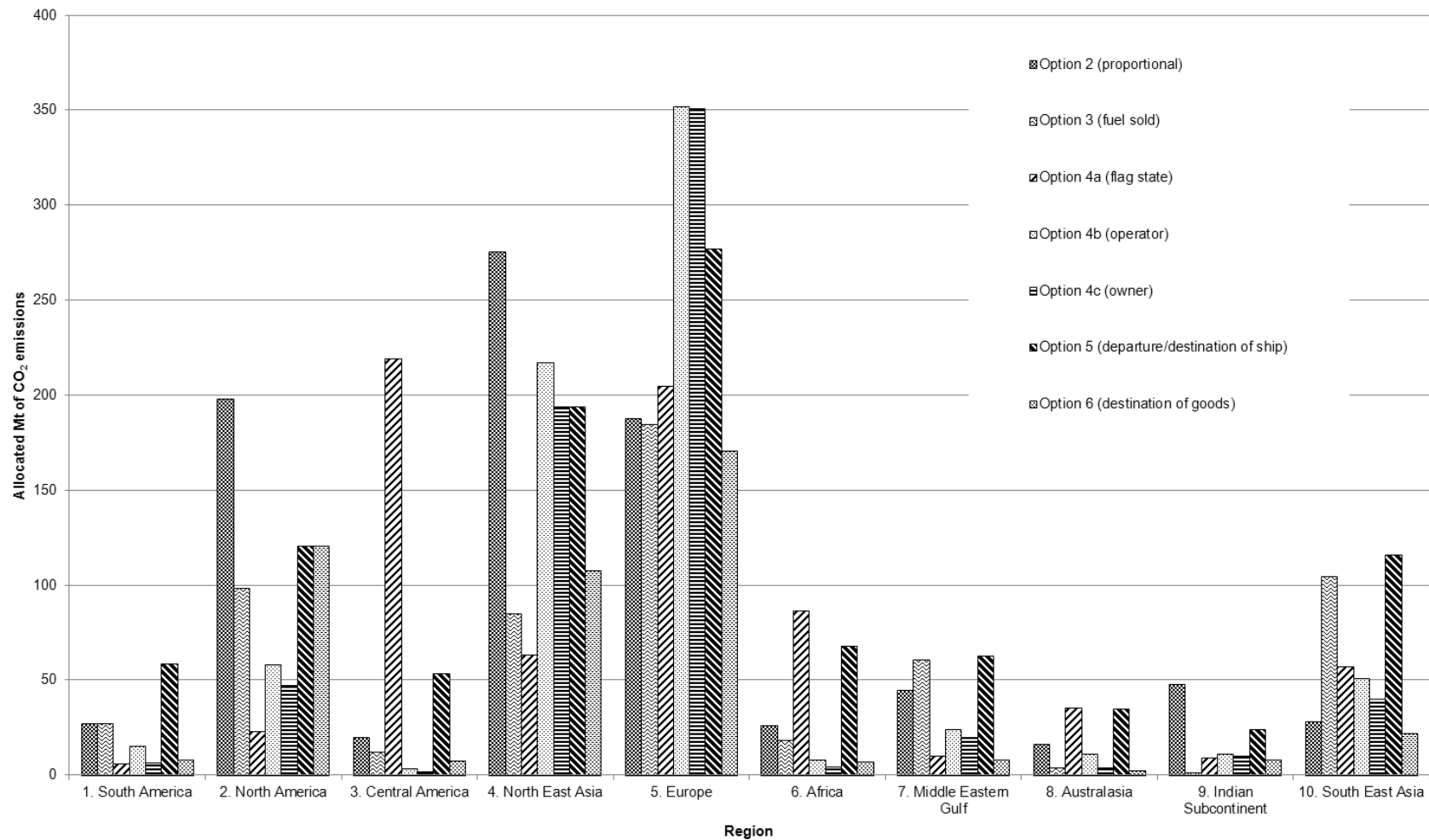
The result of allocation option 3 (*fuel sold*) shows that over 70 % of CO<sub>2</sub> emissions from international marine bunker fuel sold would be comprised of the top ten countries with the largest shares burdened on Singapore and the US, followed by the Netherlands. Allocation option 2 (*proportional*) – proportional add-on of shipping emissions to existing total national emissions – gives a cross-sectoral balance of emission totals. Hence, the countries that would be burdened the most by this allocation are those that have the highest share of total national emissions to begin with, i.e. China and the US: they alone account for almost 40% of global emissions, whilst none of them have any Kyoto Protocol commitments.

#### ***4.3. Putting the results into perspective***

Now, the different options analysed in section 4.2 will be compared to the options analysed in the studies of [13, 7]. In order to make them comparable, the regional aggregation of [7] is chosen. Their analysis is conducted at the level of 10 world regions, whereas the analysis of [13] is conducted at the level of 17 world regions. The analysis in this paper is conducted at the level of countries.<sup>12</sup> Also note that allocated emissions in option 5 (*departure/destination of ship*) are based on the year 2006 [7], option 6 (*destination of goods*) on the year 2000 [13], and options 2–4 on the year 2007. Figure 2 shows the regional allocation effects of international shipping emissions according to the various options.

---

<sup>12</sup> The aggregation of country level data to the level of the 10 world regions is straightforward, whereas the aggregation of the 17 world regions to the level of the 10 world regions is not. The reason is that the regions do not coincide in terms of geographical scope (assigned countries per region). For example, in [13] Russia belongs to one region, whereas in [7] it is split up and assigned to different regions. Thus the accuracy of option 6’s indicated Mt of CO<sub>2</sub> emissions is limited.



**Figure 2:** Comparison of allocation options on a regional scale. The figure shows the regional allocation effects of international shipping emissions according to the various options. *Source:* [7] for option 5, [13] for option 6, own calculations based on [24], [1], and [26] for option 2, 4(a-c).

At first glance, the picture looks extremely heterogeneous. To gain a better understanding, first it will be examined whether regions exist that score high in terms of allocated shipping emissions in all options. Next, it will be examined which option most equally distributes allocated shipping emissions across all regions. For this purpose the variation coefficient is used to illustrate the dispersion from the average within each option's distribution. Finally, options 3–6 will be related to option 2—proportional addition of shipping emissions to existing total national emissions. This delivers insight regarding to what extent the shipping-based allocation options 3–6 deviate from the country emissions-based allocation option 2 in each region. The term “shipping-based allocation option” is associated with an allocation based on general shipping activities, for example selling marine bunker fuel or owning a ship, whereas the term “country emissions-based allocation option” is associated with an allocation based on emissions within national territories.

In each option Europe is allocated at least 15% of total international shipping emissions, scoring higher than all other regions in options 3, 4b, 4c, 5, and 6. Thus, no matter which option is chosen, Europe is burdened with a large share of total international shipping emissions, followed by North East Asia and North America. Calculation of the variation coefficient shows that allocation in option 5 is less dispersed than in other options, allocating shipping emissions most equally across all regions, followed by options 3 and 2.

Regarding the distinction between shipping-based allocation options 3–6 and country emissions-based allocation option 2, the following observations can be made. Europe is allocated more emissions by shipping-based options than by the country emissions-based option, whereas the opposite is the case for North America and North East Asia. This implies that, if option 2 is chosen as an allocation rule, European shipping activities are underestimated. In contrast, if option 2 is chosen as an allocation rule, North American and North East Asian shipping activities are overestimated.

## **5. Discussion of allocation results**

### ***5.1. Scenario description and evaluation criteria***

In the following it will be distinguished between two international climate regime scenarios and three criteria for evaluation will be defined. The first scenario “Kyoto Accord” is based on the countries presently taking action as they already have concrete emission reduction targets under the Kyoto regime (Annex I countries). The second scenario “Copenhagen Accord” includes all countries that have committed to plans for reducing their greenhouse gas emissions by 2020, despite varying commitment levels. This list is much longer than the Kyoto Protocol list of Annex I countries because it also includes large developing and transition countries such as China, India, Brazil and South Africa, since all of these have made some emission reduction commitments,<sup>1</sup> albeit not in internationally binding treaties.

To evaluate the allocation results in the context of the two scenarios, three criteria are defined: The first evaluation criterion is that of environmental effectiveness, which examines the potential emission reductions. The second criterion is that of legal effectiveness, i.e., the potential for preventing regulation evasion. The third criterion is that of fair burden sharing and should be based on the polluter pays principle. The first group of polluters to be examined is defined as countries that import and export goods, thereby benefitting from trade, in which the shipping sector plays a large part. The second group of polluters is defined as countries that employ ships, i.e., the more ships are registered, owned or operated by that country, the more shipping emissions should be allocated to it.

### ***5.2. Discussion***

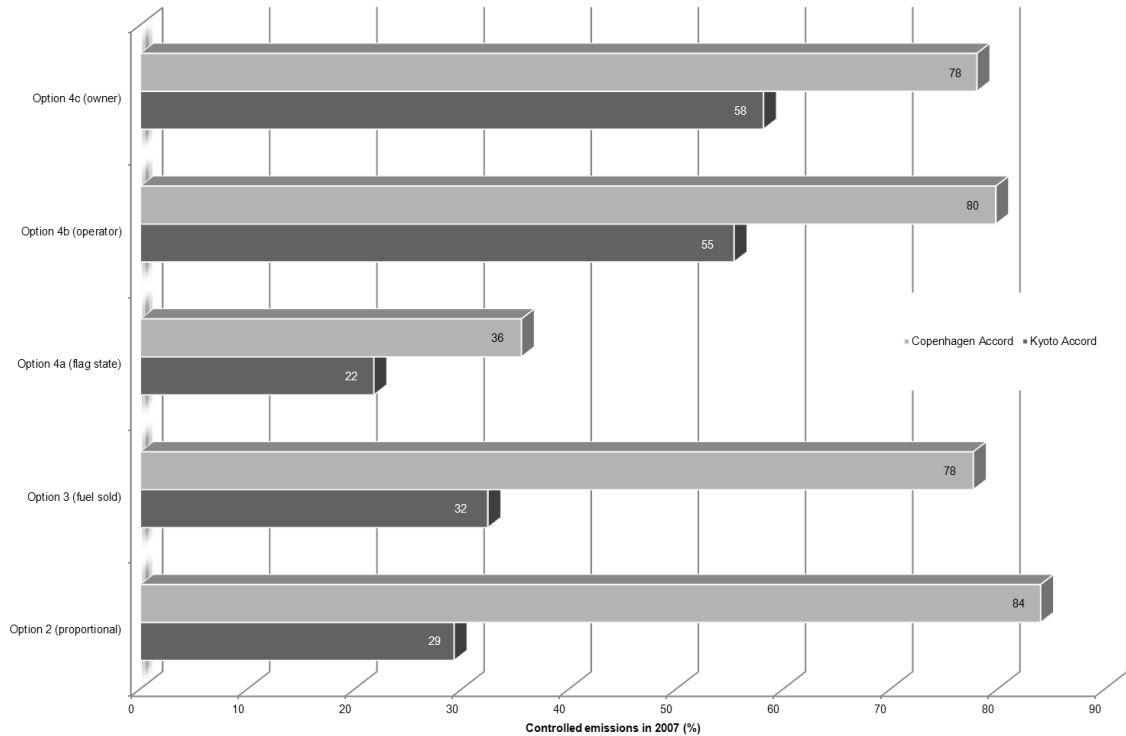
#### ***5.2.1. Environmental effectiveness***

The results for environmental effectiveness are presented in figure 3, showing the share of international shipping emissions in 2007 relative to the ideal case of a global climate regime (100% controlled emissions) according to the options 2, 3, and 4(a–c) which would be controlled in the two different scenarios described in section 5.1. Note that an

---

<sup>1</sup> A complete scenario description is in the Appendix B table B1, source for “Copenhagen Accord” list: <http://www.usclimatenetwork.org/policy/copenhagen-accord-commitments>. This list is updated regularly. Our scenario is based on the list’s status in August 2010.

analysis of this kind is not possible for the options discussed in [13] and [7] because they are based on a regional scale, making a distinction between Kyoto Annex I and non-Annex I countries impossible. The same applies to the second scenario “Copenhagen Accord” and in part to the third evaluation criteria “fair burden sharing”.



**Figure 3:** Comparison of environmental effectiveness. The figure shows the environmental effectiveness of allocation options 2, 3, 4a, 4b, and 4c according to scenarios Copenhagen and Kyoto Accord. *Source:* Own calculations based on [25], [1], [27].

It is evident that the registration of a ship as a basis for regulation (option 4a) would be environmentally ineffective both under the Kyoto and Copenhagen Accord scenarios because most shipping emissions would fall under flag states that have no commitments. Moreover, the process of “flagging out a ship” is easily done. Under the Kyoto Accord scenario options 4c and 4b indicate the highest levels of controlled emissions and therefore should be preferred over the other options. However, under the Copenhagen Accord scenario apart from option 4a all the other options indicate a similarly high level of coverage, around 80%, with no great disparities between them.



### 5.2.2. Legal effectiveness

The global nature of the shipping sector entails the danger that if only few countries burden their shipping sector with emission regulation, its stakeholders will search for ways of evading the regulation.

Owners or operators (4b and 4c) will simply relocate their head offices to a country where no such regulations exist or where they would be exempt from emission reduction targets. The same is true for option 4a, as flagging out a ship is easily done. Evasion of regulation on a grand scale is also possible for option 3, as ships can be fuelled up in countries without regulation or emission reduction commitments. Evasion in the case of Option 5 (*departure/destination of ship*) and 6 (*destination of goods*) is only possible if ships call at or imports (cargo) are discharged at ports in countries without regulation or emission reduction commitments [11, 28]. All these options imply that allocated shipping emissions would be directed away from committed countries to countries with no commitments or regulations. Only in the case of option 2 – adding shipping emissions to the grand total of national emissions as a fixed percentage for all countries – does the evasion of regulation have no effect on allocated emissions. In summary, environmental effectiveness is heavily dependent on the legal effectiveness, and, for all options, a level of cooperative enforcement is potentially desirable.

The number of countries willing to regulate their shipping emissions should be fairly considerable taking into account the cost-effectiveness of abatement measures and the abatement potential in this sector, as laid out in the introduction. The downside of course is the evasion of regulation and loss of competitiveness in this highly global and competitive sector. However, if enough countries are willing to cooperate, they could introduce IMO regulation affecting operators, owners, or flag states. Ideally, it should be the responsibility of operators because they have control over shipping routes, speed, and other operational details determining emission levels—and they have the opportunity to charge owners for their services as the two parties agree. Hence, if a certain number of countries implement the IMO regulation obliging operators to achieve certain targets, it comes into force. And, as explained in section 2.2, once an IMO regulation is in force, countries can impose the regulation on their operators even though the ship is registered under another flag. The allocation option 4b – allocated emissions to operators – is also beneficial for this purpose because it includes countries with very

busy ports such as EU countries, Singapore and Hong Kong, whose consent would be valuable for an effective implementation.

### 5.2.3. Burden sharing

Tables 3a and 3b represent the top 10 trading countries defined by their relative share of world goods exports and imports in 2007. They also show whether these countries are under the top ten most burdened countries according to each option (Figure 1 in section 4.2). The listed countries are the top polluters of international shipping emissions according to our fairness criterion and, consequently, the largest share of emissions should be allocated to them.

**Table 3a:** Representation of the top 10 trading countries defined by their relative share of world goods exports in 2007.

Country	Share of world goods exports in 2007 (%)	Country included in options				
		2	3	4a	4b	4c
Germany	9.84	x			x	x
China	8.89	x	x	x	x	x
US	8.40	x	x		x	x
Japan	4.94	x	x		x	x
France	3.98					
Italy	3.66					
Netherlands	3.37		x			
UK	3.22	x		x	x	x
Canada	3.15	x				
South Korea	2.76	x	x		x	

Source: [26] (goods exports, BoP, current US\$).

**Table 3b:** Representation of the top 10 trading countries defined by their relative share of world goods imports in 2007.

Country	Share of world goods imports in 2007 (%)	Country included in options				
		2	3	4a	4b	4c
US	14.55	x	x		x	x
Germany	7.98	x			x	x
China	6.69	x	x	x	x	x
UK	4.59	x		x	x	x
France	4.44					
Japan	4.24	x	x		x	x
Italy	3.69					
Netherlands	3.01		x			
Spain	2.88		x			
Canada	2.75	x				

Source: [27] (goods imports, BoP, current US\$).

A glance at the right column “Country included in options” highlights that no option perfectly mirrors this list of countries. The case which best accounts for the global distribution of trade and wealth is obviously option 2. This option is followed by option 4b, 3 and 4c. It is obvious with the exception of China and the United Kingdom, that option 4c does not reflect the list of top 10 trading countries at all.

The first result for the second group of polluters is that options 2, 3, 5 and 6 can be discarded as fair allocation options since they are not based on owning or operating ships or having them registered. Only the three sub cases of option 4 would lead to a fair allocation within the shipping sector. The second result is that out of all three sub cases option 4b – allocation based on operator – is favoured. The country where operators are based should be burdened with the emissions that are caused by their operations. This is because operators have the most control over their ship’s emission levels by regulating speed and routes. Furthermore, they are in a position to charge their clients or ship owners for their services.

## **6. Conclusion**

Abatement cost studies that analyse the potential technological and operational measures for reducing CO<sub>2</sub> emissions within the shipping sector and their costs show a considerable total abatement potential and that, even in the absence of a CO<sub>2</sub> regulation, the implementation of most of these measures is economically beneficial. Due to this apparent cost-effectiveness, there is a strong case for regulating shipping emissions within either a UNFCCC climate regime or sectoral approach based on IMO regulations.

Focussing on regulation within a UNFCCC climate regime, in this paper various options for allocating CO<sub>2</sub> emissions from international shipping to individual countries proposed by the Subsidiary Body for Scientific and Technological Advice of the UNFCCC were analysed. The analysis has shown that there is no single allocation option that can be regarded as environmentally effective, legally effective, and allowing for fair burden sharing. It could be argued that the simplistic option 2 with the proportional add-on is, in some respects, the best scoring option in the scenario “Copenhagen

Accord”, as it burdens the largest economies in terms of overall emissions and in terms of trade benefits. Thus, compared to other options, option 2 is environmentally effective and entails a fair burden sharing. However, it heavily disadvantages those large economies that are landlocked or do not significantly engage in shipping. It also advantages those small island states that benefit from being used as registration or relocation destinations. Currently, due to the negotiations in Copenhagen 2009 failing, the “Kyoto Accord” scenario should be taken as the most serious basis for discussion. From this perspective, it is clear that the most environmentally effective options are those of 4b (operator) and 4c (owner). As option 4b scores better than option 4c in terms of a fair burden sharing, it should be the preferred option. If, in addition, evasion of regulation is prevented by an IMO regulation, then operators have the most control over the emission levels of their ships by regulating speed and routes. Furthermore, they are in a position to charge their clients or the ship owners for their services. Consequently, the conclusion is drawn that the best way to allocate international shipping emissions within a UNFCCC regime is on the basis of the operating company—option 4b.

However, it is recognised that the political realisation will be difficult and it is not clear whether the international community will agree to shipping emission reductions, neither within the UNFCCC nor the IMO regime. As the BBC reported on 7<sup>th</sup> October 2010, China is against emissions regulations or standards in the shipping industry unless it is accompanied by financial aid to developing countries.<sup>2</sup> Hence, the most effective ways to allocate shipping emissions within a UNFCCC regime have been sketched—but implementation thereof depends on political will and, currently, progress in this field is not likely.

A number of limitations apply. First, the conclusions are based on results derived from 2007 data. Since this reflects the situation of the shipping sector for only one year, future studies should try to extend the analysis to several years making results more robust. Second, the use of ship movement data would be preferable to assess the actual miles that a country’s fleet travelled in one year. However, at present such data is not affordable for researchers. In the future it would be interesting to achieve a more detailed evaluation of who would gain or lose from regulating CO<sub>2</sub> emissions from

---

<sup>2</sup> <http://www.bbc.co.uk/news/science-environment-11497829>.

international shipping in a Post-Kyoto agreement and therefore oppose or support a specific allocation option.

## 7. References

- [1] Buhaug Ø, Corbett JJ, Endresen Ø, Eyring V, Faber J, Hanayama S, Lee DS, Lee D, Lindstad H, Markowska AZ, Mjelde A, Nelissen D, Nilsen J, Pålsson C, Winebrake JJ, Wu W–Q, Yoshida K., 2009. Second IMO GHG study 2009. London: International Maritime Organization (IMO).
- [2] Wigley TML, Richels R, Edmonds JA. Economic and Environmental Choices in the Stabilization of Atmospheric CO<sub>2</sub> Concentrations. *Nature* 1996; 379: 240–243.
- [3] ISL. Shipping Statistics Yearbook 2008. Bremen: Institute of Shipping Economics and Logistics (ISL); 2008.
- [4] Stopford M. *Maritime Economics*, 3rd Edition. Routledge; 2009.
- [5] Alvik S, Eide MS, Endresen Ø, Hoffmann P, Longva T. Pathways to Low Carbon Shipping: Abatement Potential Towards 2030. DNV (Det Norske Veritas); 2010. [http://www.dnv.com/binaries/Pathways\\_to\\_low\\_carbon\\_shipping\\_tcm4420472\\_tcm4-428628.pdf](http://www.dnv.com/binaries/Pathways_to_low_carbon_shipping_tcm4420472_tcm4-428628.pdf) (accessed 4/16/2010).
- [6] Eide MS, Endresen Ø, Skjonga R, Longva T, Alvik S. Cost-effectiveness Assessment of CO<sub>2</sub> Reducing Measures in Shipping. *Maritime Policy & Management* 2009; 36 (4): 367–384.
- [7] Faber J, Markowska A, Nelissen D, Davidson M, Eyring V, Cionni I, Selstad E, Kågeson P, Lee D, Buhaug Ø, Lindstad H, Roche P, Humpries E, Graichen J, Cames M, Schwarz W. Technical Support for European Action to Reducing Greenhouse Gas Emissions from International Maritime Transport. Delft: CE Delft; 2009. [http://www.ce.nl/publicatie/technical\\_support\\_for\\_european\\_action\\_to\\_reducing\\_greenhouse\\_gas\\_emissions\\_from\\_international\\_maritime\\_transport/1005](http://www.ce.nl/publicatie/technical_support_for_european_action_to_reducing_greenhouse_gas_emissions_from_international_maritime_transport/1005) (accessed 4/12/2010).
- [8] Åhman M. Why International Transport Needs a Sectoral Approach. In Egenhofer C (ed.). *Beyond Bali – Strategic Issues for the Post-2010 Climate Change Regime*. Ch. 11, pp. 146–155. Brussels: Centre for European Policy Studies; 2008.
- [9] Kågeson P. *The Maritime Emissions Trading Scheme*. Stockholm: Nature Associates; 2008. <http://www.natureassociates.se/pdf/METS%20final.pdf> (accessed 11/23/2009).

- [10] Zetterberg L. How to Integrate International Aviation and Shipping into a Global Emissions Trading system. In Egenhofer C (ed.). *Beyond Bali – Strategic Issues for the Post-2010 Climate Change Regime*. Ch. 12, pp. 156–162. Brussels: Centre for European Policy Studies; 2008.
- [11] Faber J, Boon B, Berk M, den Elzen M, Olivier J, Lee D. *Aviation and Maritime Transport in a post 2012 Climate Policy Regime*. Report 500102 008. Bilthoven: Netherlands Environmental Assessment Agency; 2007.  
<http://www.rivm.nl/bibliotheek/rapporten/500102008.pdf> (accessed 4/12/2010).
- [12] Bode S, Isensee J, Krause K, Michaelowa A. International Climate Policy: Analysis of Ecological, Technical and Economic Implications for International Maritime Transport. *Journal of Maritime Economics* 2002; 4 (2): 164–184.
- [13] den Elzen M, Olivier J, Berk M. An Analysis of Options for Including International Aviation and Marine Emissions in a post-2012 Climate Mitigation Regime. MNP Report 500114007/2007; 2007.
- [14] UNCTAD. *Review of Maritime Transport*. New York and Geneva: UNCTAD; 2009.
- [15] Wang C, Corbett JJ, Firestone J. Improving Spatial Representation of Global Ship Emissions Inventories. *Environmental Science and Technology* 2008; 42 (1): 193–199.
- [16] Wang C, Corbett JJ, Firestone J. Modeling Energy Use and Emissions from North American Shipping: Application of the Ship Traffic, Energy and Environment Model. *Environmental Science and Technology* 2007; 41 (9): 3226–3232.
- [17] Paxian A, Eyring V, Beer W, Sausen R, Wright C. Present-day and Future Global Bottom-up Ship Emission Inventories Including Polar Routes. *Environmental Science and Technology* 2010; 44 (4): 1333–1339.
- [18] Eyring V, Köhler HW, van Aardenne J, Lauer A. Emissions from International Shipping: 1. The last 50 years. *Journal of Geophysical Research* 2005; 110 (D17305): 1–12.
- [19] Endresen Ø, Sørsgård E, Behrens HL, Brett PO, Isaksen ISA. A Historical Reconstruction of Ships Fuel Consumption and Emissions. *Journal of Geophysical Research* 2007; 112 (D12301): 1–17.
- [20] Endresen Ø, Sørsgård E, Sundet JK, Dalsøren SB, Isaksen ISA, Berglen TF, Gravir G. Emission from International Sea Transportation and Environmental Impact. *Journal of Geophysical Research* 2003; 108 (D17): 1–22.

- [21] Corbett JJ and Köhler HW. Updated Emissions from Ocean Shipping. *Journal of Geophysical Research* 2003; 108 (D20): 1–15.
- [22] United Nations Convention on the Law of the Sea of 10 December 1982  
[www.un.org/Depts/los/convention\\_agreements/texts/unclos/UNCLOS-TOC.htm](http://www.un.org/Depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm).
- [23] UNFCCC. Report of the Ad Hoc Working Group on Long-term Cooperative Action under the Convention on its seventh session, held in Bangkok from 28 September to 9 October 2009, and Barcelona from 2 to 6 November 2009. Bonn: UNFCCC; 2009.
- [24] SBSTA. National Communication of the Subsidiary Body for Scientific and Technological Advice, FCCC/SBSTA/1996/9/Add.1, 24<sup>th</sup> October 1996.
- [25] IEA. CO<sub>2</sub> Emissions from Fuel Combustion, 2009 Edition. Paris: IEA; 2009.
- [26] World Bank. World Development Indicators 2009. World Bank Group; 2009.
- [27] ISL. Data on Owner, Operator, and Flag State Registration. Bremen: Institute of Shipping Economics and Logistics (ISL); 2008.
- [28] Faber J, and Rensma K. Left on the High Seas: Global Climate Policies for International Transport. October 2008 update. Delft: CE Delft; 2008.  
[http://www.ce.nl/publicatie/left\\_on\\_high\\_seas/846](http://www.ce.nl/publicatie/left_on_high_seas/846) (accessed 11/23/2009).

## 8. Appendix A

Tables A1 to A4 show the resulting top 10 countries according to allocation options 4a, 4b, 4c, and 3, if international shipping emissions would be allocated to total national emissions.

**Table A1:** Top 10 countries according to relative increase in total national emissions (in %).

Country	Relative increase (in %)	$\Delta$ in 1000 t
<i>Option 4a (flag state)</i>		
Marshall Islands	36 179	31 476
Liberia	21 874	80 935
Antigua & Barbuda	3 473	15 054
Saint Vincent	2 988	5 737
Panama	2 367	153 605
Bahamas	1 689	36 330
Bermuda	1 463	8 427
Comoro Islands	1 251	786
Vanuatu	1 239	1 120
Malta	920	25 030

*Source:* Own calculations based on IEA [26], Buhaug et al. [1], World Bank [27], and ISL [3].

**Table A2:** Top 10 countries according to relative increase in total national emissions (in %).

Country	Relative increase (in %)	$\Delta$ in 1000 t
<i>Option 4b (operator)</i>		
Bermuda	787	4 534
Marshall Islands	189	165
Denmark*	101	51 069
Greece*	73	71 235
Gibraltar	72	341
Switzerland*	70	29 638
Norway*	66	24 253
Kiribati	64	18
Singapore	61	27 508
Hong Kong, China	57	24 735

*Source:* Own calculations based on IEA [26], Buhaug et al. [1], World Bank [27], and ISL [3].



**Table A3:** Top 10 countries according to relative increase in total national emissions (in %).

Country	Relative increase (in %)	$\Delta$ in 1000 t
<i>Option 4c (owner)</i>		
Bermuda	216	1 247
Greece*	89	87 505
Gibraltar	74	349
Norway*	74	27 171
Cyprus	66	4 815
Kiribati	64	18
Hong Kong, China	47	20 553
Denmark*	45	22 493
Singapore	40	17 931
Bahamas	19	415

*Source:* Own calculations based on IEA [26], Buhaug et al. [1], World Bank [27], and ISL [3].

**Table A4:** Top 10 countries according to relative increase in total national emissions (in %).

Country	Relative increase (%)	$\Delta$ in 1000 t
<i>Option 3 (fuel sold)</i>		
Gibraltar	817	3.84
Singapore	216	97.28
Netherlands Antilles	128	5.77
Malta	98	2.67
Hong Kong, China	60	25.95
United Arab Emirates	34	44.22
Netherlands*	28	50.92
Belgium*	28	29.54
Gabon	19	0.48
Uruguay	18	1.04

*Source:* Own calculations based on IEA [26] and World Bank [27].

## 9. Appendix B

**Table B1:** Scenario description.

Kyoto Accord	Copenhagen Accord	Global Accord
Australia	Australia	all countries
Austria	Austria	Russian Federation
Belgium	Belarus <sup>a</sup>	Singapore <sup>a</sup>
Bulgaria	Belgium	Slovak Republic
Canada	Brazil <sup>a</sup>	Slovenia
Croatia	Bulgaria	South Africa <sup>a</sup>
Czech Republic	Canada	South Korea <sup>a</sup>
Denmark	China <sup>a</sup>	Spain
Estonia	Croatia	Sweden
Finland	Czech Republic	Switzerland
France	Denmark	Ukraine
Germany	Estonia	United Kingdom
Greece	Finland	United States <sup>a</sup>
Hungary	France	
Iceland	Germany	
Ireland	Greece	
Italy	Hungary	
Japan	Iceland	
Latvia	India <sup>a</sup>	
Lithuania	Indonesia <sup>a</sup>	
Luxembourg	Ireland	
Netherlands	Italy	
New Zealand	Japan	
Norway	Kazakhstan <sup>a</sup>	
Poland	Latvia	
Portugal	Liechtenstein <sup>a</sup>	
Romania	Lithuania	
Russian Federation	Maldives <sup>a</sup>	
Slovak Republic	Mexico <sup>a</sup>	
Slovenia	Luxembourg	
Spain	Netherlands	
Sweden	New Zealand	
Switzerland	Norway	
Ukraine	Poland	
United Kingdom	Portugal	

<sup>a</sup>All countries that are not Party to the Kyoto Protocol but associated with action or targets in the Copenhagen Accord

Source: USCAN <http://www.usclimatenetwork.org/policy/copenhagen-accord-commitments>

## Part II

### Climate Change Policy

#### Paper II: The Potential Contribution of the Shipping Sector to an Efficient Reduction of Global Carbon Dioxide Emissions

Heitmann, N., Peterson, S., 2012.

The Potential Contribution of the Shipping Sector to an Efficient Reduction of Global Carbon Dioxide Emissions, Kiel Working Paper No. 1813, Kiel Institute for the World Economy.

# The Potential Contribution of the Shipping Sector to an Efficient Reduction of Global Carbon Dioxide Emissions <sup>\*</sup>

Nadine Heitmann<sup>a</sup> and Sonja Peterson<sup>a</sup>

<sup>a</sup> Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

## Abstract

In this paper, we analyze how much the shipping sector could contribute to global CO<sub>2</sub> emission reductions from an efficiency point of view. To do this, a marginal abatement cost curve (MACC) for the shipping sector is generated that can be combined with a MACC for conventional CO<sub>2</sub> abatement in the production and consumption sectors around the world. These two MACCs are used to assess the following as regards the various global reduction targets: (a) what the maximum global cost savings would be that could be achieved by abating emissions in the shipping sector, (b) how much the shipping sector could contribute to abating emissions cost efficiently, and (c) what the potential additional costs of implementing a separate solution for the shipping sector would be. The focus is on the year 2020. We find that the shipping sector could always contribute to efficient global emission reductions and thus could always achieve global cost savings, but also that the size of the contribution and the size of cost savings depend heavily on the MACC case assumed, i.e., on how the existence of negative abatement costs is treated in a MACC, and on the reduction potentials and costs of measures assumed.

**Keywords:** climate change, shipping sector, CO<sub>2</sub> emissions, marginal abatement cost curve

**JEL classification:** Q52, Q54, Q58

---

<sup>\*</sup> We are grateful to Katrin Rehdanz, Markus Pape, and Matthias Weitzel for their helpful suggestions and comments. Moreover, we would like to thank 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.

## 1. Introduction

The Second IMO GHG Study 2009 (Buhaug et al., 2009) of the International Maritime Organization (IMO) on greenhouse gases (GHG) in the shipping sector presented two important insights. First, the shipping sector contributed about 3.3% to global GHG emissions in 2007, which is more than what was assumed before.<sup>1</sup> Second, the shipping sector's CO<sub>2</sub> emissions are projected to increase significantly in the coming decades if its emissions remain unregulated (Buhaug et al., 2009). The consequence would be that in the next decades the shipping sector's CO<sub>2</sub> emissions would constitute a considerable proportion of the maximum allowed emissions, i.e., the maximum emissions that are in line with the United Nations Framework Convention on Climate Change's (UNFCCC) 2°C target (UNEP, 2011). Thus, other sectors would have to emit less and reduce their emissions further to offset the increase in shipping emissions.

This has led to discussions on how to regulate the shipping sector's CO<sub>2</sub> emissions, discussions which are continuing not only in the IMO, but also in the scientific community. These discussions center around the question whether this sector should be subject to an emission cap or whether it should be subject to some other means of reducing emissions (UNEP, 2011). Progress was made when the IMO agreed on two mandatory efficiency measures to reduce CO<sub>2</sub> emissions from shipping in July 2011, (MEPC, 2011): the Energy Efficiency Design Index (EEDI), which is exclusively for newly built ships, and the Ship Energy Efficiency Management Plan (SEEMP). Market-based policies for the shipping sector are also being discussed and investigated (MEPC, 2010).

While there is some literature on the pros and cons of different allocation options to allocate shipping emissions to countries and on their effects for specific country groups (den Elzen et al., 2007, Gilbert and Bows, 2012, Heitmann und Khalilian, 2011, Wang, 2010) and some literature on technical abatement potentials and the costs of different measures (Buhaug et al., 2009, Eide et al. 2011, 2009, Faber et al., 2011a/Wang et al., 2010,<sup>2</sup> Faber et al., 2009, Longva et al., 2010), the literature on how much the shipping sector should contribute to global emission reductions from an efficiency point of view

---

<sup>1</sup> In addition, the shipping sector was one of the world's major CO<sub>2</sub> emitters in 2007 (evidenced by comparing CO<sub>2</sub> emissions of shipping in 2007 (Buhaug et al., 2009) with data on CO<sub>2</sub> emissions from fuel combustion per country in 2007 (IEA, 2009b).

<sup>2</sup> Note that Faber et al. (2011a) is an updated version of Wang et al. (2010), but that only the later provides data that we make use of in this paper.

remains limited. Only Eide et al. (2009) derive a decision criterion for regulating CO<sub>2</sub> emissions in the shipping sector that is in line with the 2°C target. Yet, the importance of regulating CO<sub>2</sub> emissions in the shipping sector can only be assessed, when the potential cost savings are known. Also, how CO<sub>2</sub> emissions should be regulated depends on what the efficient contribution of the shipping sector actually is. In this paper, we thus want to address these issues.

From a methodological point of view, the problem is that global top-down economy-climate models or integrated assessment models (IAMs) that are able to analyze the cost efficient contributions of various sectors do not or do not explicitly include the shipping sector. Another approach, which is less sophisticated and simpler, to include the shipping sector is using marginal abatement cost curves (MACCs) (see Criqui et al., 1999, Ellerman and Decaux, 1998). This approach is mostly used to analyze the impacts of international emissions trading at the country level (see, e.g., Ellerman and Decaux, 1998, den Elzen et al., 2005, Löschel and Zhang, 2002, Rickels et al., 2012), but can also be used to calculate sectoral contributions to emission reductions. While using MACCs has some drawbacks and results have to be treated with care (Kesicki and Ekins, 2012, Kesicki and Strachan, 2011, Klepper and Peterson, 2006, Morris et al., forth.), MACCs can nevertheless provide an indication of the cost effective contributions of various nations/sectors to emission reductions.

The information on abatement costs and potentials that is available for the shipping sector is a few expert-based MACC studies that have been published recently (Buhaug et al. 2009, Eide et al. 2011, Faber et al. 2011a/Wang et al. 2010, and Faber et al., 2009). We use this information to generate a global MACC for the shipping sector that can be combined with a MACC for conventional CO<sub>2</sub> abatement in the production and consumption sectors around the world. We then use these two MACCs to assess for various global reduction targets: (a) the maximum global cost savings that could be achieved by emission abatement in the shipping sector, (b) the cost efficient abatement contributions of the shipping sector to the global reduction targets, and (c) the potential additional costs that would be incurred by implementing a separate solution for the shipping sector. We focus on the year 2020.

This paper is structured as follows. Section 2 provides some background information on the shipping sector, gives an overview of existing MACC studies, and discusses the

methodological challenges that arise when using an expert-based cost assessment in combination with MACCs generated by a top-down model. The main challenge is how to treat the negative abatement costs that are found in the MACC studies of the shipping sector. We discuss how these negative abatement costs can be interpreted and suggest three different approaches to deal with them in our context. Accordingly, we derive three different MACCs and corresponding marginal abatement cost functions for the shipping sector. Section 3 shows how the computable general equilibrium (CGE) model DART (Dynamic Applied Regional Trade) can be used to generate a global MACC, excluding the shipping sector, and a corresponding marginal abatement cost function. Section 4 describes three global emission reduction scenarios and presents the model results for these scenarios, in particular, the efficient contribution of the shipping sector and the global cost savings. Section 5 discusses the results and Section 6 summarizes and concludes.

## **2. Generating a MACC for the shipping sector**

### ***2.1. Overview of MACC studies***

Faber et al. (2011b) provide a comparative analysis of recently published MACC studies for the world fleet. Overall, four major expert-based MACC studies exist that estimate the maximum reduction potential of abatement measures, which are mainly energy-efficiency measures, and their respective abatement costs for the world fleet (or a specific share of it) for the years 2010, 2020, and 2030 (Buhaug et al. 2009, Eide et al., 2011, Faber et al., 2011a/Wang et al., 2010, and Faber et al., 2009). Table 1 presents an overview of the assumptions made in these studies and results for the year 2020, the year we focus on in our analysis.<sup>3</sup>

---

<sup>3</sup> Faber et al. (2009) present a MACC for the year 2030 that is not included in Table 1.

**Table 1:** Overview of expert-based MACCs: assumptions and results

Study	Year	Base year	Baseline emissions (Mt CO <sub>2</sub> )	Maximum abatement potential (Mt CO <sub>2</sub> )	Cost effective potential <0\$/t (Mt CO <sub>2</sub> )	Measures included	Measures applied to	Fuel price (\$/t)	Discount rate (in %)
Buhaug et al. (2009)	2020	2007	1250	210-440	135-365	25 grouped into 10	fleet average	500 (1,000, 1,500)	4 (16)
Eide et al. (2011)	2020	2008	1191	487	290	25	59 ship segments	350 (HFO) 500 (MDO) 350-450 (LNG)	5
Faber et al. (2011a)	2020	2007	<sup>a</sup> ~1290	436	340	22 grouped into 15	53 ship segments	700, 900	10 (4 and 18)

<sup>a</sup> In Faber et al. (2011a), the baseline is not given explicitly (central estimate 436 Mt are 33% of the baseline in 2020 and 340 Mt are 26% of the baseline in 2020).

*Source:* Own presentation based on Buhaug et al. (2009), Eide et al. (2011), and Faber et al. (2011a).

The MACC estimates shown in Table 1 have in common that the maximum abatement potential of the world fleet is large (about 15% – 40% relative to business-as-usual (BAU) emissions) and that an important share of the maximum abatement potential could be achieved at negative costs. This cost-effective abatement potential is, without any further regulation being required, in the order of between 255 Mt CO<sub>2</sub><sup>4</sup> and 340 Mt CO<sub>2</sub> for 2020 (Eide et al., 2011, Faber et al., 2011a/Wang et al., 2010), or between 20%–26% of projected emissions in 2020.

Data is often not available on the costs and abatement potentials of abatement measures. Therefore, the MACC studies include only measures for which costs and abatement potential estimates exist (e.g., Faber et al., 2011a/Wang et al., 2010). Some measures may be mutually exclusive, which also has to be taken into account when generating the abatement cost curves from these data (Faber et al., 2011a). This fact also allows the generated curves to be interpreted as MACCs, which they are not in the narrower sense, since they only calculate the average cost per ton abated and not of the marginal (last) ton abated.

The MACC studies often differentiate between several categories of abatement measures, which differ from each other in terms of, e.g., costs and implementation, see

<sup>4</sup> This number represents the central estimate of cost-effective potential (<0\$/t) in Buhaug et al. (2009).



Table 2. For example, Faber et al. (2011a)/Wang et al. (2010) differentiate between operational and technical measures, whereas Eide et al. (2011) differentiate between operational and technical measures, alternative fuels and/or power sources, and structural changes.

**Table 2:** Categories of measure types.

	Operational measures	Technical measures	Alternative fuels/ power sources	Structural changes
Purpose	operation and maintenance of ships	reduction of power requirement to engines or improving energy-efficiency	alternative set of technical measures	include energy-efficiency improvements in interaction between two counterparts in shipping
Examples	enhanced weather routing, hull and propeller cleaning, slow steaming	lower energy consumption in main and auxiliary engines, optimised hulls	LNG, wind power, solar panels	improved charter contracts, enhanced logistics and fleet planning
Costs	low investment costs, moderate operating costs	high investment costs, moderate operating costs,	high investment costs	
Emission reduction potential	low	high	high	high
Implementation	in general all ships	often limited to new ships	<sup>a</sup> lack of infrastructure (supply and size of storage tanks on board), still R&D status, or only for niche market	in general hard to develop and implement

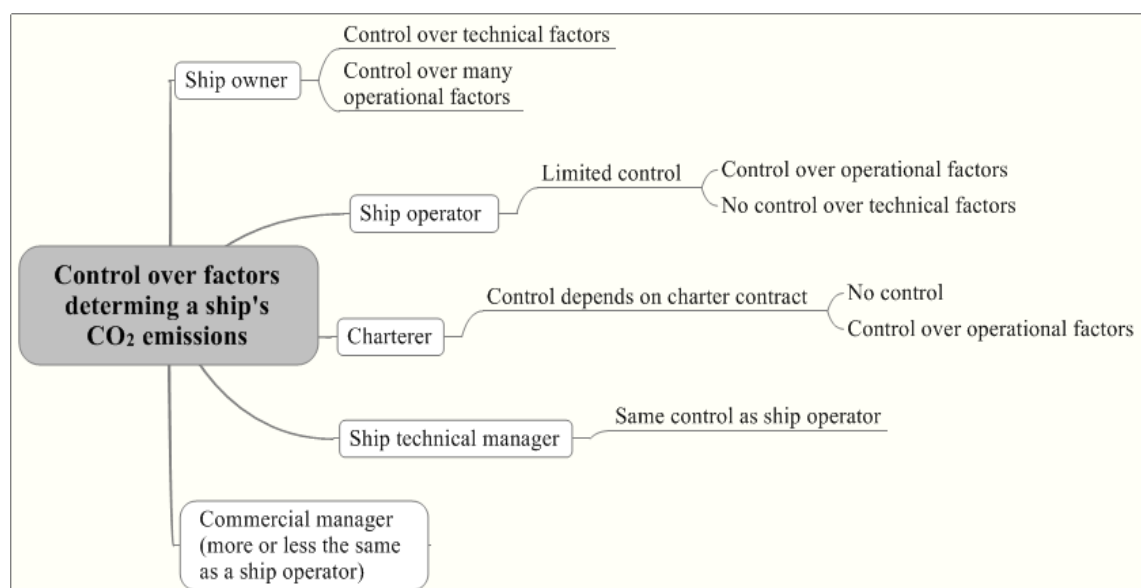
<sup>a</sup>Faber et al. (2011a)

*Source:* Own presentation based on Eide et al. (2011) and Faber et al. (2011a).

Operational measures mainly concern the operation and maintenance of ships and are characterized by low investment and moderate operating costs, and low abatement potential. An example for such a measure is the implementation of a system that improves routing, i.e., to avoid unfavorable conditions that cause unnecessary fuel consumption. The measure reduces fuel costs and CO<sub>2</sub> emissions, but incurs investment

costs to buy and implement the system and it incurs operating costs to maintain and manage the system. Technical measures mainly concern technical design features of ships and are characterized by high investment and moderate operating costs. An example for such a measure is the implementation of a waste heat recovery system that can be used to generate electricity alternatively to auxiliary engines and thus reduce fuel consumption (Faber et al., 2011a/Wang et al., 2010). Structural changes mainly concern the improvement of common practice, e.g., charter contracts or port efficiency, with regard to energy efficiency. Alternative fuels/power sources mainly concern substitutes, e.g., liquefied natural gas for motive power, for the use of carbon-intensive fuels. Both categories of measure types are characterized by high abatement potential, but at the same time are limited in application, e.g., because there is a lack of mature infrastructure for liquefied natural gas, or are difficult to develop (Eide et al., 2011, Faber et al., 2011a).

Finally, it is important to keep in mind that multiple actors in the shipping sector control the factors that determine a ship's CO<sub>2</sub> emissions, see Figure 1.



**Figure 1:** Actors in shipping and their control over factors determining a ship's CO<sub>2</sub> emissions. *Source:* Own presentation based on Faber et al. (2011a, 2010).

Ship owners have control over technical measures and many operational measures, whereas the other actors mainly have control over operational measures only. The owner can decide whether or not to implement technical measures, whereas the other

actors cannot. Nevertheless, they might be able to decide whether or not to apply/implement operational measures, but this depends on the contract between the owner and the other actors (Faber et al., 2010). However, both technical and operational measures are mostly subject to the issue of split incentives (ICCT, 2011) and this distinction is crucial for constructing our own set of MACCs for the shipping sector and, in particular, for how we treat negative abatement costs.

## ***2.2. Negative abatement costs***

One problem with expert-based MACCs is the existence of negative abatement costs.<sup>5</sup> In contrast, MACCs generated by models (bottom-up partial-equilibrium models and top-down CGE models) by construction generate only positive abatement costs. The assumption in all models is that rational individuals implement abatement measures that have negative costs even in the absence of climate policy, whereas they implement abatement measures that have positive abatement costs only if climate policy gives rise to a price on CO<sub>2</sub> emissions. However, the question arises why such abatement measures (that have negative abatement costs), which often represent established, nonrisky technological or operational measures, are not embraced by the market participants. Various studies have tried to explain the existence of negative abatement costs in expert-based MACC estimates in general (IPCC, 2007, Kesicki and Ekins, 2012). Their main explanation is that expert-based MACCs are mostly based on a very narrow cost definition, namely project costs that ignore potential additional costs. The project costs are the costs of an individual abatement option that is assumed to have no significant indirect economic impacts on markets and prices. Of the potential additional costs that are ignored, those that stem from barriers to implementation are, in particular, important for the shipping sector. Several such barriers are presented in the shipping-specific literature (Eide et al., 2011, Faber et al., 2011a/Wang et al., 2010, ICCT, 2011). Faber et al. (2011b) find four important reasons for nonadoption of cost-effective measures: low priority of energy-efficiency improvements, split incentives<sup>6</sup> between the owner of a ship and a charterer, transaction costs to collect relevant information about

---

<sup>5</sup> See, e.g., the very popular abatement cost curves published by McKinsey (Enkvist et al., 2010).

<sup>6</sup> Jaffe and Stavins (1994) argue that if the actor who invests in an efficiency-improving measure is not the same actor as the actor who benefits, implementation is unlikely. Investment will occur only, if the investor gets the investment recovered by the beneficiary of the efficiency-improving measure. In case of the shipping sector, this issue concerns the relationship between the ship owner and the charterer.

energy-efficiency improvement measures, and the possibility of time lags between the implementation of measures and the measures becoming cost-effective. Here, the issue of split incentives is that the ship owner bears the investment costs of an abatement measure (e.g., main engine retrofit), whereas the operator/charterer receives the benefits in terms of reductions in operating costs (e.g., less fuel consumption) (Faber et al., 2010). Eide et al. (2011) stress in particular that the issue of split incentives between ship owners and charterers can, to a certain degree, explain the nonadoption of cost-effective measures. Generally, Faber et al. (2011b) argue that the main barriers are of a technical, financial, and structural/institutional nature. Understanding the barriers to implementation is important in order to design effective regulation. Some barriers may be overcome by having price signals, whereas others may be overcome by enacting laws.

We follow Hyman et al. (2002) to deal with negative abatement costs in expert-based MACCs. They propose two approaches to approximate a function based on an underlying engineering estimate of marginal abatement costs.

The first approach is to assume that no-regret options, i.e., measures that reduce emissions at negative net costs (IPCC, 2001), are not economical when accounting for all relevant costs and to shift up the MACC so that it lies above the horizontal axis. The second approach is to assume that all no-regret options are undertaken, even in the absence of any climate policy. Thus, only the positive part of the MACC, i.e., the reduction potential at positive marginal abatement costs (MACs), is relevant. Here, the negative part of the MACC needs to be subtracted from the baseline emissions, where the reduction potentials of these measures, i.e., the measures that have negative abatement costs, are not taken into account yet. The first approach implicitly assumes that the barriers to implementation or extra cost are relevant for the implementation of all measures, also for the ones with positive abatement costs. Since it assumes that the level of the extra costs is exactly the level of the measure with the highest negative costs, it uses, in some sense, a lower bound estimate for the extra costs. It thus tends to overestimate the size of the contribution of the shipping sector to emission reductions. The second approach underestimates total global CO<sub>2</sub> emissions in the business-as-usual (BAU) or reference scenario without any emission reduction measures, since not all of the measures with negative abatement costs may actually be undertaken, and at the same

time it underestimates the size of the contribution of the shipping sector to emission reductions, since some of the measures with negative abatement costs may be implemented only with the extra incentives of carbon prices. For this reason, we add a third approach to those of Hyman et al. (2002) that deals with the issue of barriers to implementation. The third approach is to assume that measures are subject to barriers to implementation, in particular, to the issue of split incentives, which is an apparent phenomena in the shipping sector. We assume that the issue of barriers to implementation is more pronounced for some measures than for others because some of the measures are already employed by a significant proportion of the world fleet according to ICCT (2011).<sup>7</sup> We thus assume that all no-regret measures for which the issue of barriers to implementation is less pronounced are undertaken, arguing that these would nevertheless be implemented by the actors who have control over such measures and at the same time bear the fuel costs. These measures are thus not considered in the MACC as is done in the second approach.<sup>8</sup> We further assume, that all no-regret measures for which the issue of barriers to implementation is pronounced are not economical when accounting for all relevant costs. The MACC is thus shifted up, so that costs lie above the horizontal axis as in the first approach. This implies that costs associated with abatement measures that have positive abatement costs for which the issue of barriers to implementation is pronounced are also shifted up.

It is difficult to tell which of these approaches is most realistic. We clearly believe that there are barriers to implementation that have some kind of shadow price. Thus, we consider the first and third approaches to be realistic, whereas we consider the second approach to be rather academic. Although we acknowledge that shifting up the MACC by exactly the level of measure with the highest negative costs is an arbitrary choice, we nevertheless, consider the first approach to be best suited as our central case.

---

<sup>7</sup> This relates to the following measures: autopilot adjustment, water flow optimization, weather routing, hull cleaning, propeller polishing, and speed controlled pumps and fans.

<sup>8</sup> Faber et al. (2011b) argue that measures that are already employed by ships should be excluded from a MACC analysis. We assume that a correction of BAU emissions is not necessary when excluding such measures from the analysis because the pre-fuel consumption of a ship, i.e., the fuel consumption before measures are employed, is assumed to already include the reduction potential of such measures.

### ***2.3. Generating MACCs and MAC functions***

We follow the methodology presented in Eide et al. (2011) and Faber et al. (2011a)/Wang et al. (2010) in order to generate customized MACCs of the shipping sector. This methodology includes, in general, a projection of the fleet development, the determination of a business-as-usual (BAU) emissions scenario, i.e., determining the amount of CO<sub>2</sub> emissions that would be emitted if no abatement measures were taken in a given year, and the calculation of CO<sub>2</sub> reduction potential and corresponding costs per measure and ship for a given year.

The MACC is obtained by ordering the costs in increasing order and then plotting them against their corresponding reduction potentials.

We assume that abatement efforts in the shipping sector start in 2020, i.e., ships first start to implement abatement measures from 2020 onwards. This assumption is based on the given condition that ships currently have no incentives, despite the two mandatory efficiency measures EEDI and SEEMP, to implement abatement measures.

Based on this assumption, we first project the world fleet composition in 2020 based on the current world fleet composition and ship-type-specific growth and scrapping rates. We use data from SeaWeb (IHS Fairplay, 2012) in order to determine the current world fleet composition, i.e., the number of ships per ship-type/ship-age category, whereby a ship type is subdivided into various ship segments.<sup>9</sup> These categories (subcategories) correspond to the categories in Buhaug et al. (2009), but since we work with data on abatement measures from Wang et al. (2010), the world fleet under consideration here consists of 14 major ship types that are divided into 53 size segments instead of 18 ship types and 70 segments, as in Buhaug et al. (2009).<sup>10</sup> We use ship-type specific growth and scrapping rates from Eide et al. (2011) in order to project the current fleet up to 2020. This means we first allocate ships of the current fleet into ship-segment/ship-age categories, which gives us the total number of ships per segment and the number per ship-segment/ship-age category. Then, we apply the growth and

---

<sup>9</sup> For example, the ship type crude oil tanker could be subdivided into various segments by deadweight (see Buhaug et al., 2009).

<sup>10</sup> The 14 ship types are the following: crude tanker, products tanker, chemical tanker, LPG tanker, LNG tanker, other tankers, bulker, general cargo, other dry general cargo, container, vehicle carrier, roro, ferry, and cruise ships. The term world fleet might be misleading because most noncargo ships (fishing boats, military ships, service ships, etc.) are not included. However, the 14 ship types include all major ship types that are predominantly cargo ships engaged in merchant shipping and noncargo ships like passenger ships. Thus, we use the term fleet instead of world fleet in the following.

scrapping rates to the total number of ships in the ship segment. We add the number of new ships to the new age category, category 1, whereupon the former age category 1 becomes age category 2, and subtract the number of scrapped ships from the last age categories. As in Wang et al. (2010) the age category ranges from 1 to 30 years. For simplicity, we treat those few ships older than 30 years that we find in the current age distribution of the world fleet the same as 30-year-old ships. In other words, abatement measures only have an effective duration of one year when applied to such ships, thus, causing high abatement costs.

We determine the baseline CO<sub>2</sub> emissions of the fleet as projected to 2020 by following Eide et al. (2011) and Faber (2011a)/Wang et al. (2010), who assume the same operational profile as the 2007 fleet in Buhaug et al. (2009) for the projected fleet. The operational profile and the ship-type-specific characteristics (for more details, see Buhaug et al., 2009) determine the fuel consumption of a ship per year. Moreover, Eide et al. (2011) introduce a general improvement factor of 5% for ships built in 2010 and 8% for ships built in 2020, which mirrors the assumption that new-built ships are more energy efficient than older ships. Given this, we assume that the fuel consumption of ships built between 2008 and 2010 decreases by 1.64% per year compared to ships built before 2008 and that of ships built between 2011 and 2020 by 0.28% per year. To calculate the BAU emissions, we multiply the number of ships per ship-segment/ship-age category in 2020 by the pre-fuel consumption of a ship, i.e., its fuel consumption before abatement measures are implemented.

The data on abatement measures from Wang et al. (2010) include high and low estimates of nonrecurring (investment) and annual recurring (operating and maintenance) costs, and fuel reduction (and thus CO<sub>2</sub> emissions abatement<sup>11</sup>) potentials for 22 measures and 14 major ship types. In addition, an effective duration (in years) is assigned to each measure, e.g., a waste heat recovery system has an effective duration of 8 years, whereas a solar energy system has an effective duration of 30 years (SNAME, 2010). Because some of the measures are mutually exclusive, they are grouped into 15 groups in order to avoid overestimating abatement potentials (Wang et al., 2010, ICCT, 2011).<sup>12</sup> Moreover, the individual reduction effects and corresponding CO<sub>2</sub> emission

---

<sup>11</sup> The assumed conversion factor is 3.13.

<sup>12</sup> The 15 groups consist of the following measures: operational speed reduction, weather routing, autopilot adjustment, propeller maintenance, hull cleaning, hull coating, optimization water flow of hull

abatement achieved by all the measures that could be implemented simultaneously on a ship are calculated first and then ordered according to their abatement costs per ton of CO<sub>2</sub> (increasing order). The measure with the lowest abatement cost is selected and assumed to be applied first. Its emission reduction is calculated based on a ship's pre-installation fuel consumption and the individual reduction effect. Then, the individual reduction effects and abatement costs of all the remaining measures are recalculated. The fuel reduction potential of the second applied measure is calculated based on the reduced fuel consumption resulting from the first applied measure (Eide et al., 2011 and Faber et al., 2011a/Wang et al., 2010).

We apply the same calculation approach as presented in Eide et al. (2009) and applied in Eide et al. (2011) to calculate abatement costs (in Eide et al., 2009, 2011 the costs are called CATCH, cost of averting a tonne of CO<sub>2</sub>-eq. heating). The abatement costs (*AC*) of a measure are determined by the net present value of total costs (*C<sub>t</sub>*) minus total benefits (*B<sub>t</sub>*) of a measure, whereby *i* represents the discount rate, divided by the total CO<sub>2</sub> emission reduction potential (see Equation 1).

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

Total costs *C<sub>t</sub>* depend on the nonrecurring (investment costs) and annual costs (operating costs).<sup>13</sup> The total benefits *B<sub>t</sub>* of a measure depend on the fuel reduction per year (in *t*) achieved by the measure and the bunker fuel price (\$/t). The total CO<sub>2</sub> emission reduction potential *T\*CO<sub>2</sub><sup>red</sup>* depends on the effective duration of a measure *T* (or remaining lifetime of the ship if this is less than the effective duration of the measure) and the fuel reduction per year multiplied by the conversion factor 3.13. Investment costs are annuitized either over the effective duration of a measure or over the remaining lifetime of a ship in order to spread investment costs over years and to account for capital costs. The result can be interpreted as a measure's cost of abating a ton of CO<sub>2</sub>

---

openings, air lubrication, propulsion upgrade, main engine adjustment, waste heat recovery, wind power, solar power, low energy lightning, and speed control of pumps and fans (see Faber et al. (2011a)/Wang et al. (2010) and ICCT (2011) for more details).

<sup>13</sup> Faber et al. (2011a)/Wang et al. (2010) additionally take opportunity costs into account, i.e., the costs for extra time to implement measures on a ship.



emissions (in net present value terms) when applied to a specific-ship segment/ship-age category.

We assume, following Faber et al. (2011a)/Wang et al. (2010), an interest and discount rate of 10% and bunker fuel prices amounting to \$700 for the year 2020, \$800 for the period 2021-2025, and \$900 for the period 2026-2030.<sup>14</sup> In addition, we also assume bunker fuel prices amounting to \$900 for the period 2031 to 2050, albeit for measures with an effective lifetime of 30 years or more.

We analyze two scenarios to cover the extremes: one that assumes high reduction potentials and low costs (*hrlc*) and one that assumes low reduction potentials and high costs (*lrhc*) of abatement measures. As Figure 2 shows, the difference between these two scenarios is mainly the amount of abatement potential at negative abatement costs and the level of these negative costs. The positive part of both curves is rather similar. How to treat the negative abatement costs it is thus very important. In this respect, we apply the three different approaches discussed in Section 2.2:

The first MACC (case 1: *full reduction potential (full\_rp)*) is a shifted-up version of the original MACC, where all parts of the MACC are above the horizontal axis.

The second MACC (case 2: *reduced reduction potential (reduced\_rp)*) is a truncated version of the original MACC, where only the positive part of the MACC is taken into account and the emission reductions associated with negative abatement costs are subtracted from BAU emissions (original baseline).

The third MACC (case 3: *barrier reduction potential (barrier\_rp)*) is a shifted-up version of a modified original MACC, where only measures which are subject to the issue of split incentives are taken into account.<sup>15</sup>

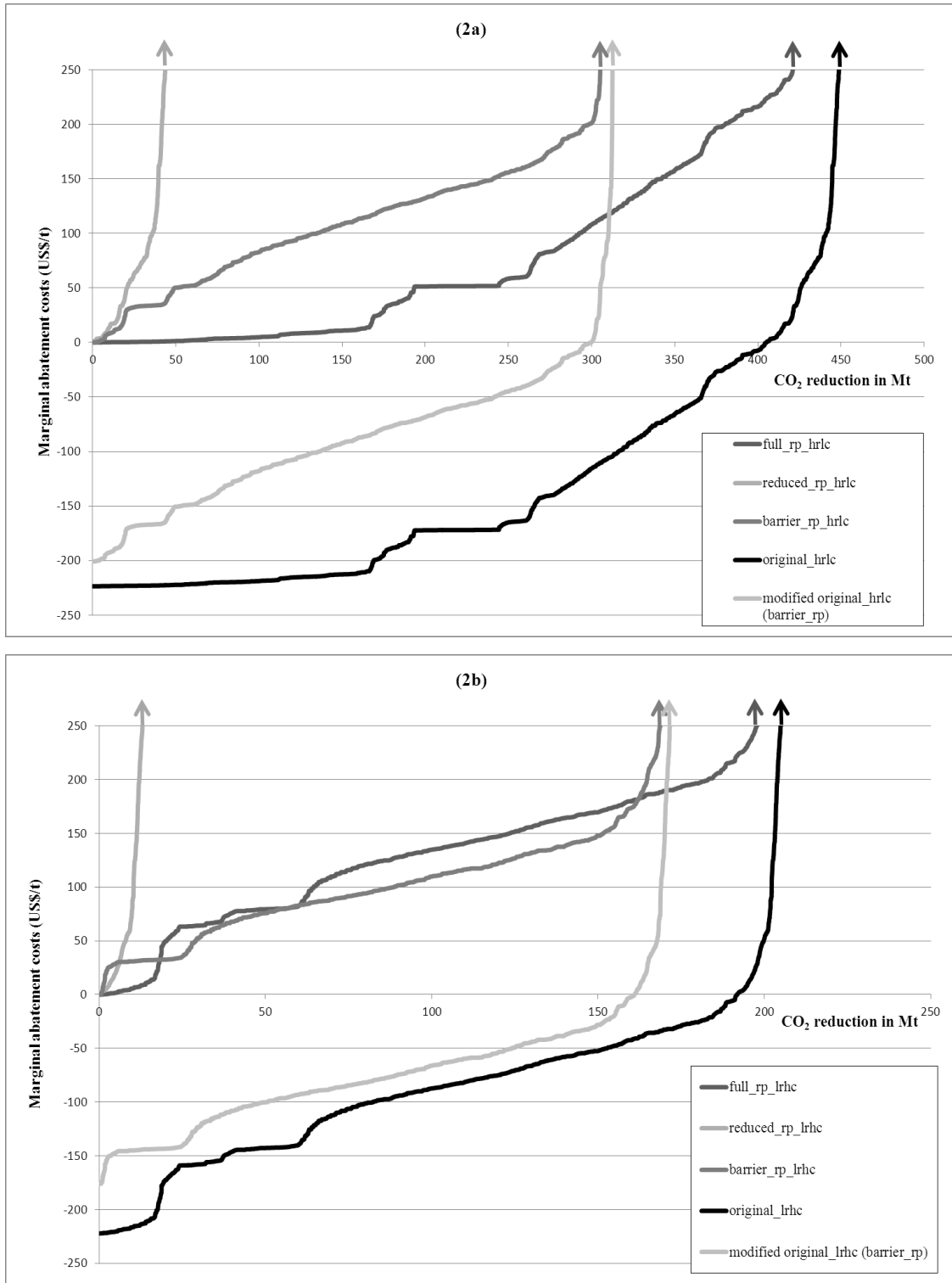
The resulting six MACCs (two different assumptions on abatement potential/abatement costs and three possibilities to deal with negative abatement costs) and the respective original and modified original MACCs (MACCs including negative

---

<sup>14</sup> Sensitivity analysis shows that, in particular, fuel prices significantly affect the abatement costs of measures and, thus, the share of cost-effective reduction potential in the MACC, i.e., the share of measures that have negative abatement costs (Eide et al., 2009, Faber et al., 2011).

<sup>15</sup> The model results in cases *full\_rp* and *reduced\_rp* show a more moderate increase in marginal abatement costs per reduction potential in the beginning than in case *barrier\_rp*. The latter case shows that a negligible share of the maximum reduction potential is available at very low marginal abatement costs (roughly -220 US\$/t), which causes a jump in the beginning of the MACC. We eliminated that negligible share of the maximum reduction potential from the MACC (0.2% of reduction potential) because it would cause the shift-up of the MACC to be distorted. Instead, we shifted-up the MACC by using the constant 200.

marginal abatement costs) are presented in Figures 2a and 2b. Their corresponding maximum reduction potentials are presented in Table 3.



**Figure 2a and 2b:** MACCs including negative abatement costs and MACCs relating to the three cases under the two reduction potentials and costs scenarios (2a: *hrhc* and 2b: *lrhc*). Source: Own calculations.

**Table 3:** Maximum reduction potentials for the six cases in 2020.

	<i>hrlc</i>			<i>lrhc</i>		
	<i>full_rp</i>	<i>reduced_rp</i>	<i>barrier_rp</i>	<i>full_rp</i>	<i>reduced_rp</i>	<i>barrier_rp</i>
CO <sub>2</sub> reduction potential in Mt	458	53	323	212	20	177

*Source:* Own calculations.

The three cases (*full\_rp*, *reduced\_rp*, and *barrier\_rp*) differ in terms of maximum reduction potential and marginal abatement costs. The case *full\_rp* always has the highest maximum reduction potential, followed by case *barrier\_rp* and case *reduced\_rp*. The maximum reduction potential in the *lrhc* scenario is less than 50% of that in the *hrlc* scenario. The share of maximum reduction potential that has negative (marginal abatement) costs is significant and amounts to about 90% in both scenarios. This is also apparent from the MACCs presented in Eide et al. (2011) and Faber et al. (2011a)/Wang et al. (2010), although it has to be remarked that their share of maximum reduction potential that has negative (marginal abatement) costs amounts to less than 90%. In Eide et al. (2011) it is 60% and in Faber et al. (2011a) it is 78%, but in Wang et al. (2010) it is roughly 90%. One explanation for this is that we base our calculations on the assumption that ships start to implement abatement measures in 2020 instead of 2007 as in Faber et al. (2011a) or 2008 as in Eide et al. (2011). As in previous studies, the fuel price is assumed to be higher as of 2020 and onwards, causing lower (marginal) abatement costs.<sup>16</sup> The maximum reduction potential of the case *barrier\_rp* is less than that of the original MACC (70% in the *hrlc* scenario and 85% in the *lrhc* scenario) because specific measures are excluded a priori, so that their reduction potential is no longer available (we assume, rather, that it is already included in the BAU emissions). Moreover, it is apparent from the figures that the negative part of the MACC is more affected than the positive part of the MACC by the different reduction potentials/costs estimates.

<sup>16</sup> The (original) MACCs presented here differ also in terms of maximum reduction potentials and (marginal abatement) costs from the MACCs presented in Eide et al. (2011) and Faber et al. (2011a)/Wang et al. (2010). The reasons for this, in addition to the above mentioned one, are the following: we base our fleet development analysis on data from 2012 instead of 2008 or 2010, and we present MACCs based on 30 age categories instead of age-category averages.

We fit continuous functions by testing linear, quadratic, and exponential functional forms to each of the six MACCs for the fleet in order to obtain marginal abatement cost functions ( $MAC(R)$ ), see Equation 2. We decided to use the linear and quadratic forms that show the best fit for the ranges of optimal abatement in the shipping sector as derived in our analysis (see Section 4.2), where we find that optimal abatement in the shipping sector is about 230 MtCO<sub>2</sub> maximum under the *hrlc* scenario and about 40 MtCO<sub>2</sub> under the *lrhc* scenario (see Equations 3, 4, 5).

$$MAC_{ij}(R_{ij}) = a_{ij} + b_{ij}R_{ij} + c_{ij}R_{ij}^2, \quad (2)$$

$$\text{for } i=1 : a_{ij} = 0 \wedge b_{ij} = 0; j=1: 0 \leq R_{ij} \leq 300, j=2: 0 \leq R_{ij} \leq 30, \quad (3)$$

$$\text{for } i=2 : a_{ij} = 0; j=1: 0 \leq R_{ij} \leq 25, j=2: 0 \leq R_{ij} \leq 10, \quad (4)$$

$$\text{for } i=3 : c_{ij} = 0; j=1: 0 \leq R_{ij} \leq 75, j=2: 0 \leq R_{ij} \leq 50, \quad (5)$$

where  $R$  refers to emission reductions,  $i$  refers to cases (1) *full\_rp*, (2) *reduced\_rp*, and (3) *barrier\_rp*, and  $j$  refers to (1) the *hrlc* scenario and (2) the *lrhc* scenario.

The parameters ( $a_{ij}$ ,  $b_{ij}$ , and  $c_{ij}$ ), the  $R^2$  (adjusted  $R^2$ ), and function plots are presented in Table A1 and in Figures A1–A6 in the Appendix.

### 3. Combining the shipping MACC with a global MACC

#### 3.1. Construction of a CGE-model-based global MACC

We use the DART (Dynamic Applied Regional Trade) CGE model, which is currently calibrated to the GTAP-7 database (Narayanan and Walmsley, 2008), to generate a global MACC for abatement measures used outside the shipping sector in 2020. The DART model is a multi-region, multi-sector recursive dynamic CGE model of the world economy designed for the analysis of international climate policies. For a more detailed description of the model see Klepper et al. (2003). The MACC contains options to reduce fossil fuel use, and thus to reduce CO<sub>2</sub> emissions, in all production and consump-

tions sectors of the world economy.<sup>17</sup> The shipping sector is not included in the DART model.<sup>18</sup>

The MACC of the DART sectors, which we denote in the following as all other sectors ( $AoS$ ), is generated by implementing a harmonized global carbon tax of different levels in all model regions and then plotting the tax level, the carbon price, against the abatement (compared to a BAU emissions scenario without any climate policy or carbon price). To set up our partial MACC-based model, we again tested several functional forms to fit a continuous function to the MACC (see Figure A7 and A8 in the Appendix). Since it turns out in our scenario analysis that optimal abatement outside the shipping sector is always between 7,000 MtCO<sub>2</sub> and 10,500 MtCO<sub>2</sub> (see Section 4.2), we decided to use the quadratic form, see Equation 6:

$$MAC_{AoS}(R_{AoS}) = 0.0027 \cdot R_{AoS} + 2.6012 \cdot 10^{-7} \cdot R_{AoS}^2, 0 \leq R_{AoS} \leq 12000, (6)$$

with  $R^2 = 0.999008$ .

### 3.2. Discussion of combining both curves

We aim to obtain an idea of what amount of emission reduction in the shipping sector would constitute an efficient contribution to achieving the global reduction target. To do this, we make use of the least cost theorem (see, e.g., Perman et al., 1999) and combine both MACCs. We suppose that both,  $AoS$  and shipping ( $S$ ), have to achieve a given joint emission target,  $A$ . When both of them reduce their BAU emissions,  $E_i$ , by the amount  $R_i$ , the sum of individual emissions reductions thus needs to fulfil the overall condition

$$\sum_i (E_i - R_i) = A, (7)$$

where  $i \in \{AoS, S\}$ . The costs of achieving the emission target are measured by the abatement cost functions,  $AC_i(R_i)$ , and amount to  $\sum_i AC_i(R_i)$ . In both sectors, the

---

<sup>17</sup> 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.

<sup>18</sup> The DART-model results are in 2004 US\$. To compare the results to the shipping-model results, which are given in 2007 US\$, we use the ratio 2007 US GDP Implicit Price Deflator/2004 US GDP Implicit Price Deflator.

optimal amount of emission reduction,  $R_i^*$ , needs to be determined so that the sum of abatement costs is minimized. The optimization problem becomes:

$$\begin{aligned} \min_{R_i} \sum_i C_i &= \sum_i AC_i(R_i) \\ \text{s.t.} \sum_i (E_i - R_i) &\leq A \wedge 0 \leq R_i \leq E_i. \end{aligned} \quad (8)$$

The optimization problem is, in general, solved by first setting up the first-order conditions<sup>19</sup> and second by solving the resulting equations simultaneously, which results in the marginal abatement costs being equal to the shadow price,  $p^*$ , (tax or permit price) of the emission constraint (= target) over both sectors:

$$AC'_i(R_i^*) = p^*. \quad (10)$$

We are aware that the combination of both MACCs is in fact not entirely consistent because they are different by construction. The calculation of mitigation costs is based on a project-level analysis in the shipping framework, whereas the calculation is based on a macro-economic analysis in the DART model. The former analysis assumes that the implementation of individual (abatement) measures do not affect prices and markets indirectly, whereas the latter analysis takes into account general equilibrium effects of climate policies that affect prices and markets. However, the impact of abatement measures in the shipping sector on prices and markets can be assumed to be small and thus the inaccuracy of combining both MACCs should be rather small as well.

## 4. Analysis of different emission reduction and climate policy scenarios

### 4.1. Description of scenarios

Before we describe the emission reduction and policy scenarios for our analysis, we need to describe the BAU emission scenarios of the two sectors under consideration: AoS and shipping. Knowledge of their BAU emissions is necessary in order to determine the emission reductions both sectors have to achieve under the reduction scenarios. The BAU emissions of AoS amount to 34.5 GtCO<sub>2</sub> in 2020 according to the DART

---

<sup>19</sup> We obtain the marginal abatement costs functions directly from the MACC analysis.

model. This number includes the CO<sub>2</sub> emissions of all the production and consumption sectors of the world economy, except the ones caused by shipping and aviation. The BAU emissions of shipping depend on the case analyzed. In cases *full\_rp* and *barrier\_rp*, the BAU emissions amount to 0.947 GtCO<sub>2</sub> in 2020 according to our calculations. In case *reduced\_rp*, the BAU emissions need to be corrected by the emission reduction potential that can be achieved at negative abatement costs (0.405 GtCO<sub>2</sub> in *hrlc* and 0.192 GtCO<sub>2</sub> in *lrhc*) because we assume that this potential is achieved even in the absence of any climate policy. As a result, the BAU emissions of shipping amount to 0.542 GtCO<sub>2</sub> under the *hrlc* scenario and 0.755 GtCO<sub>2</sub> under the *lrhc* scenario. The BAU emissions of aviation amount to 0.494 GtCO<sub>2</sub> in 2020 according to the IEA (2009a).

Now we can proceed to describe the emission reduction scenarios, of which there are three, each of which differ in terms of the assumed global reduction requirements. In the first scenario, the global reduction requirement is determined by the 2°C target, which was acknowledged by the Copenhagen Accord and the G8 summit. In the other two scenarios, the global reduction requirement is determined by the Copenhagen Pledges, which consist of an unconditional (CP low) and conditional (CP high) pledge scenario. These pledges are national reduction pledges for 2020, which have been submitted by many Annex I and non-Annex I countries to the UNFCCC in the context of the Copenhagen meeting (UNFCCC, 2010a,b,c) and which are the only targets – though nonbinding – that exist.

Concerning the 2°C target, the UNEP report (UNEP, 2010) assumes that an overall greenhouse gas emission level of 45 GtCO<sub>2</sub>-eq. needs to be reached in 2020 to have a 50–66% chance of meeting the 2°C target. For our analysis, we need to derive a target for CO<sub>2</sub> emissions of the sectors covered in the DART model plus the shipping sector. To do so, we assume that the GHG share of CO<sub>2</sub> emissions resulting from fossil fuel use, which was according to IPCC (2007) 56.6% in 2004, stay constant over time. Consequently, around 25.47 GtCO<sub>2</sub> emissions from fossil fuel use can be emitted in 2020. This still includes 0.494 GtCO<sub>2</sub> emitted by aviation in 2020 (IEA, 2009a). Since we assume that aviation has no obligation to abate emissions, we also assume that these emissions stay constant and subtract them from 25.47 GtCO<sub>2</sub> to arrive at our final 2°C target of 24.796 GtCO<sub>2</sub> for the sectors covered in our analysis.

Concerning the Copenhagen Pledges, the low pledges from all countries would – according to den Elzen et al. (2011) – lead to a global emission level of 49.7 GtCO<sub>2</sub>-eq and the high pledges to a level of 48.6 GtCO<sub>2</sub>-eq. in 2020. These numbers include the CO<sub>2</sub> emissions of international bunkers (and thus of shipping and aviation combined), which amount to 1.1 GtCO<sub>2</sub> and are thus not consistent with our own BAU shipping emissions and the aviation emissions published by the IEA (2009a). To be consistent in our scenarios, we thus subtract these 1.1 GtCO<sub>2</sub> and add our BAU shipping emissions (0.947 GtCO<sub>2</sub> (*hrlc* and *lrhc*) in cases *full\_rp* and *barrier\_rp* and 0.542 GtCO<sub>2</sub> (*hrlc*) and 0.755 GtCO<sub>2</sub> (*lrhc*) in case *reduced\_rp*) and the aviation emissions of 0.494 GtCO<sub>2</sub> published by the IEA (2009a) instead. The “revised Copenhagen Pledges” then amount to 50.041 GtCO<sub>2</sub>, respectively, 49.636 GtCO<sub>2</sub> (*hrlc*) and 49.849 GtCO<sub>2</sub> (*lrhc*) in case *reduced\_rp*, in the low pledges and 48.941 GtCO<sub>2</sub>, respectively, 48.536 GtCO<sub>2</sub> (*hrlc*) and 48.749 GtCO<sub>2</sub> (*lrhc*) in case *reduced\_rp*, in the high pledges scenario. Again, we then multiply these targets by 0.556 to obtain a target for CO<sub>2</sub> emissions only and finally subtract aviation emissions. Table 4 shows the BAU emissions, emission targets, and implied reduction targets for our different scenarios.

**Table 4:** Emission targets, BAU emissions, and implied reduction targets.

Cases	Targets (CO <sub>2</sub> -eq.)	Revised Copenhagen Pledges (CO <sub>2</sub> -eq.)	Targets for AoS and S		∑ BAU emissions AoS and S		Reduction targets AoS+shipping		
		<i>full_rp</i> & <i>barrier_rp</i>	<i>reduced</i> <i>_rp</i>	<i>full_rp</i> & <i>barrier_rp</i>	<i>reduced</i> <i>_rp</i>	<i>full_rp</i> & <i>barrier_rp</i>	<i>reduced</i> <i>_rp</i>	<i>full_rp</i> & <i>barrier_rp</i>	<i>reduced</i> <i>_rp</i>
2°C	45.000			24.976		35.447	35.042/ 35.255	29.5%	28,4%/ 29.0%
CP low	49.700	50.041	<sup>a</sup> 49.636 / 49.849	27.829	<sup>a</sup> 27.600/ 27.721	35.447	35.042/ 35.255	21.0%	21,2%/ 21.4%
CP high	48.600	48.941	<sup>a</sup> 48.536/ 48.749	27.207	<sup>a</sup> 26.977/ 27.098	35.447	35.042/ 35.255	23.0%	23,2%/ 23.1%

<sup>a</sup> Revised numbers for case *reduced\_rp* under the *hrlc* and *lrhc* scenarios.

Source: den Elzen et al. (2011), UNEP (2010), IEA (2009a), and own calculations.

The aim of our analysis is to assess for three different global reduction targets (a) the maximum global cost savings that could be achieved by emission abatement in the shipping sector, (b) the cost efficient abatement contributions of the shipping sector to



the global reduction targets, and (c) the potential additional costs that would be incurred by implementing a separate solution for the shipping sector. We base our analysis on two alternative policy scenarios. One policy scenario assumes that AoS and shipping have a joint target, i.e., both sectors contribute (efficiently) to the joint overall reduction target (*joint target* scenario). The other policy scenario assumes that AoS has to bear the full reduction burden, while the shipping sector remains unregulated (*AoS without shipping* scenario). Comparing both scenarios indicates the potential gains that could be achieved by including the shipping sector in climate policy on CO<sub>2</sub> emission reductions.

#### **4.2. Results**

We start by discussing the results of the policy scenario *joint target* (these results are also summarized in Table 5) and thereafter discuss the results of the comparison between the policy scenario *joint target* and policy scenario *AoS without shipping*.

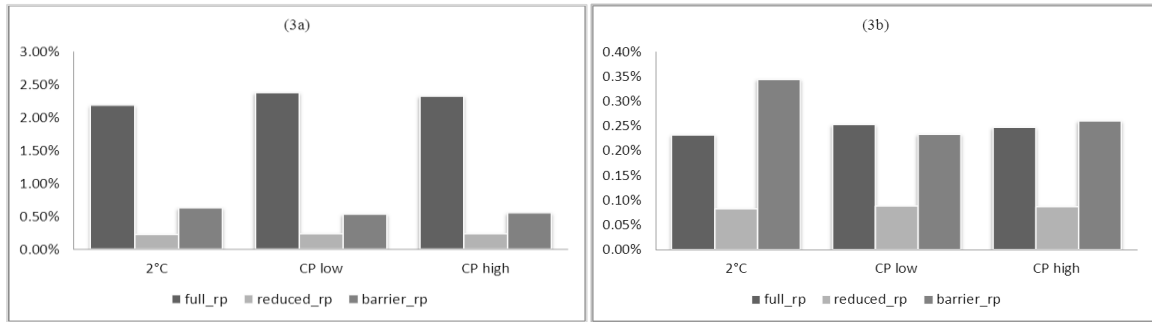
The CO<sub>2</sub> prices range, depending on the case analyzed and assumed reduction potentials/costs scenario (*hrlc* and *lrhc*), between \$53.5 and \$56.8 under the 2°C target, between \$34.5 and \$35.7 under the low Copenhagen Pledges, and between \$38.7 and \$39.9 under the high Copenhagen Pledges. CO<sub>2</sub> prices are always higher in the *lrhc* scenario than in the *hrlc* scenario because it has a smaller reduction potential and higher cost per abated ton of CO<sub>2</sub>. CO<sub>2</sub> prices are always the lowest in case *reduced\_rp*, independent of the assumed reduction potentials/costs scenario (*hrlc* or *lrhc*), because the BAU emissions in cases *full\_rp* and *barrier\_rp* are higher than in case *reduced\_rp*, causing higher reduction needs.

**Table 5:** CO<sub>2</sub> prices, efficient reduction relative to BAU emissions and to overall target.

Reduction/ costs scenario	Cases	2°C			CP low			CP high		
		CO <sub>2</sub> price	R <sub>S</sub> rel.to BAU emissions	R <sub>S</sub> rel.to overall target	CO <sub>2</sub> price	R <sub>S</sub> rel.to BAU emissions	R <sub>S</sub> rel.to overall target	CO <sub>2</sub> price	R <sub>S</sub> rel.to BAU emissions	R <sub>S</sub> rel.to overall target
	<i>full_rp</i>	55.11	24.2%	2.19%	34.59	19.2%	2.38%	38.71	20.28%	2.33%
<i>hrlc</i>	<i>reduced_rp</i>	53.52	4.1%	0.22%	34.51	3.3%	0.24%	38.70	3.47%	0.23%
	<i>barrier_rp</i>	56.43	6.9%	0.63%	35.52	4.3%	0.53%	39.73	4.80%	0.55%
	<i>full_rp</i>	56.77	2.6%	0.23%	35.66	2.0%	0.25%	39.91	2.15%	0.25%
<i>lrhc</i>	<i>reduced_rp</i>	55.34	1.1%	0.08%	35.20	0.9%	0.09%	39.42	0.93%	0.09%
	<i>barrier_rp</i>	56.67	3.8%	0.34%	35.67	1.9%	0.23%	39.90	2.26%	0.26%

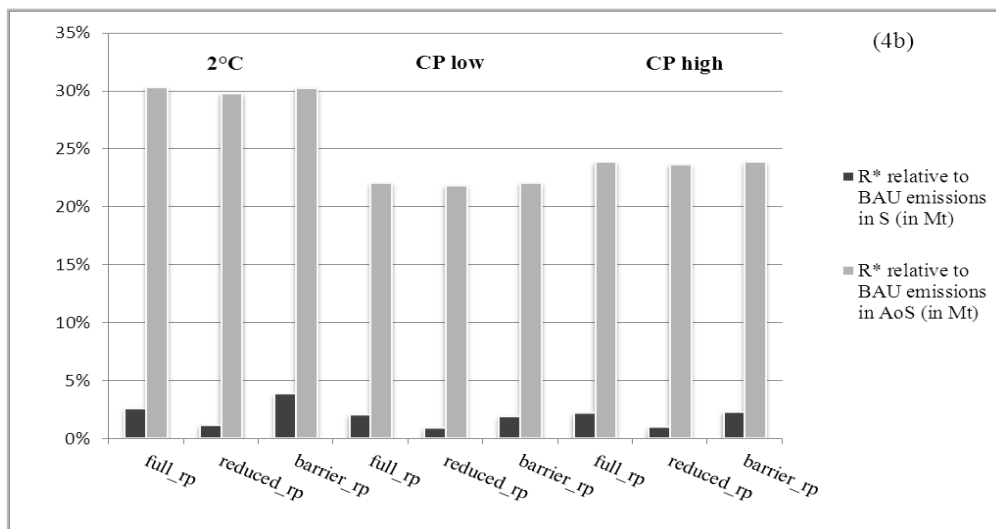
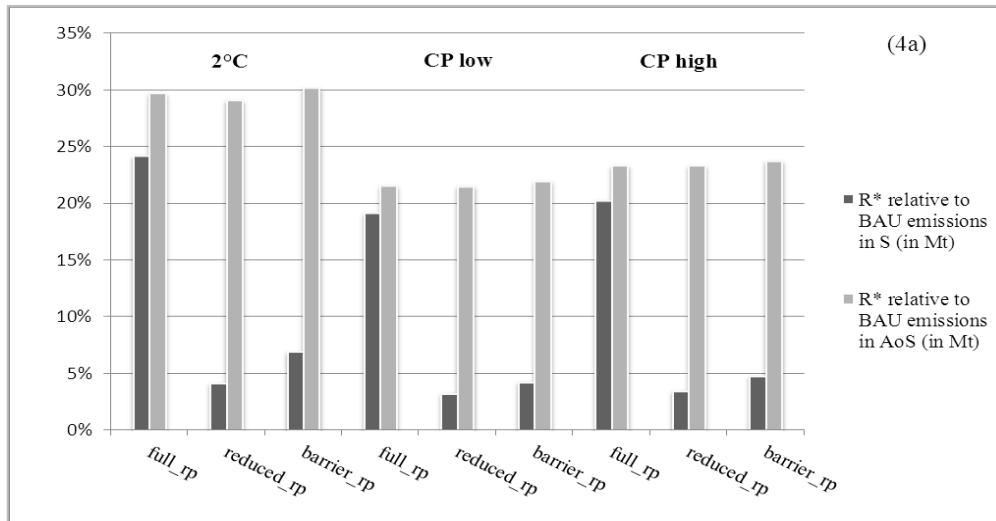
Source: Own calculations.

The efficient contribution of shipping to overall reductions varies between 0.1% and 2.2% under the 2°C target, between 0.1% and 2.4% under the low Copenhagen Pledges, and between 0.1% and 2.3% under the high Copenhagen Pledges. It is the highest in case *full\_rp*, followed by case *barrier\_rp* and case *reduced\_rp* in the *hrlc* scenario (see Figure 3a). The reason for this is that the MACCs of cases *full\_rp* and *barrier\_rp* have higher maximum reduction potentials and are less steep in the beginning than in case *reduced\_rp* (see Figure A9 in the Appendix). The picture is different in the *lrhc* scenario. The efficient contribution of shipping to overall reductions is the highest in case *barrier\_rp* (except under the low Copenhagen Pledges scenario), followed by case *full\_rp* and case *reduced\_rp* in the *lrhc* scenario (see Figure 3b). Here, the MACCs of cases *full\_rp* and *reduced\_rp* are steeper in the beginning, but start at a lower cost level than case *barrier\_rp* (see Figure A9 in the Appendix). Moreover, the lower the overall reduction target (CP *low* < CP *high* < 2°C), the higher the efficient contribution of shipping to the overall target in cases *full\_rp* and *reduced\_rp* in both of the reduction potentials and costs scenarios (*hrlc* and *lrhc*) assumed. This is caused by the quadratic functional form of the approximated MAC functions. The opposite, i.e., the lower the overall reduction target (CP *low* < CP *high* < 2°C), the lower the efficient contribution of shipping to the overall target, is true for case *barrier\_rp*. This is caused by the linear functional form of the approximated MAC functions.



**Figure 3a and 3b:** Efficient contribution of shipping to the three overall reduction targets in the *hrlc* scenario (a) and the *lrhc* scenario (b). *Source:* Own calculations.

The emission reductions of the shipping sector relative to its BAU emissions range, depending on the analyzed case and assumed reduction potentials/costs scenario, between 1% and 24% under the 2°C target, between 1% and 19% under the low Copenhagen Pledges, and between 1% and 20% under the high Copenhagen Pledges. Emission reductions relative to BAU emissions are always the highest in case *full\_rp*, followed by case *barrier\_rp* and case *reduced\_rp* in the *hrlc* scenario. The order changes in the *lrhc* scenario. Here, emission reductions relative to BAU emissions are always the highest in case *barrier\_rp*, followed by case *full\_rp* and case *reduced\_rp*, except under the low Copenhagen Pledges. The reason for this is that the increase in marginal abatement costs is less steep in case *barrier\_rp* (see Figure A9). Emission reductions relative to BAU emissions in AoS range between 29% and 30% under the 2°C target, between 21% and 22% under the low Copenhagen Pledges, and between 23% and 24% under the high Copenhagen Pledges. Figures 4a and 4b compare the efficient emission reductions relative to BAU emissions in shipping and AoS.

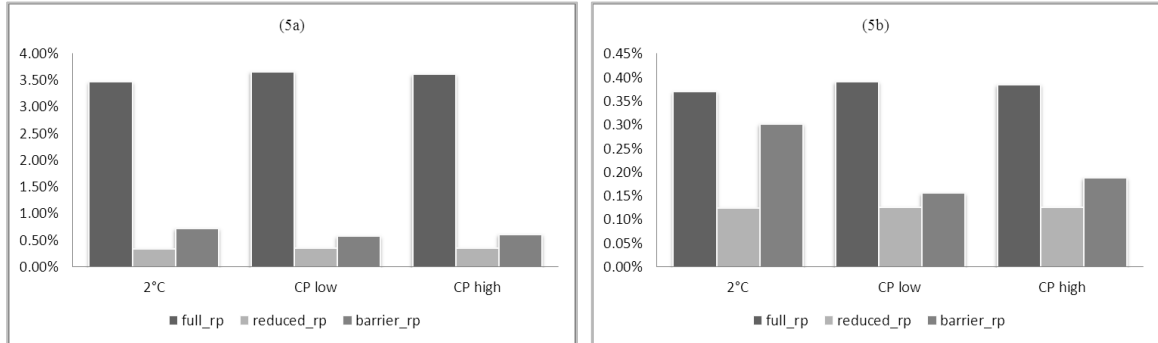


**Figure 4a and 4b:** Comparison of efficient emission reductions relative to BAU emissions of AoS and S (a) in *hrlc* scenario and (b) in *lrhc* scenario. *Source:* Own calculations.

They show, first, that the variation between the different shipping cases is higher in the *hrlc* scenario (Figure 4a) than in the *lrhc* scenario (Figure 4b), second, that efficient emission reductions relative to BAU emissions in shipping and AoS are only similar in the case *full\_rp* in the *hrlc* scenario. In all other cases, the relative reductions of shipping are significantly lower than the ones of AoS. This has policy implications, which we discuss in Section 5.

Now, we discuss the results of the comparison between the policy scenario *joint target* and the policy scenario *AoS without shipping*, i.e., the scenario where only AoS

has to bear the entire reduction burden. The results are shown in the following Figures 5a and 5b.



**Figure 5a and 5b:** Relative global cost savings of the two policy scenarios: (a) AoS and S have a joint target versus AoS without S in the *hrlc* scenario and (b) AoS and S have a joint target versus AoS without S in the *lrhc* scenario. *Source:* Own calculations.

The relative cost savings range, depending on the case analyzed and reduction potentials and costs scenario assumed, between 0.1% and 3.5% under the 2°C target, between 0.1% and 3.7% under the low Copenhagen Pledges, and between 0.1% and 3.6% under the high Copenhagen Pledges. The relative cost savings are always positive if AoS and shipping have a joint target because shipping contributes an additional reduction potential at low (marginal) abatement costs. Naturally, the cost savings are larger under the optimistic *hrlc* scenario than in the pessimistic *lrhc* scenario. The relative cost savings are always the highest in case *full\_rp*, followed by case *barrier\_rp* and *reduced\_rp*.

The change in CO<sub>2</sub> prices compared to the joint reduction scenario is small (< 1%) in all the cases and under all the reduction scenarios. Only in case *full\_rp* under the *hrlc* scenario, where shipping contributes significantly more to overall reduction than in all other cases under both reduction potentials and costs scenarios assumed, does the CO<sub>2</sub> price increase by more than 3% under all reduction scenarios. When looking at the share of shipping's abatement costs ( $AC_S$ ) in overall abatement costs ( $AC_{AoS} + AC_S$ ), this is smaller than the share of its reductions ( $R_S$ ) in overall reductions ( $R_{AoS} + R_S$ ) in most cases under the *hrlc* and *lrhc* scenarios. Thus, overall cost savings are higher than the mere share of reductions in the shipping sector suggests. While the shipping sector overall does not contribute a large share of reductions, the potential reduction measures

are relatively cheap. Case *barrier\_rp* is the only exception under all three global reduction target scenarios.

Tables A2–A4 in the Appendix provide more results (in absolute terms) of the three global reduction requirement scenarios.

## 5. Discussion

Our results show that the shipping sector could always contribute to efficient global emission reductions and that this contribution could always achieve global cost savings. However, the contribution of the shipping sector to efficient global emission reductions and the potential cost savings depend to a large degree on the MACC case assumed, i.e., depend on how the existence of negative abatement costs is treated in a MACC, and on the reduction potentials and costs of measures assumed.

If we are generally optimistic about reduction potentials and costs (*hrlc* scenario), the contribution and potential cost savings are significant in the case with the highest maximum reduction potential (*full\_rp*), almost negligible in the case with the smallest maximum reduction potential (*reduced\_rp*), and small in the case with the moderate maximum reduction potential (*barrier\_rp*). The reasons for this are obviously that in case *barrier\_rp*, fewer measures are taken into account and in case *reduced\_rp*, a huge share of the maximum reduction potential (the reduction potential at negative costs) is assumed to be achieved even in the absence of climate policy, so that this reduction potential no longer contributes to cost savings when regulating the shipping sector. Thus, only a small share of the maximum reduction potential remains. However, it is difficult to say which of the cases resulting from the approaches presented in Section 2.2 is most realistic. We clearly believe that there are barriers to implementation that have some kind of shadow price so that we see the second approach as rather academic. Therefore, its corresponding case (*reduced\_rp*), the one with the smallest maximum reduction potential, seems to be less realistic than the other two cases because it assumes that all reduction potentials at negative costs will be implemented, i.e., that there are no barriers to implementation or extra costs, whereas both cases, *full\_rp* and *barrier\_rp*, assume that barriers to implementation or extra costs exist. However, the case *barrier\_rp* might underestimate the reduction potential by excluding measures

from the MACC analysis that are assumed to be already used by a significant share of the world fleet. The opposite might be true for case *full\_rp* by assuming that all the analyzed measures are not being used yet. Moreover, shifting up the MACC by exactly the level of the measure with the highest negative costs involves making an arbitrary choice. Extra costs could be even higher (or lower), affecting the contribution of shipping to efficient abatement. Nevertheless, we suggest that the case with the highest maximum reduction potential (*full\_rp*) should be considered the most realistic one.

If we are generally pessimistic about reduction potentials and costs (*lrhc* scenario) the general picture is different. Now global cost savings are almost negligible (in the order of less than 0.5%) and there is no significant difference between cases *full\_rp* and *barrier\_rp*.

Comparing the two reduction potential and costs scenarios (*hrlc/lrhc*) shows that the difference between the maximum reduction potentials is large, the difference between the marginal abatement costs is not so obvious (see Figure 2a and 2b). Thus, results are more affected by the assumption about the potential reduction effects of measures than by the assumption about the range of potential costs (see in addition the discussion in Eide et al., 2011). Consequently, more research should be conducted in order to reduce the uncertainty about the potential performance of measures, i.e., to minimize the range of a measure's potential reduction effect.

Comparing the three emission reduction scenarios, the status of today's climate negotiations suggests that the scenario low Copenhagen Pledges will be the most realistic one. This scenario is in favor of the inclusion of the shipping sector. The smaller the joint reduction target is, the larger the shipping sector's relative contribution is to efficient global emission reductions in cases *full\_rp* and *reduced\_rp*. This implies that the shipping sector accommodates a small, but at the same time, a cost-effective reduction potential that should be exploited for global emission reductions.

The results for all the scenarios also provide us with an idea of what the efficient reduction targets should be when a separate solution for the shipping sector is the regulatory choice. The separate solution is being discussed in the IMO, as mentioned in the Introduction, but also in the EU. The Council of the European Union (2009)

proposed a 20% reduction target for the shipping sector below 2005 by 2020.<sup>20</sup> Our calculations show that this target is close to the cost minimizing reduction level when assuming high reduction potentials and low costs (*hrlc* scenario) and the full reduction potential (*full\_rp*). When we compare to this target our targets implied by the Copenhagen pledges, we find that there is in this case a perfect match, while we find in the case of the 2°C target that the optimal reduction target in the shipping sector would be about 25%. Under these assumptions, requiring the same relative reductions in the shipping sector and AoS is thus almost cost efficient. Under all other assumptions (low abatement potentials and higher costs, i.e., all *lrhc* scenarios and all *reduced\_rp* and *barrier\_rp* scenarios), the relative reduction target for the shipping sector that is cost minimizing is much lower than 20% and mostly in the order of a 1–5% reduction only.

A comparison to the other studies (see Table 1) shows that the shipping sector’s cost-effective reduction potential becomes considerably smaller when treating the existence of negative marginal abatement costs as a calculation artifact caused by the narrow cost definition of project-level analysis (our scenarios *full\_rp* and *barrier\_rp*). According to Eide et al. (2011), emission reductions in the order of between 27% and 31% relative to BAU emissions could be achieved in 2020 if a decision criterion (marginal cost threshold) of <20US\$/t, <50US\$/t, respectively, were to be applied. These emission reductions include not only reductions that have positive costs, but also the ones that have negative costs. We, on the other hand, found that (efficient) emission reductions amount to 19% relative to BAU emissions in the most optimistic scenario (*full\_rp/hrlc*) and to only 1% in the most pessimistic case (*reduced\_rp/lrhc*) under the low Copenhagen Pledges (~35US\$/t).

## 6. Conclusion

While it is clear that emissions generated by the shipping sector are substantial and can be reduced, at least partially, at low costs, it has not been analyzed so far how much emissions should actually be reduced when the objective is to reach a given global emission target at minimal costs. In this paper, we have thus determined whether the

---

<sup>20</sup> The reduction in absolute terms would be ~311 MtCO<sub>2</sub>. We based the calculation on the emission estimate for 2005 in Buhaug et al. (2009) and the BAU emissions used in this paper.



shipping sector could contribute to reducing global emissions efficiently to reach certain global emission targets under different policy scenarios by making use of marginal abatement cost curves (MACC). We have presented an approach to deal with the existence of negative abatement costs in the expert-based MACC generated for the shipping sector in order to combine it with a CGE model-based MACC generated for abatement measures used outside the shipping sector. We focus on the year 2020.

The main findings are that the shipping sector could always contribute to efficient global emission reductions and thus could always achieve global cost savings. Yet, the optimal contribution and the possible cost savings depend much on the MACC case assumed, i.e., depend on how the existence of negative abatement costs in a MACC is treated, and the assumed reduction potentials and costs of measures. Under optimistic assumptions about the use of abatement measures, the shipping sector can reduce costs by 3.5%, while under less optimistic assumptions it can only reduce costs by less than 1%.

Yet, it is important to point out that we did not have data for the reduction potentials and costs of all possible abatement measures in the shipping sector and also since we only included 14 ship types, representing only a part of the world fleet, although this part is significant in terms of transported tonnage. This implies that the reduction potential might increase when more measures and more ship types are included in the analysis.

Overall, we thus conclude that emissions generated in the shipping sector should be regulated in order to prevent emissions generated by the shipping sector from consuming a considerable share of allowed emissions in the coming decades and to prevent other sectors from having to compensate by exploiting more expensive abatement options. Since there is uncertainty about what the optimal reduction level in the shipping sector would be, an approach that allows equalization of marginal abatement costs in the shipping sector and other sectors (such as including the shipping sector in an emission trading scheme or applying a carbon tax at a level of prices in existing emission trading schemes) is preferable to isolated regulation of the shipping sector.

## 7. References

Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Markowska, A.Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W-Q., Yoshida, K., 2009. Second IMO GHG Study. London: International Maritime Organization (IMO).

Council of the European Union, 2009. Council Conclusions on EU position for the Copenhagen Climate Conference (7–18 December 2009). 2968th Environment Council meeting, Luxembourg, 21 October 2009.

[http://www.consilium.europa.eu/uedocs/cms\\_data/docs/pressdata/en/envir/110634.pdf](http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/envir/110634.pdf) (accessed 08/12/2012).

Criqui, P., Mima, S., Viguier L., 1999. Marginal Abatement Cost of CO<sub>2</sub> Emission Reductions, Geography, Flexibility and Concrete Ceilings: an Assessment Using the POLES Model. *Energy Policy* 27: 585–601.

den Elzen, M., Hof, A.F., Roelfsema, M., 2011. The Emissions Gap between the Copenhagen Pledges and the 2°C Climate Goal: Options for Closing and Risks that Could Widen the Gap. *Global Environmental Change* 21: 733–743.

den Elzen M., Olivier J., Berk M., 2007. An Analysis of Options for Including International Aviation and Marine Emissions in a post-2012 Climate Mitigation Regime, MNP Report 500114007/2007.

den Elzen, M, P. Lucas, D. van Vuuren, 2005. Abatement Costs of post-Kyoto Climate Regimes. *Energy Policy* 33 (16): 2138–2151.

Eide, M.S., Longva, T., Hoffmann, P., Endresen, Ø., Dalsøren, S.B., 2011. Future Cost Scenarios for Reduction of CO<sub>2</sub> Emissions. *Maritime Policy and Management* 38 (1):11-37.

Eide, M.S., Endresen, Ø., Skjong, R., Longva, T., Alvik, S., 2009. Cost-effectiveness Assessment of CO<sub>2</sub> Reducing Measures in Shipping. *Maritime Policy and Management* 36 (4): 367–384.

Ellerman, D. A., Decaux, A., 1998. Analysis of Post-Kyoto CO<sub>2</sub> Emission Trading Using Marginal Abatement Curves. Report 40, Cambridge, Massachusetts: Massachusetts Institute of Technology. Joint Program on the Science and Policy of Global Change.

Enkvist, P., Dinkel, J., Lin, C., 2010. Impact of the Financial Crisis on Carbon Economics: Version 2.1 of the Global Greenhouse Gas Abatement Cost Curves. McKinsey & Company.

- Faber, J., Wang, H., Nelissen, D., Russel, B., St Amand, D., 2011a. Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures. MEPC 62 INF 7. <http://www.imarest.org/LinkClick.aspx?fileticket=5kj0E0WMK8w%3D&tabid=878> (accessed 11/14/2011).
- Faber, J., Behrends, B., Nelissen, D., 2011b. Analysis of GHG Marginal Abatement Cost Curves. Delft, CE Delft, March 2011. [http://www.cedelft.eu/publicatie/analysis\\_of\\_ghg\\_marginal\\_abatement\\_cost\\_curves/1155](http://www.cedelft.eu/publicatie/analysis_of_ghg_marginal_abatement_cost_curves/1155) (accessed 11/14/2011).
- Faber, J., Markowska, A., Eyring, V., Cionni, I., Selstad, E., 2010. A Global Maritime Emissions Trading System. Design and Impacts on the Shipping Sector, Countries and Regions. Delft, CE Delft, January 2010. [http://www.cedelft.eu/publicatie/a\\_global\\_maritime\\_emissions\\_trading\\_system/1024](http://www.cedelft.eu/publicatie/a_global_maritime_emissions_trading_system/1024) (accessed 04/12/2010).
- Faber, J., Markowska, A., Nelissen, D., Davidson, M., Eyring, V., Cionni, I., Selstad, E., Kageson, P., Lee, D., Buhaug, Ø., Lindtsad, H., Roche, P., Humpries, E., Graichen, J., Cames, M., Schwarz, W., 2009. Technical Support for European Action to Reducing Greenhouse Gas Emissions from International Maritime Transport. Delft: CE Delft. [http://www.ce.nl/publicatie/technical\\_support\\_for\\_european\\_action\\_to\\_reducing\\_greenhouse\\_gas\\_emissions\\_from\\_international\\_maritime\\_transport/1005S](http://www.ce.nl/publicatie/technical_support_for_european_action_to_reducing_greenhouse_gas_emissions_from_international_maritime_transport/1005S) (accessed 04/12/2010).
- Gilbert, P., Bows, A., 2012. Exploring the Scope for Complementary Sub-global Policy to Mitigate CO<sub>2</sub> from Shipping. *Energy Policy* 50: 613–622.
- Heitmann, N., Khalilian, S., 2011. Accounting for CO<sub>2</sub> Emissions from International Shipping: Burden Sharing under Different UNFCCC Allocation Options and Regime Scenarios. *Marine Policy* 35: 682–691.
- Hyman, R.C., Reilly, J., Babiker, M.H., De Masin, A., Jacoby, H.D., 2002. Modeling Non-CO<sub>2</sub> Greenhouse Gas Abatement. *Environmental Modeling and Assessment* 8: 175–186.
- ICCT (International Council on Clean Transportation), 2011. Reducing Greenhouse Gas Emissions from Ships. Cost Effectiveness of Available Options. White Paper Number 11, July 2011.
- IEA (International Energy Agency), 2009a. World Energy Outlook 2009. Paris; OECD/IEA.
- IEA, 2009b. CO<sub>2</sub> Emissions from Fuel Combustion, 2009 Edition. Paris: IEA.

IHS Fairplay, 2012. Sea-Web data base.

IPCC (Intergovernmental Panel on Climate Change), 2007. IPCC Third Assessment Report. Climate Change 2007: Working Group III: Mitigation.

IPCC, 2001. IPCC Third Assessment Report. Climate Change 2001: Working Group III: Mitigation.

Jaffe, A.B., Stavins, R.N., 1994. The Energy-efficiency Gap. What Does it Mean? *Energy Policy* 1994 22 (10): 804–810.

Kesicki, F., Ekins, P., 2012. Marginal Abatement Cost Curves: a Call for Caution. *Climate Policy* 12: 219–236.

Kesicki, F., Stachan, N., 2011. Marginal Abatement Cost (MAC) Curves: Confronting Theory and Practice. *Environmental Science and Policy* 14: 1195–1204.

Klepper, G., Peterson, S., 2006. Marginal Abatement Cost Curves in General Equilibrium: the Influence of World Energy Prices. *Resource and Energy Economics* 28 (10): 1–23.

Klepper, G., Peterson, S., Springer, K., 2003. DART97. A Description of the Multi-regional, Multi-sectoral Trade Model for the Analysis of Climate Policies. Kiel Working Paper 1138, Kiel Institute for the World Economy.

Longva, T., Eide, M.S., Skjong, R., 2010. Determining a Required Energy Efficiency Design Index Level for New Ships Based on a Cost-effectiveness Criterion. *Maritime Policy and Management* 37 (2): 129–143.

Löschel, A., Zhang, Z. X., 2002. The Economic and Environmental Implications of the US Repudiation of the Kyoto Protocol and the Subsequent Deals in Bonn and Marrakesh. *Weltwirtschaftliches Archiv* 138: 711–746.

MEPC (Marine Environment Protection Committee), 2011. Mandatory Energy Efficiency Measures for International Shipping Adopted at IMO Environment Meeting. MEPC – 62<sup>nd</sup> session: 11 to 15 July 2011.

<http://www.imo.org/MediaCentre/PressBriefings/Pages/42-mepc-ghg.aspx>  
(accessed 09/28/2011).

MEPC, 2010. Reduction of GHG Emissions from Ships. Full Report of the Work Undertaken by the Expert Group on Feasibility Study and Impact Assessment of Possible Market-based Measures. MEPC 61/INF.2. MEPC – 61st session: 13 August 2010.

<http://www.imo.org/ourwork/environment/pollutionprevention/airpollution/documents/inf-2.pdf> (accessed 09/17/2011).

Morris, J., Paltsev, S., Reilly, J., (forth.). Marginal Abatement Costs and Marginal Welfare Costs from Greenhouse Gas Emissions Reductions: Results from the EPPA Model. Environmental Modelling and Assessment.

Narayanan, G. B., Walmsley, T. L., 2008. Global Trade, Assistance, and Production: The GTAP 7 Data Base. West Lafayette, Indiana (USA): Center for Global Trade Analysis, Purdue University.

Perman, R., Ma, Y., McGilvary, J., Common, M., 1999. Natural Resource and Environmental Economics. Second Edition. Essex: Pearson Education.

Rickels, W., Rehdanz, K., Oschlies, A., 2012. Economic Prospects of Ocean Iron Fertilization in an International Carbon Market. Resource and Energy Economics, 34(1): 129–150.

SNAME (Society of Naval Architect and Naval Engineers), 2010. Marginal Abatement Costs and Cost Effectiveness of Fuel-Efficiency Measures. Jersey City: Society of Naval Architect and Naval Engineers.

<http://www.sname.org/SNAME/climatechange/MACreport> (accessed 11/14/2011).

UNEP (United Nations Environment Programme), 2011. Bridging the Emissions Gap. November 2011.

[http://www.unep.org/pdf/UNEP\\_bridging\\_gap.pdf](http://www.unep.org/pdf/UNEP_bridging_gap.pdf) (accessed 06/05/12).

UNEP, 2010. The Emissions Gap Report: Are the Copenhagen Accord Pledges Sufficient to Limit Global Warming to 2° C or 1.5° C? A Preliminary Assessment. Full Report. November 2010.

<http://www.unep.org/publications/ebooks/emissionsgapreport/> (accessed 06/05/12).

UNFCCC (United Nations Framework Convention on Climate Change), 2010a. Communications received from Parties in relation to the listing in the chapeau of the Copenhagen Accord.

[http://unfccc.int/meetings/copenhagen\\_dec\\_2009/items/5276.php](http://unfccc.int/meetings/copenhagen_dec_2009/items/5276.php) (accessed 09/05/12).

UNFCCC, 2010b. Appendix I - Quantified Economy-Wide Emissions Targets for 2020. [http://unfccc.int/meetings/copenhagen\\_dec\\_2009/items/5264.php](http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php) (accessed 09/05/12).

UNFCCC, 2010c. Appendix II - Nationally Appropriate Mitigation Actions of Developing Country Parties.

[http://unfccc.int/meetings/cop\\_15/copenhagen\\_accord/items/5265.php](http://unfccc.int/meetings/cop_15/copenhagen_accord/items/5265.php) (accessed 09/05/12).

Wang, H., 2010. Economic Costs of CO<sub>2</sub> Emissions Reduction for Non-Annex I Countries in International Shipping. Energy for Sustainable Development 14: 280–286.

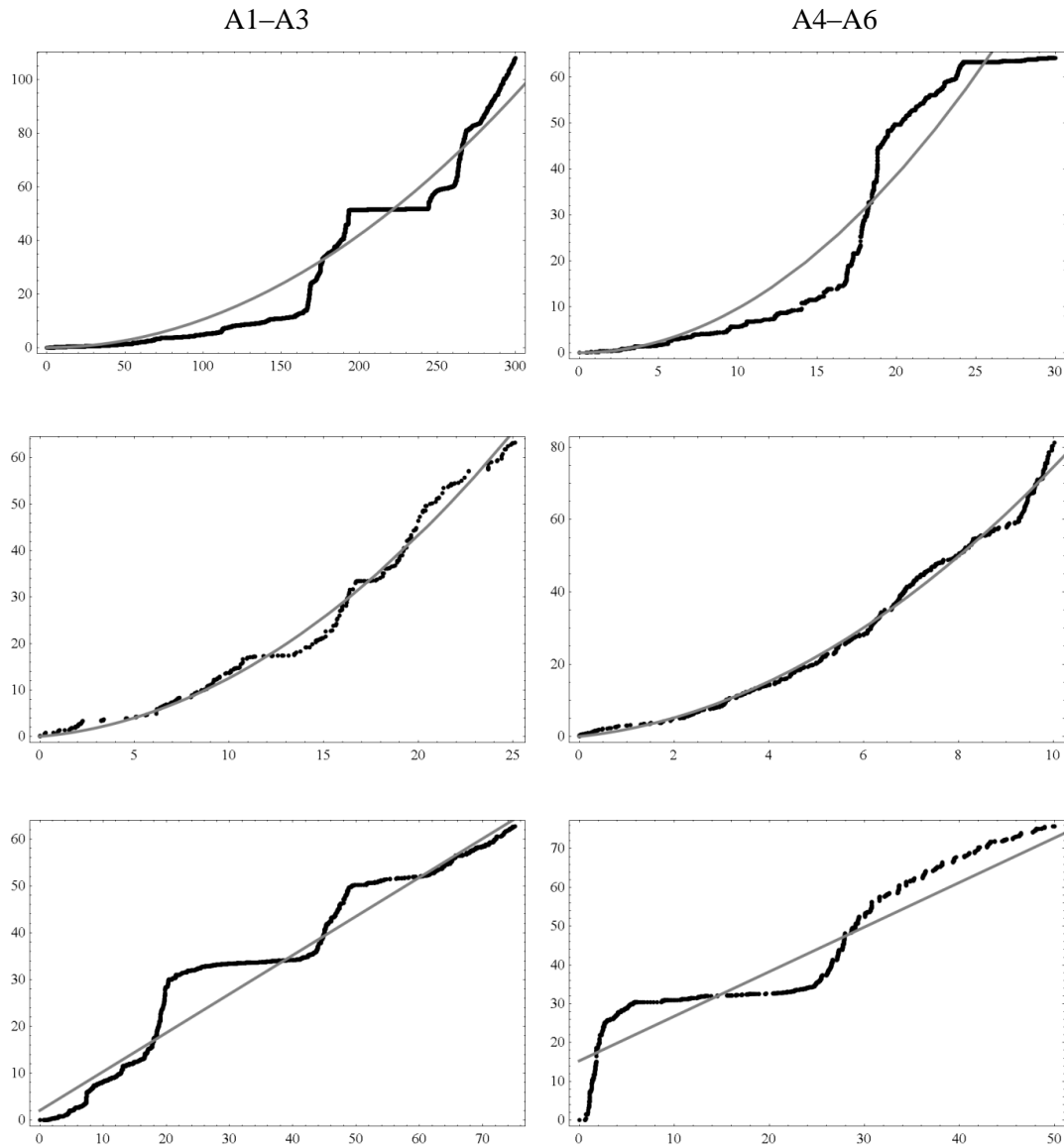
Wang, H., Faber, J., Nelissen, D., Russel, B., St Amand, D., 2010. Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures. MEPC 61 INF 18. [http://www.cedelft.eu/publicatie/marginal\\_abatement\\_costs\\_and\\_cost-effectiveness\\_of\\_energy-efficiency\\_measures/1090](http://www.cedelft.eu/publicatie/marginal_abatement_costs_and_cost-effectiveness_of_energy-efficiency_measures/1090) (accessed 11/14/2011).

## 8. Appendix

**Table A1:** Parameter values and (adjusted)  $R^2$  of approximated marginal abatement cost functions.

Case	Reduction and costs scenario	Parameter values			$R^2$	adj. $R^2$
		a	b	c		
<i>full_rp</i>	<i>hrlc</i>			0.00105054	0.980893	0.980891
	<i>lrhc</i>			0.09675131	0.968225	0.968214
<i>reduced_rp</i>	<i>hrlc</i>		0.34804264	0.09087283	0.995681	0.995653
	<i>lrhc</i>		1.36010899	0.60900788	0.997943	0.997940
<i>barrier_rp</i>	<i>hrlc</i>	2.054096808	0.82941192		0.968542	
	<i>lrhc</i>	15.28405984	1.15011927		0.851306	

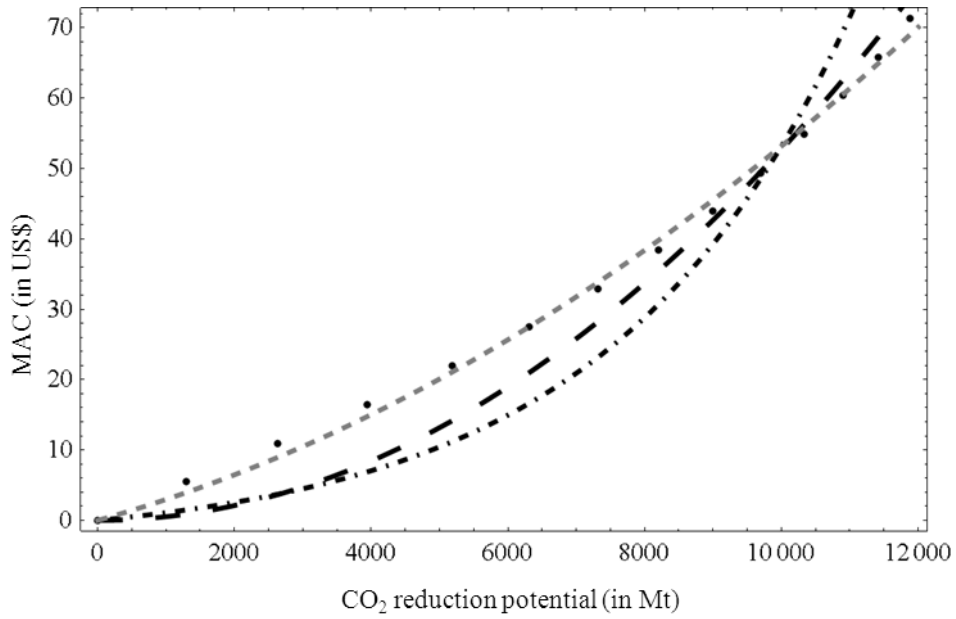
*Source:* Own calculations.



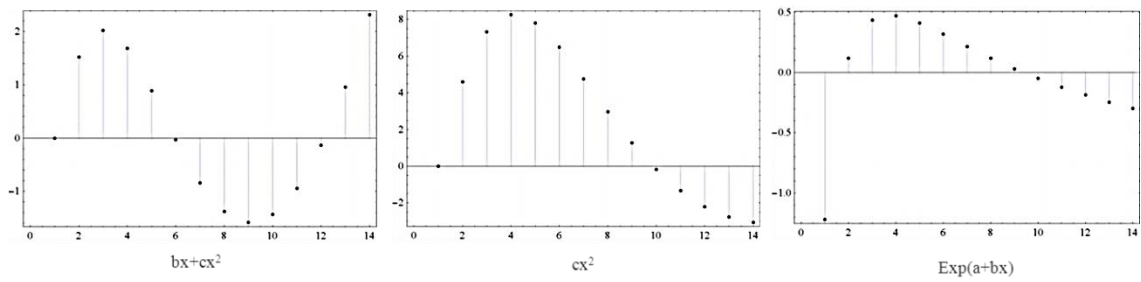
**Figures A1–A3:** show the approximated functions for the high reduction and low costs scenario (*hrlc*). *Source:* Own calculations.

**Figures A4–A6:** show the approximated functions for the high reduction and low costs scenario (*lrhc*). *Source:* Own calculations.

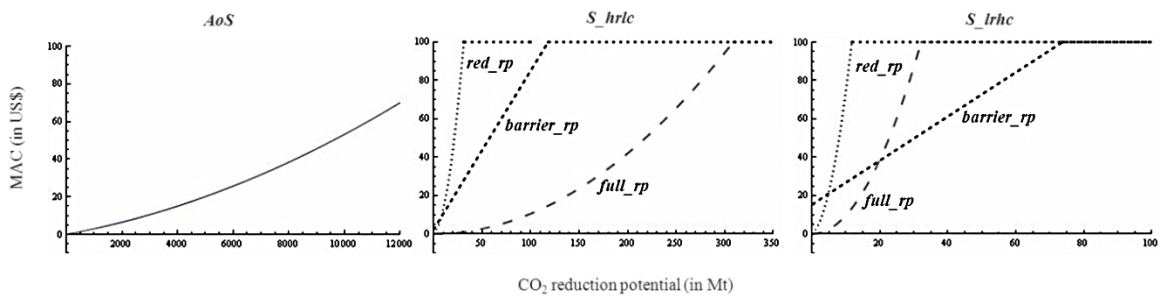
Figure A7 shows three approximated functions for AoS. As the figure shows, the quadratic form (gray dashed line:  $bx+cx^2$ ) has a better fit than the other quadratic (black dashed line:  $cx^2$ ) and the exponential form (black dotted-dashed line:  $\exp(a+bx)$ ) for abatement levels between 7,000 and 10,500 MtCO<sub>2</sub>.



**Figure A7:** Comparison of functional fits with global (AoS) MACC. *Source:* Own presentation. MACC generated with the DART model.



**Figure A8:** Residuals plots. *Source:* Own calculations.



**Figure A9:** Global (AoS) MACC and shipping MACCs. *Source:* Own calculations.



**Table A2:** Emissions, abatement costs, and prices under the 2°C target.

Policy scenario	Reduction and costs scenario	Cases	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 <sub>S</sub> in billion 2007US\$)	Abatement costs AoS (AC <sub>AoS</sub> in billion 2007US\$)	Abatement costs (AC <sub>AoS</sub> + AC <sub>S</sub> in billion 2007US\$)	CO <sub>2</sub> price/ton (in 2007US\$)=MAC <sub>AoS</sub>	CO <sub>2</sub> price/ton (in 2007US\$)=MAC <sub>AoS</sub> =MAC <sub>S</sub>
Joint target for AoS and shipping		<i>full_rp</i>	947	34500	718	24258	4.21	235.65	239.86	55.11
		<i>hrhc reduced_rp</i>	542	34500	519	24456	0.43	224.87	225.30	53.52
		<i>barrier_rp</i>	947	34500	881	24095	1.92	244.76	246.68	56.43
		<i>full_rp</i>	947	34500	922	24053	0.46	247.10	247.56	56.77
		<i>lrhc reduced_rp</i>	755	34500	746	24230	0.17	237.22	237.39	55.34
		<i>barrier_rp</i>	947	34500	911	24065	1.29	246.43	247.72	56.67
AoS without shipping		<i>full_rp</i>		34500		24029		248.48		56.97
	AoS (DART)	<i>reduced_rp</i>		34500		24434		226.07		53.70
		<i>barrier_rp</i>		34500		24029		248.48		56.97
		<i>full_rp</i>		34500		24029		248.48		56.97
	AoS (DART)	<i>reduced_rp</i>		34500		24221		237.69		55.41
		<i>barrier_rp</i>		34500		24029		248.48		56.97

Source: Own calculations.

**Table A3:** Emissions, abatement costs, and prices under the low Copenhagen Pledges target.

Policy scenario	Reduction and costs scenario	Cases	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 <sub>S</sub> in billion 2007US\$)	Abatement costs AoS (AC <sub>AoS</sub> in billion 2007US\$)	Abatement costs (AC <sub>AoS</sub> + AC <sub>S</sub> in billion 2007US\$)	CO <sub>2</sub> price/ton (in 2007US\$)=MAC <sub>AoS</sub>	CO <sub>2</sub> price/ton (in 2007US\$)=MAC <sub>AoS</sub> =MAC <sub>S</sub>
Joint target for AoS and shipping		<i>full_rp</i>	947	34500	765	27063	2.09	110.78	112.87	34.59
	<i>hrhc</i>	<i>reduced_rp</i>	542	34500	524	27076	0.22	110.36	110.58	34.51
		<i>barrier_rp</i>	947	34500	906	26922	0.76	115.73	116.49	35.52
		<i>full_rp</i>	947	34500	927	26901	0.23	116.48	116.71	35.66
	<i>lrhc</i>	<i>reduced_rp</i>	755	34500	748	26972	0.09	113.99	114.07	35.20
		<i>barrier_rp</i>	947	34500	929	26900	0.45	116.53	116.98	35.67
AoS without shipping		<i>full_rp</i>		34500		26882		117.17		35.79
	<i>AoS (DART)</i>	<i>reduced_rp</i>		34500		27058		110.97		34.62
		<i>barrier_rp</i>		34500		26882		117.17		35.79
		<i>full_rp</i>		34500		26882		117.17		35.79
	<i>AoS (DART)</i>	<i>reduced_rp</i>		34500		26965		114.22		35.24
		<i>barrier_rp</i>		34500		26882		117.17		35.79

Source: Own calculations.

**Table A4:** Emissions, abatement costs, and prices under the high Copenhagen Pledges target.

Policy scenario	Reduction and costs scenario	Cases	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 <sub>S</sub> in billion 2007US\$)	Abatement costs AoS (AC <sub>AoS</sub> in billion 2007US\$)	Abatement costs (AC <sub>AoS</sub> + AC <sub>S</sub> in billion 2007US\$)	CO <sub>2</sub> price/ton (in 2007US\$)= MAC <sub>AoS</sub>	CO <sub>2</sub> price/ton (in 2007US\$) =MAC <sub>AoS</sub> =MAC <sub>S</sub>
Joint target for AoS and shipping		<i>full_rp</i>	947	34500	755	26452	2.48	133.18	135.66	38.71
	<i>hrlc</i>	<i>reduced_rp</i>	542	34500	523	26454	0.26	133.11	133.37	38.70
		<i>barrier_rp</i>	947	34500	901	26305	0.95	138.93	139.88	39.73
		<i>full_rp</i>	947	34500	926	26280	0.27	139.93	140.20	39.91
	<i>lrhc</i>	<i>reduced_rp</i>	755	34500	748	26350	0.10	137.16	137.26	39.42
		<i>barrier_rp</i>	947	34500	925	26281	0.59	139.89	140.48	39.90
RoW without shipping		<i>full_rp</i>		34500		26260		140.74	40.05	
	<i>AoS (DART)</i>	<i>reduced_rp</i>		34500		26435		133.84	38.83	
		<i>barrier_rp</i>		34500		26260		140.74	40.05	
		<i>full_rp</i>		34500		26260		140.74	40.05	
	<i>AoS (DART)</i>	<i>reduced_rp</i>		34500		26343		137.44	39.47	
		<i>barrier_rp</i>		34500		26260		140.74	40.05	

Source: Own calculations.

## Part II

# Climate Change Policy

### Paper III: Including Maritime Transport in the EU's Climate Change Policy: Country-Based Allocation and Effects

Heitmann, N., 2013.

Including Maritime Transport in the EU's Climate Change Policy: Country-Based Allocation and Effects, Kiel Working Paper No. 1824, Kiel Institute for the World Economy.

# Including Maritime Transport in the EU's Climate Change Policy: Country-Based Allocation and Effects<sup>\*</sup>

Nadine Heitmann<sup>a</sup>

<sup>a</sup> Kiel Institute for the World Economy, Hindenburgufer 66, 24105 Kiel, Germany

## 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

---

<sup>\*</sup> 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.

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, CO<sub>2</sub> emissions, marginal abatement cost curve

**JEL classification:** Q52, Q54, Q58

## 1. Introduction

Carbon dioxide emissions generated by the shipping sector accounted for about 3% of global carbon emissions in 2007.<sup>1</sup> 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<sup>2</sup> 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).<sup>3</sup>

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 allocation rules to allocate the shipping sector's emissions to individual countries

---

<sup>1</sup> 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).

<sup>2</sup> We denote carbon dioxide emissions from now on as emissions.

<sup>3</sup> 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](http://ec.europa.eu/clima/events/0035/index_en.htm).

(SBSTA, 1996).<sup>4</sup> 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).<sup>5</sup> 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 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

---

<sup>4</sup> 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.

<sup>5</sup> 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).



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,<sup>6</sup> and even on national levels, e.g., in the framework of the German Integrated Energy and Climate Package (BMU, 2007) and Energy Concept Germany (BMW 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.<sup>7</sup> The Kyoto

---

<sup>6</sup> 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).

<sup>7</sup> 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).<sup>8</sup> 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<sub>2</sub>-eq. with the unconditional pledge and to 3.90 GtCO<sub>2</sub>-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<sub>2</sub>-eq. in 2011 and to 5.58 GtCO<sub>2</sub>-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.<sup>9</sup> However, the shipping sector's emissions are neither included in the EU ETS nor tackled by any other climate change policy instrument.

---

<sup>8</sup> 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).

<sup>9</sup> [http://ec.europa.eu/clima/policies/ets/index\\_en.htm](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

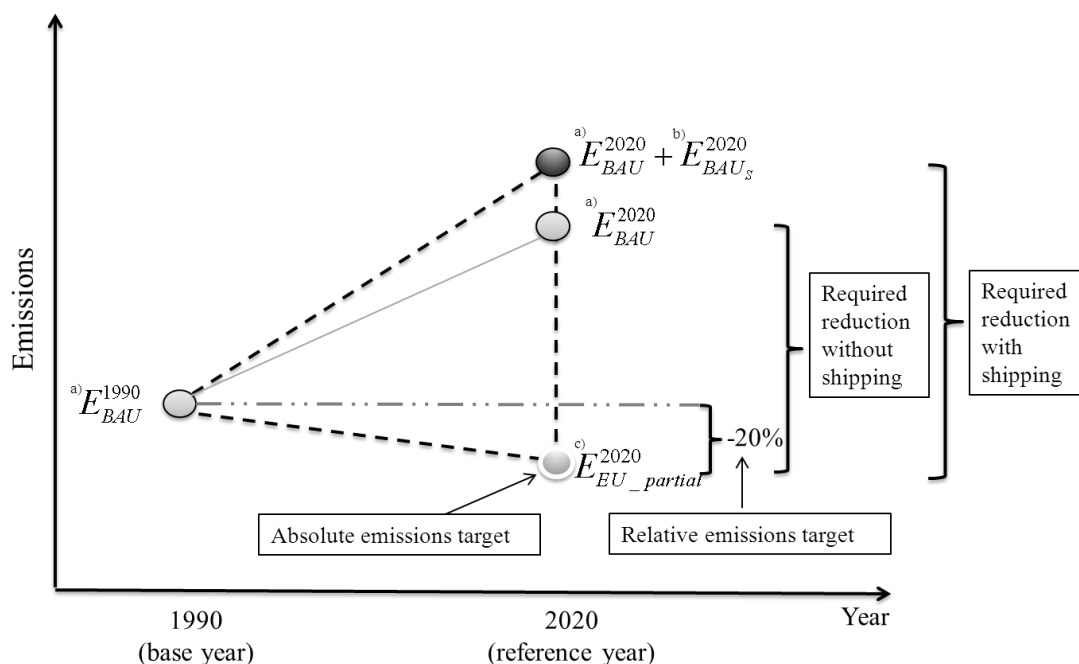
#### 3.1. Absolute versus relative target

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.<sup>10</sup> 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*.

---

<sup>10</sup> 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).



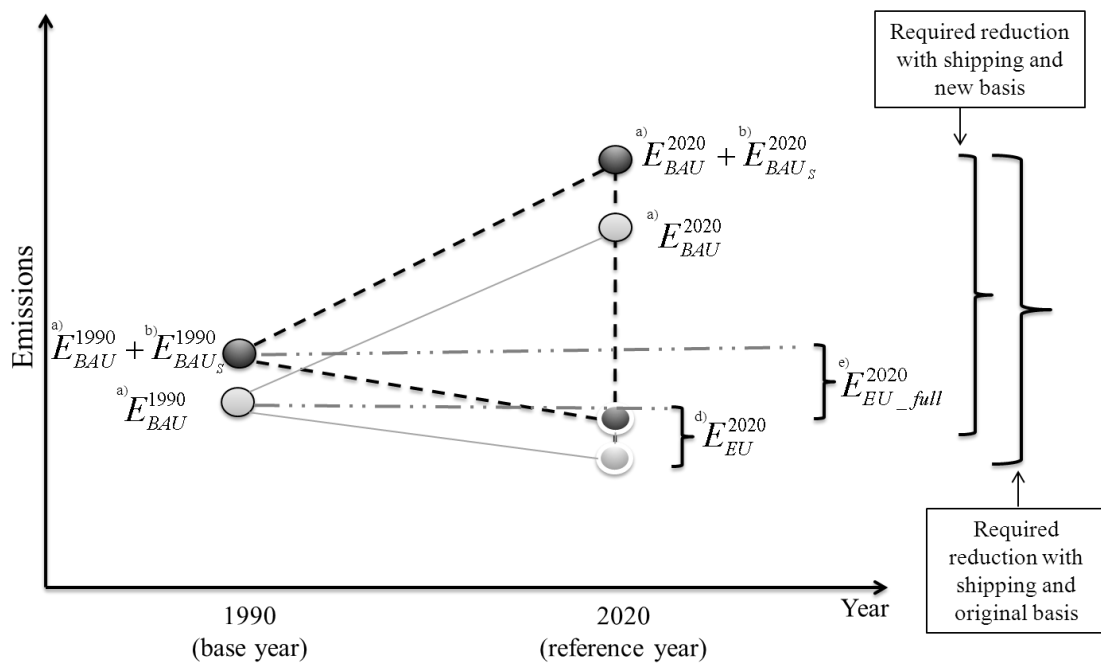
**Figure 1:** *Partial integration approach (absolute reduction target remains constant)*  
 Source: Own presentation.

**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

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). 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 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<sup>11</sup> 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.<sup>12</sup> 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).<sup>13</sup>

---

<sup>11</sup> 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.

<sup>12</sup> 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).

<sup>13</sup> 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 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.

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

	<i>Owner</i>	<i>Operator</i>	<i>Flag</i>
<i>BAU emissions of the EU fleet in Mt</i>	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).<sup>14</sup> 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 *operator* (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<sub>2</sub>-eq in 2020 gives us the required emission reductions.

<sup>14</sup> 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<sub>2</sub> 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,<sup>15</sup> and that, according to Buhaug et al. (2009), the BAU emissions of the shipping sector in that year amounted to 468 MtCO<sub>2</sub>. Thus, we add 140 MtCO<sub>2</sub> in case of the *EU-owned fleet* to the regular base year emissions in 1990 (see Figure 2), 131 MtCO<sub>2</sub> in the case of *EU-operated fleet*, and 84 MtCO<sub>2</sub> 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.

---

<sup>15</sup> We have neither information about owner, operator, or flag state registration nor about the operational profiles of ships for the year 1990.

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

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<sub>2</sub> emission reduction potential ( $T \cdot CO_2^{red}$ ), see Equation 1:

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

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

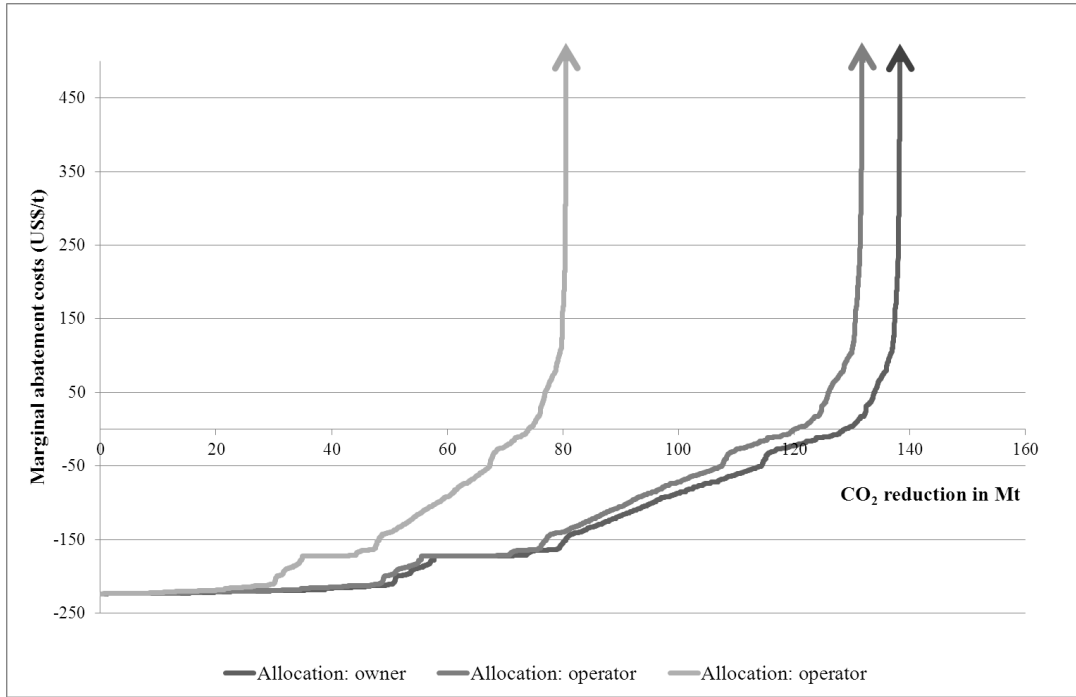
In this paper, we use the reduction potentials and abatement costs per measure calculated in Heitmann and Peterson (2012) to generate MACCs of the EU shipping sector in 2020. They assume that ships start to apply abatement measures from 2020 onwards because they currently have little incentives to implement abatement measures.<sup>17</sup> 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 (*hrhc*) and low reduction potentials and high costs (*lrhc*). Thus, combining their reduction potential and abate-

---

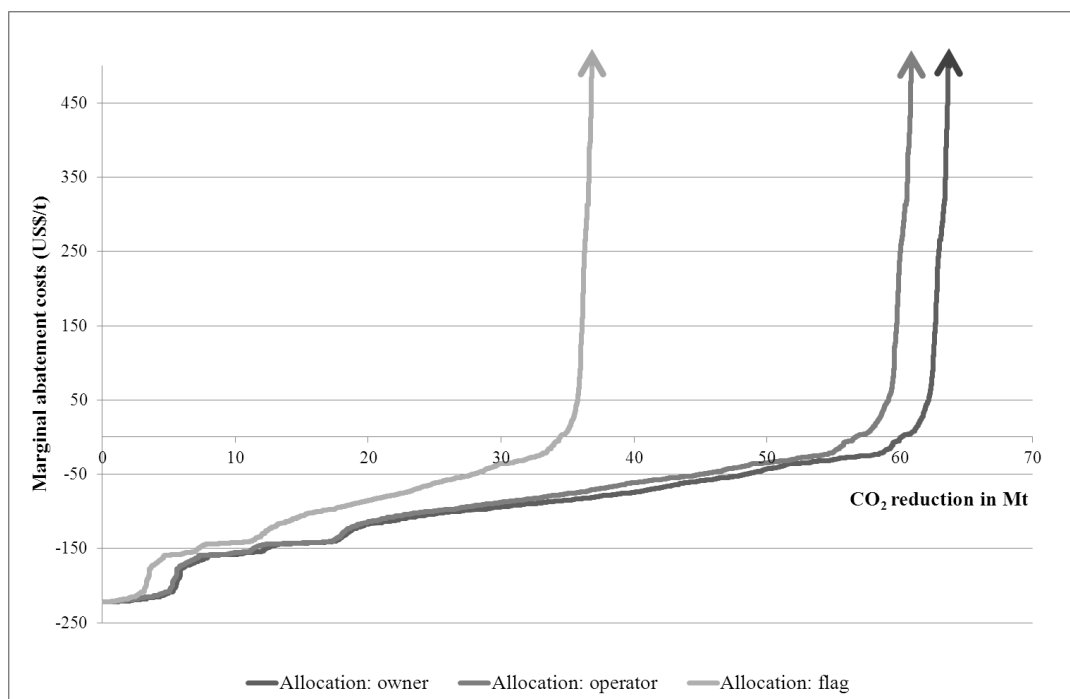
<sup>16</sup> Faber et al. (2011) is an updated version of Wang et al. (2010).

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

ments 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.



**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<sub>2</sub> emissions).

Allocation way		<i>Owner</i>	<i>Operator</i>	<i>Flag</i>
Reduction/costs scenarios	<i>hrlc</i>	139	133	81
	<i>lrhc</i>	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<sub>2</sub>. 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.

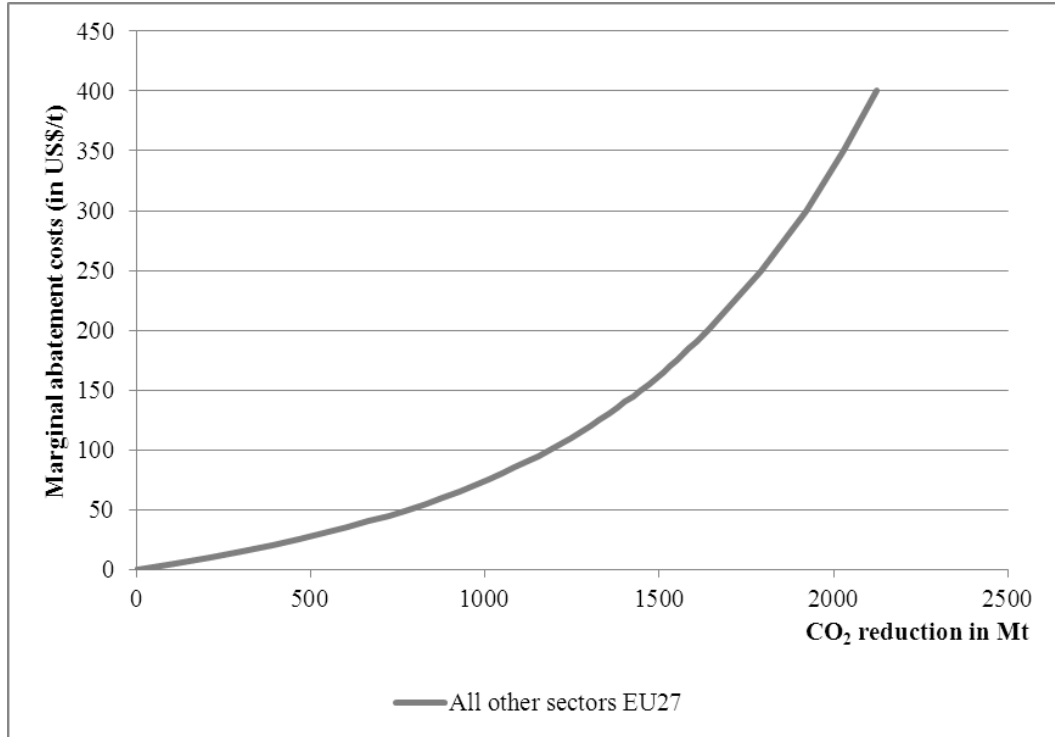
#### ***4.2. MACC and corresponding abatement cost function for all other EU sectors***

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.<sup>18</sup> The DART model is currently calibrated to the GTAP-8 database (Narayanan et al., 2012) and includes 14 world regions.<sup>19</sup> 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.

---

<sup>18</sup> 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.

<sup>19</sup> 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.



**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<sub>2</sub>, 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* ( $MAC_{AoS}(R_{AoS})$ ).

$$MAC_{AoS}(R_{AoS}) = 0.0182965 \cdot R_{AoS} + 0.0000578 \cdot R_{AoS}^2, \quad (2)$$

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.<sup>20</sup> 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).<sup>21</sup> 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),<sup>22</sup> 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 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.<sup>23</sup> For this purpose, we make use of an approach presented in Hyman et al. (2002)

---

<sup>20</sup> 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.

<sup>21</sup> 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).

<sup>22</sup> 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.

<sup>23</sup> 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.

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.<sup>24</sup> 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.

$$MAC_{ij}^{\text{exp}}(R_{ij}) = \exp(a_{ij} + b_{ij}R_{ij}), \quad (3)$$

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

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.

---

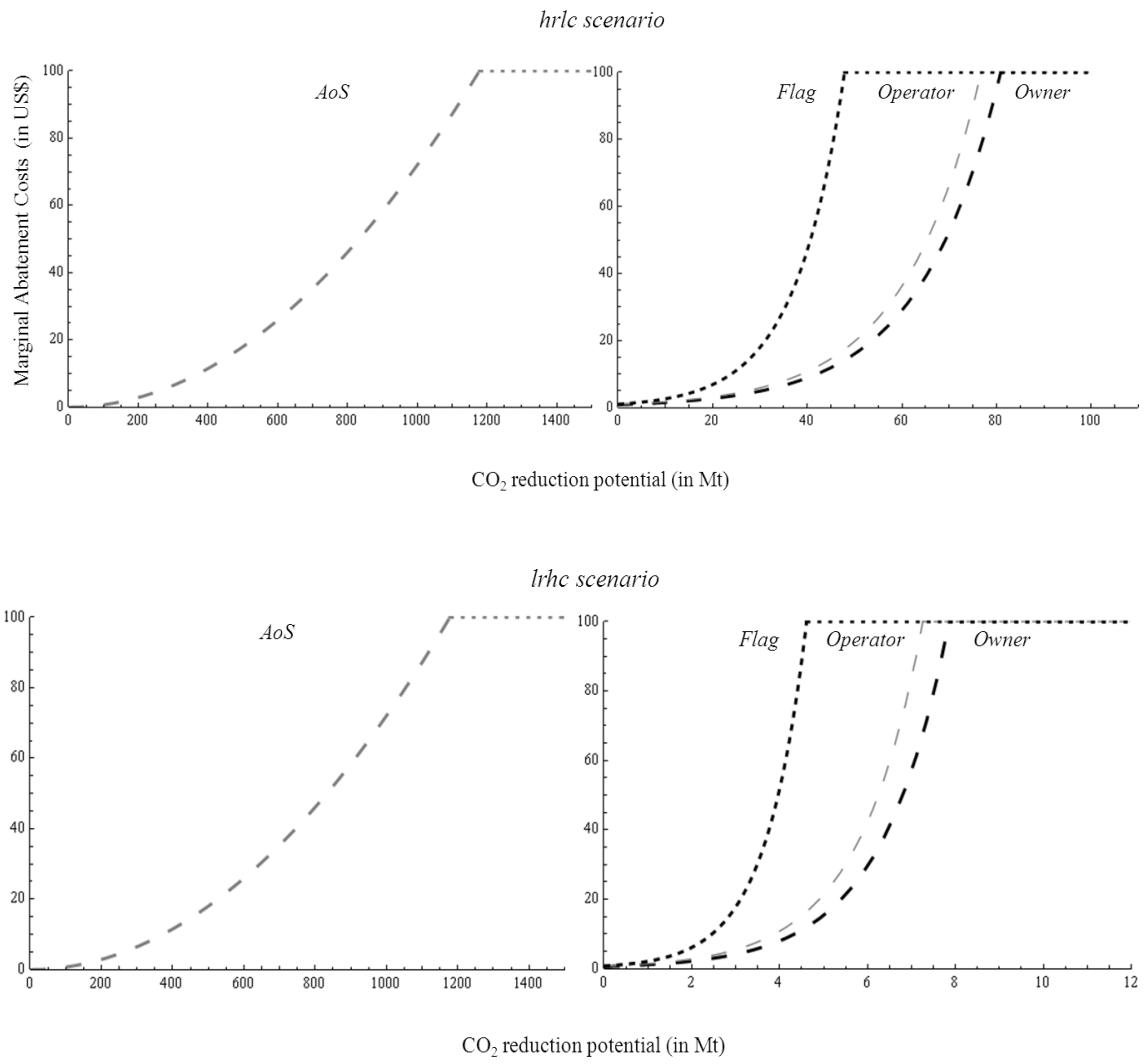
<sup>24</sup> When looking at how much the shipping sector could contribute efficiently to the joint target, both functional forms give rise to very similar values.



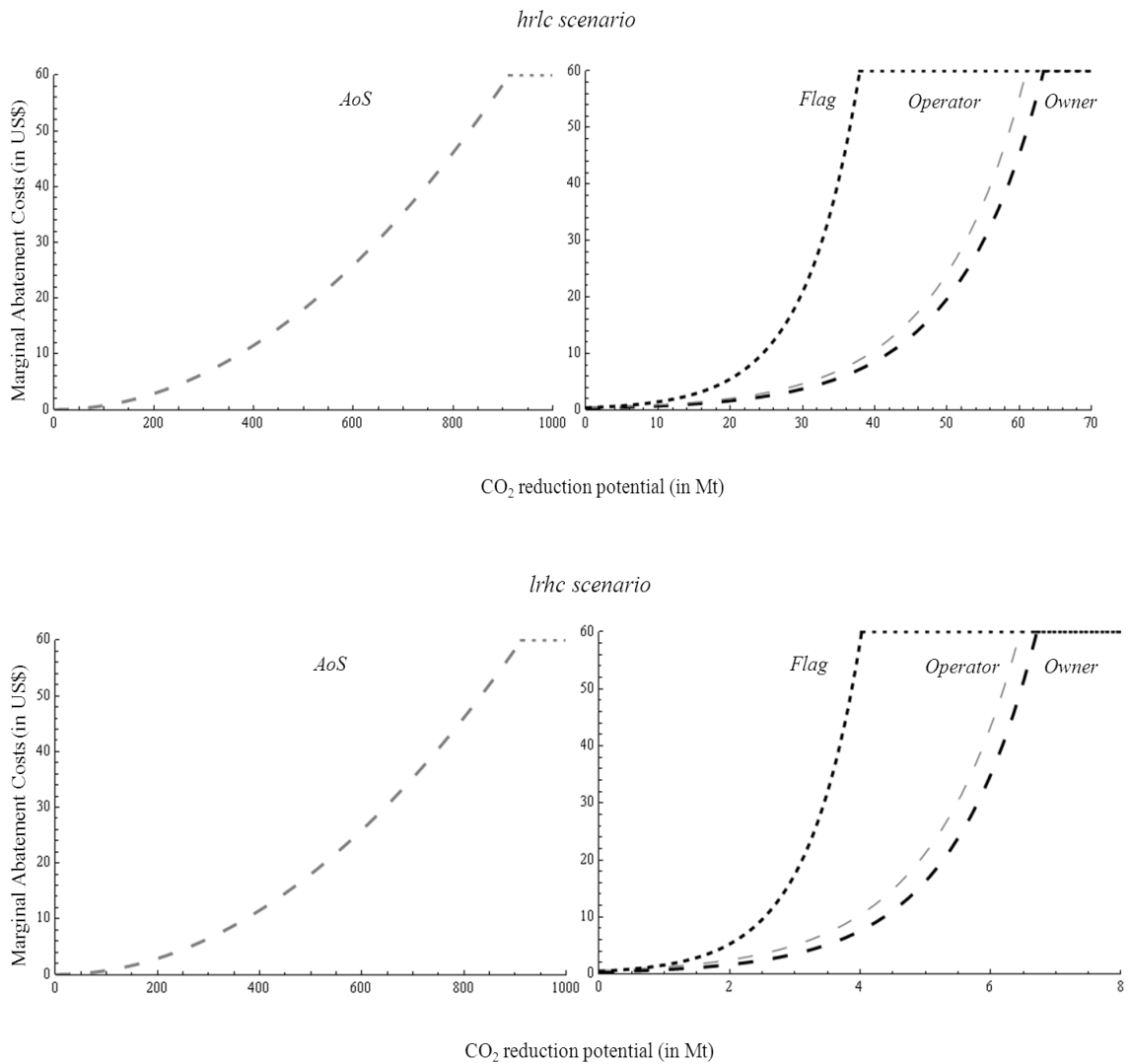
**Table 3:** Value restrictions under the *partial* and the *full integration* approach

<i>Integration approach</i>	$R_{ij}$	$i=1$ (owner)	$i=2$ (operator)	$i=3$ (flag)
<i>Partial integration</i>	$j=1$ ( <i>hrlc</i> )	[0,90]	[0,85]	[0,50]
	$j=2$ ( <i>lrhc</i> )	[0,8]	[0,8]	[0,4.5]
<i>Full integration</i>	$j=1$ ( <i>hrlc</i> )	[0,60]	[0,55]	[0,35]
	$j=2$ ( <i>lrhc</i> )	[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<sub>2</sub> in 2020 according to the DART model. As mentioned before, this number includes CO<sub>2</sub> 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		
		<i>Owner</i>	<i>Operator</i>	<i>Flag</i>
<i>BAU emissions in Mt</i>	4249	286	276	173

*Source:* Own calculations.

Because we are mainly interested in the abatement of CO<sub>2</sub> emissions resulting from fossil fuel use in the EU27, we need to derive a target for CO<sub>2</sub> emissions of the sectors covered in DART (*AoS*) plus the shipping sector. Therefore, we analyze only the share of CO<sub>2</sub> emissions in total GHG emissions.

We assume that the share of CO<sub>2</sub> 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).<sup>25</sup> 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<sub>2</sub>, in the EU27 are 4,450 MtCO<sub>2</sub>-eq. in 2020. We multiply this number with the share of CO<sub>2</sub> 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<sub>2</sub> emissions from fossil fuel use to stay in line with meeting the absolute target in 2020. If we apply the *full integration* approach (the shipping sector’s emissions are

<sup>25</sup> This number excludes CO<sub>2</sub> emissions from LULUCF.

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<sub>2</sub>, in the case of *operator* allocation 3,767 MtCO<sub>2</sub>, and in the case of *flag* allocation 3,730 MtCO<sub>2</sub>. 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<sub>2</sub>) of the shipping sector and *AoS* in 2020

Integration approach	Allocation way		
	<i>Owner</i>	<i>Operator</i>	<i>Flag</i>
<i>Partial integration</i>	886	876	773
<i>Full integration</i>	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*.<sup>26</sup>

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<sub>2</sub> 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).

---

<sup>26</sup> The difference between *AoS* BAU emissions (4,249 MtCO<sub>2</sub>) and allowed emissions (3,649 MtCO<sub>2</sub>), 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<sub>2</sub>.

**Table 6:** Resulting CO<sub>2</sub> prices (in US\$) and efficient reductions in relative terms in 2020 for scenario *S* included in reduction effort

Reduction potentials/costs scenario	Allocation way	<i>Partial integration approach</i>			<i>Full integration approach</i>		
		CO <sub>2</sub> price (in US\$)	<sup>a)</sup> R <sub>S</sub> rel.to BAU emissions	<sup>a)</sup> R <sub>S</sub> rel.to overall target	CO <sub>2</sub> price (in US\$)	<sup>a)</sup> R <sub>S</sub> rel.to BAU emissions	<sup>a)</sup> R <sub>S</sub> rel.to overall target
<i>hrlc</i>	<i>Owner</i>	53.38	24.6%	7.94%	41.34	20.6%	7.74%
	<i>Operator</i>	52.72	24.0%	7.56%	41.28	20.5%	7.45%
	<i>Flag</i>	44.52	22.8%	5.10%	39.98	19.8%	4.96%
<i>lrhc</i>	<i>Owner</i>	60.73	2.5%	0.80%	46.72	2.2%	0.84%
	<i>Operator</i>	59.61	2.4%	0.74%	46.44	2.2%	0.80%
	<i>Flag</i>	48.26	2.3%	0.51%	39.98	2.1%	0.53%

<sup>a)</sup>R<sub>S</sub> refers to emission reductions of the shipping sector.

Source: Own calculations.

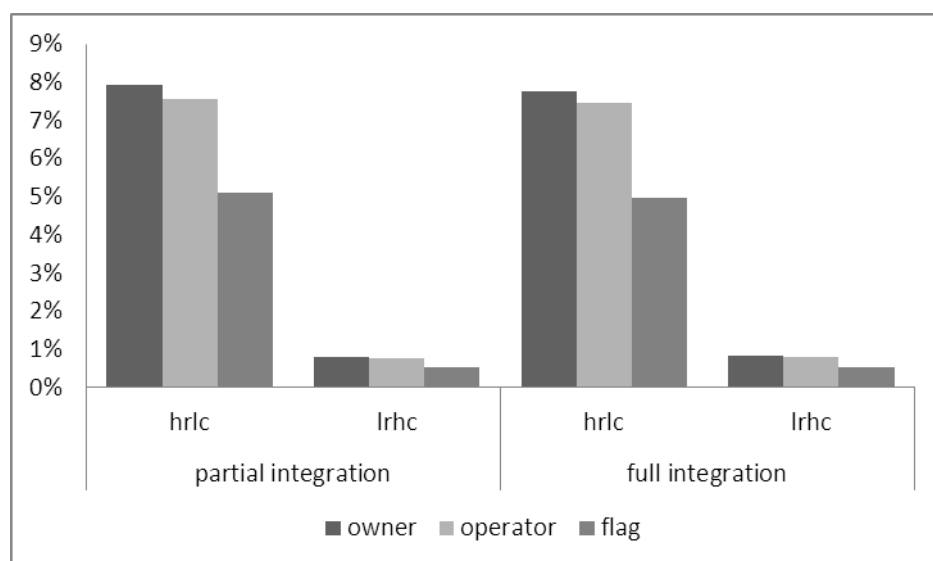
The CO<sub>2</sub> prices are in a range between 45 and 61 US\$/t under the *partial integration approach* and in a range between 40 and 47 US\$/t under the *full integration approach*. The allocation rule *owner*, independent of the assumed reduction potentials/costs scenario and of the approach to include the shipping sector's emissions into the reduction commitment (*partial* and *full integration approach*), causes always the highest CO<sub>2</sub> 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<sub>2</sub> 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*).

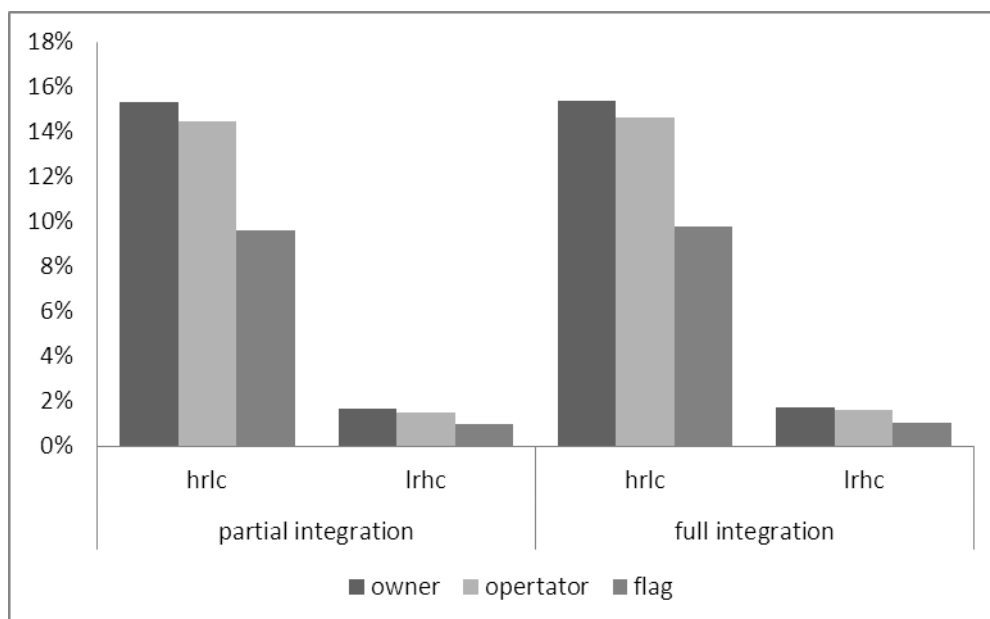
Looking at Figure 7, which shows the efficient contribution (in %) of the shipping sector to the assumed targets under the *partial* and *full integration approach*, it is apparent that the efficient contribution of the shipping sector under the *full integration approach* (at most 7.74%) is almost the same (*hrhc* 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 of 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.





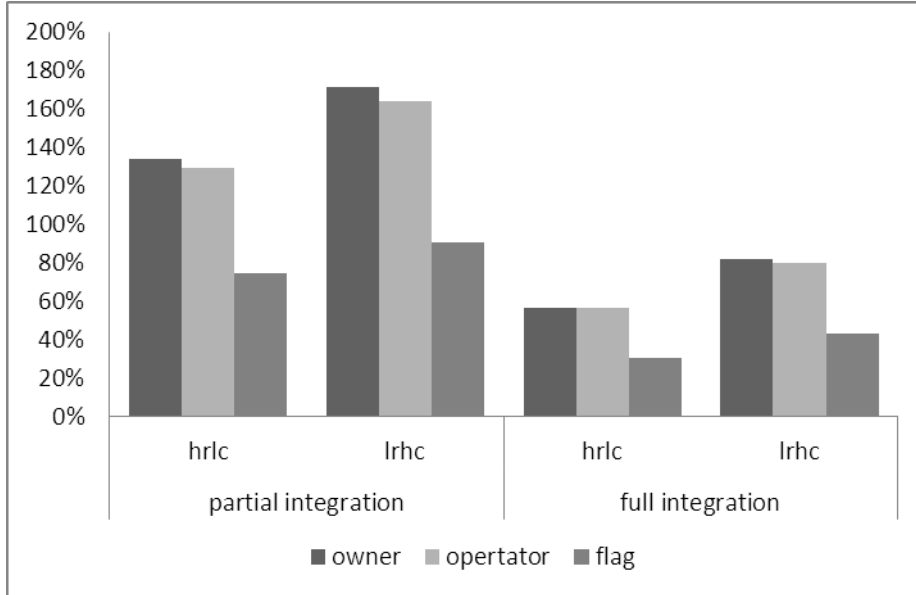
**Figure 8:** Abatement costs savings (in %) if the shipping sector would be included in reduction efforts under the *partial* and the *full integration* approach. *Source:* Own calculations.

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.<sup>27</sup> 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<sub>2</sub> price and abatement costs increase significantly if the EU would include the shipping sector's emissions in its reduction commitment; see Table A3–A4 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 integration approach*, depending on the reduction potentials/costs scenario assumed.

<sup>27</sup> See, e.g., Ellerman and Decaux (1998).

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:

$$ratio_k = \frac{R_k^*}{E_{BAU_k}} \bigg/ \frac{\sum_k R_k^*}{\sum_k E_{BAU_k}}, \quad (5)$$

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 <sub>k</sub>	Country	ratio <sub>k</sub>	Country	ratio <sub>k</sub>
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<sup>28</sup> 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.

---

<sup>28</sup> 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.

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

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).<sup>29</sup> However, the commitment was based on a specific set of activities and sectors resulting in GHG emissions that excluded international bunker fuel emissions.<sup>30</sup> 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.<sup>31</sup>

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 GtCO<sub>2</sub>-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.

---

<sup>29</sup> 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.

<sup>30</sup> Total GHG emissions do not include emissions from international bunkers (EEA, 2012).

<sup>31</sup> 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 to 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 short-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.<sup>32</sup> 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<sub>2</sub>-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

---

<sup>32</sup> This issue is discussed in Buhaug et al. (2009) and in Faber et al. (2009).

and reassesses the base year emissions in 1990 by including the shipping sector's emissions.

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 the 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 short-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.

## 8. References

Anger, A., 2010. Including Aviation in the European Emissions Trading Scheme: Impacts on the Industry, CO<sub>2</sub> Emissions and Macroeconomic Activity in the EU. *Journal of Air Transport Management* 16: 100–105.

Anger, A., Köhler, J., 2010. Including Aviation Emissions in the EU ETS: Much Ado About Nothing? A Review. *Transport Policy* 17: 38–46.

BMWi (Bundesministerium für Wirtschaft und Technologie) and BMU (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit), 2010. *Energiekonzept für eine umweltschonende, zuverlässige und bezahlbare Energieversorgung*. Berlin: BMWi.

BMU, 2007. *Das Integrierte Energie- und Klimaprogramm der Bundesregierung*. [http://www.bmu.de/fileadmin/bmu-import/files/pdfs/allgemein/application/pdf/hintergrund\\_meseberg.pdf](http://www.bmu.de/fileadmin/bmu-import/files/pdfs/allgemein/application/pdf/hintergrund_meseberg.pdf) (accessed 01/10/2012).

Buhaug, Ø., Corbett, J.J., Endresen, Ø., Eyring, V., Faber, J., Hanayama, S., Lee, D.S., Lee, D., Lindstad, H., Markowska, A.Z., Mjelde, A., Nelissen, D., Nilsen, J., Pålsson, C., Winebrake, J.J., Wu, W.-Q., Yoshida, K., 2009. *Second IMO GHG Study 2009*. London: International Maritime Organization (IMO).

Council of the European Union, 2009. *Council Conclusions on EU Position for the Copenhagen Climate Conference (7–18 December 2009)*. 2968th Environment Council meeting, Luxembourg, 21 October 2009. [http://www.consilium.europa.eu/uedocs/cms\\_data/docs/pressdata/en/envir/110634.pdf](http://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/envir/110634.pdf) (accessed 08/12/2012).

Committee on Climate Change, 2011. *Review of UK Shipping Emissions*. November 2011, London. [http://downloads.theccc.org.uk.s3.amazonaws.com/Shipping%20Review/CCC\\_Shipping%20Review\\_single%20page\\_smaller.pdf](http://downloads.theccc.org.uk.s3.amazonaws.com/Shipping%20Review/CCC_Shipping%20Review_single%20page_smaller.pdf) (accessed 14/09/2012).

Directive 2009/31/EC. Directive 2009/31/EC of the European Parliament and the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006. L 140/114, EN Official Journal of the European Union, 5.6.2009.

Directive 2009/29/EC. Directive 2009/29/EC of the European Parliament and 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. L 140/63, EN Official Journal of the European Union, 5.6.2009.

Directive 2009/28/EC. Directive 2009/28/EC of the European Parliament and 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. L 140/16, EN Official Journal of the European Union, 5.6.2009.

Directive 2008/101/EC. Directive 2008/101/EC of the European Parliament and the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community. L 8/3, EN Official Journal of the European Union, 13.1.2009.

den Elzen, M., Hof, A.F., Roelfsema, M., 2011. The Emissions Gap Between the Copenhagen Pledges and the 2°C Climate Goal: Options for Closing and Risks that Could Widen the Gap. *Global Environmental Change* 21: 733–743.

den Elzen, M., Olivier, J., Berk, M., 2007. An Analysis of Options for Including International Aviation and Marine Emissions in a post-2012 Climate Mitigation Regime. MNP Report 500114007/2007.

EU (European Union), 2009. Decision No 406/2009/EC of the European Parliament and 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. L 140/136, EN, Official Journal of the European Union, 5.6.2009.

EEA (European Environment Agency), 2012. Greenhouse Gas Emission Trends and Projections in Europe 2012. EEA Report No 6/2012.

EC (European Commission), 2012. Stopping the Clock of ETS and Aviation Emissions Following Last Week's International Civil Aviation Organisation (ICAO) Council. MEMO/12/854. Event Date: 12/11/2012.  
[http://europa.eu/rapid/press-release\\_MEMO-12-854\\_en.htm](http://europa.eu/rapid/press-release_MEMO-12-854_en.htm) (accessed 01/02/2013).

EC (European Commission), 2010. Expression of Willingness to be Associated with the Copenhagen Accord and Submission of the Quantified Economy-wide Emissions Reduction Targets for 2020. Brussels, 2010.  
[http://unfccc.int/files/meetings/cop\\_15/copenhagen\\_accord/application/pdf/europeanunioncphaccord\\_app1.pdf](http://unfccc.int/files/meetings/cop_15/copenhagen_accord/application/pdf/europeanunioncphaccord_app1.pdf) (accessed 09/05/12).

EC (European Commission), 2008. Decision of the European Parliament and the Council 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. Brussels, 23.1.2008 COM(2008) 17 final 2008/0014 (COD).

ECCP (European Climate Change Programme). Background Document: Main Possible Policy Options. 3rd Meeting of the ECCP Working Group on Reducing Greenhouse Gas Emissions from Ships. 15-16 November 2011.

Eide, M.S., Longva, T., Hoffmann, P., Endresen, Ø., Dalsøren, S.B., 2011. Future Cost Scenarios for Reduction of CO<sub>2</sub> Emissions. *Maritime Policy and Management* 38 (1):11–37.

Eide, M.S., Endresen, Ø., Skjong, R., Longva, T., Alvik, S., 2009. Cost-effectiveness Assessment of CO<sub>2</sub> Reducing Measures in Shipping. *Maritime Policy and Management* 36 (4): 367–384.

Ellerman, D. A., Decaux, A., 1998. Analysis of Post-Kyoto CO<sub>2</sub> Emission Trading Using Marginal Abatement Curves. Report 40. Cambridge, Massachusetts: Massachusetts Institute of Technology. Joint Program on the Science and Policy of Global Change.

Faber, J., Markowska, A., Eyring, V., Cionni, I., Selstad, E., 2010. A Global Maritime Emissions Trading System. Design and Impacts on the Shipping Sector, Countries and Regions. Delft, CE Delft, January 2010.

[http://www.cedelft.eu/publicatie/a\\_global\\_maritime\\_emissions\\_trading\\_system/1024](http://www.cedelft.eu/publicatie/a_global_maritime_emissions_trading_system/1024) (accessed 04/12/2010).

Faber, J., Wang, H., Nelissen, D., Russel, B., St Amand, D., 2011. Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures. MEPC 62 INF 7. <http://www.imarest.org/LinkClick.aspx?fileticket=5kj0E0WMK8w%3D&tabid=878> (accessed 11/14/2011).

Faber J., and Rensma K., 2008. Left on the High Seas: Global Climate Policies for International Transport. October 2008 update. Delft: CE Delft. [http://www.ce.nl/publicatie/left\\_on\\_high\\_seas/846](http://www.ce.nl/publicatie/left_on_high_seas/846) (accessed 11/23/2009)

Faber, J., Markowska, A., Nelissen, D., Davidson, M., Eyring, V., Cionni, I., Selstad, E., Kageson, P., Lee, D., Buhaug, Ø., Lindtsad, H., Roche, P., Humpries, E., Graichen, J., Cames, M., Schwarz, W., 2009. Technical Support for European Action to Reducing Greenhouse Gas Emissions from International Maritime Transport. Delft: CE Delft. [http://www.ce.nl/publicatie/technical\\_support\\_for\\_european\\_action\\_to\\_reducing\\_greenhouse\\_gas\\_emissions\\_from\\_international\\_maritime\\_transport/1005S](http://www.ce.nl/publicatie/technical_support_for_european_action_to_reducing_greenhouse_gas_emissions_from_international_maritime_transport/1005S) (accessed 04/12/2010).

Gilbert, P., Bows, A., 2012. Exploring the Scope for Complementary Sub-global Policy to Mitigate CO<sub>2</sub> from Shipping. *Energy Policy* 50: 613–622.

Gudmundsson, S.V., Anger, A., 2012. Global Carbon Dioxide Emissions Scenarios for Aviation Derived from IPCC Storylines: A Meta-analysis. *Transportation Research Part D* 17: 61–65.

Heitmann, N., Peterson, S., 2012. The Potential Contribution of the Shipping Sector to an Efficient Reduction of Global Carbon Emissions. Kiel Working Paper 1813, Kiel Institute for the World Economy.

Heitmann, N., Khalilian, S., 2011. Accounting for CO<sub>2</sub> Emissions from International Shipping: Burden Sharing under Different UNFCCC Allocation Options and Regime Scenarios. *Marine Policy* 35: 682–691.

Hyman, R.C., Reilly, J., Babiker, M.H., De Masin, A., Jacoby, H.D., 2002. Modeling non-CO<sub>2</sub> Greenhouse Gas Abatement. *Environmental Modeling and Assessment* 8: 175–186.

IHS Fairplay, 2012. Sea-Web data base.

IMO (International Maritime Organization), 2012. IMO's Work to Address GHG Emissions from International Shipping in 2012. Submission by the International Maritime Organization to the thirty-seventh session of the Subsidiary Body for Scientific and Technological Advice (SBSTA 37), Agenda item 11(d) Emissions from Fuel Used for International Aviation and Maritime Transport. Doha, Qatar, 26 November to 1 December 2012.

<http://www.imo.org/OurWork/Environment/PollutionPrevention/AirPollution/Documents/COP%2018/IMO%20Info%20Note%20to%20SBSTA%2037final.pdf>  
(accessed 01/14/2013).

IPCC, 2007. IPCC Third Assessment Report. *Climate Change 2007: Working Group I: The Physical Science Basis*.

Klepper, G., Peterson, S., Springer, K., 2003. DART97. A Description of the Multi-regional, Multi-sectoral Trade Model for the Analysis of Climate Policies. Kiel Working Paper 1138, Kiel Institute for the World Economy.

MEPC (Marine Environment Protection Committee), 2011. Mandatory Energy Efficiency Measures for International Shipping Adopted at IMO Environment Meeting. MEPC – 62nd session: 11 to 15 July 2011.

<http://www.imo.org/MediaCentre/PressBriefings/Pages/42-mepc-ghg.aspx>  
(accessed 09/28/2011).

Narayanan, G.B., Aguiar, A., McDougall, R., 2012. Global Trade, Assistance, and Production: The GTAP 8 Data Base. Eds. 2012. Center for Global Trade Analysis, Purdue University.

Nelissen, D., Faber, J., 2012. EU Policies to Address Maritime GHG Emissions. Analysis of the Impacts on GHG Emissions. Discussion Paper. On behalf of the Federal Environment Agency (Germany). Dessau-Roßlau, October 2012.

Perman, R., Ma, Y., McGilvary, J., Common, M., 1999. Natural Resource and Environmental Economics. Second Edition. Essex: Pearson Education.

SBSTA (1996): National Communication of the Subsidiary Body for Scientific and Technological Advice, FCCC/SBSTA/1996/9/Add.1, 24th October 1996.

Scheelhaase, J., Grimme, W., Schaefer, M., 2010. The Inclusion of Aviation Into the EU Emission Trading Scheme – Impacts on Competition Between European and Non-European Network Airlines. Transportation Research Part D 15: 14–25.

UNEP (United Nations Environment Programme), 2011. Bridging the Emissions Gap. [http://www.unep.org/pdf/UNEP\\_bridging\\_gap.pdf](http://www.unep.org/pdf/UNEP_bridging_gap.pdf) (accessed 06/05/12).

UNFCCC (United Nations Framework Convention on Climate Change), 2012. Doha Amendment to the Kyoto Protocol.

[http://unfccc.int/files/kyoto\\_protocol/application/pdf/kp\\_doha\\_amendment\\_english.pdf](http://unfccc.int/files/kyoto_protocol/application/pdf/kp_doha_amendment_english.pdf) (accessed 01/14/13)

UNFCCC, 2010a. Appendix I - Quantified Economy-wide Emissions Targets for 2020. [http://unfccc.int/meetings/copenhagen\\_dec\\_2009/items/5264.php](http://unfccc.int/meetings/copenhagen_dec_2009/items/5264.php). (accessed 09/05/12)

UNFCCC, 2010b. Appendix II - Nationally Appropriate Mitigation Actions of Developing Country Parties.

[http://unfccc.int/meetings/cop\\_15/copenhagen\\_accord/items/5265.php](http://unfccc.int/meetings/cop_15/copenhagen_accord/items/5265.php) (accessed 09/05/12)

UNFCCC, 2009. Report of the Ad Hoc Working Group on Long-term Cooperative Action Under the Convention on its Seventh Session, held in Bangkok from 28 September to 9 October 2009, and Barcelona from 2 to 6 November 2009. Bonn: UNFCCC.

Wang, H., 2010. Economic Costs of CO<sub>2</sub> Emissions Reduction for Non-Annex I Countries in International Shipping. Energy for Sustainable Development 14: 280–286.

Wang, H., Faber, J., Nelissen, D., Russel, B., St Amand, D., 2010. Marginal Abatement Costs and Cost Effectiveness of Energy-Efficiency Measures. MEPC 61 INF 18. [http://www.cedelft.eu/publicatie/marginal\\_abatement\\_costs\\_and\\_cost-effectiveness\\_of\\_energy-efficiency\\_measures/1090](http://www.cedelft.eu/publicatie/marginal_abatement_costs_and_cost-effectiveness_of_energy-efficiency_measures/1090) (accessed 11/14/2011).

## 9. Appendix

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

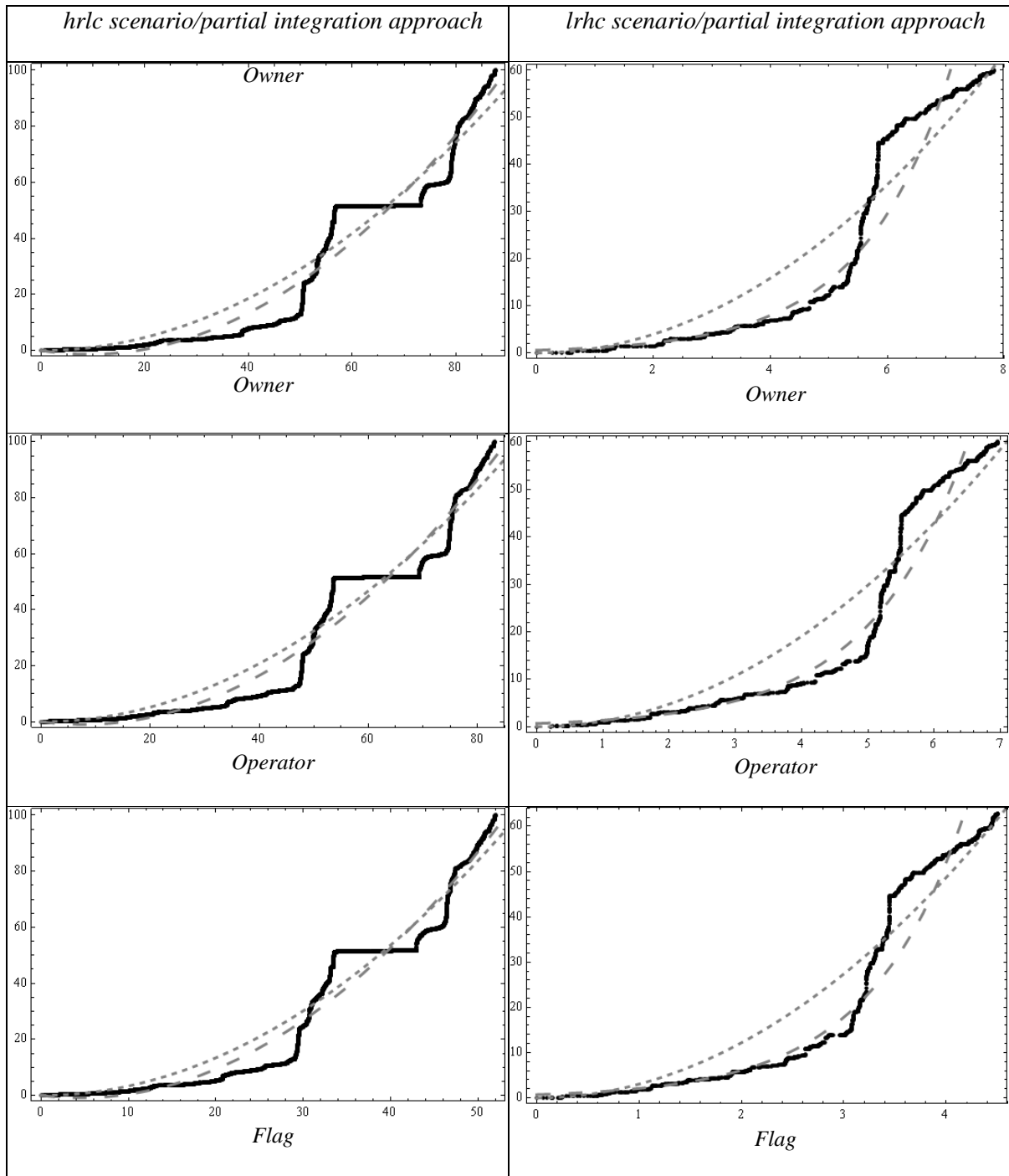
Allocation way	Reduction/costs scenario	Parameter values		R <sup>2</sup>
		a	b	
<i>Owner</i>	<i>hrlc</i>	-0.18852	0.05926	0.903777
	<i>lrhc</i>	-0.54954	0.65629	0.933384
<i>Operator</i>	<i>hrlc</i>	-0.04894	0.06064	0.910114
	<i>lrhc</i>	-0.35586	0.68333	0.957638
<i>Fleet</i>	<i>hrlc</i>	0.00558	0.09607	0.909094
	<i>lrhc</i>	-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 <sup>2</sup>
		a	b	
<i>Owner</i>	<i>hrlc</i>	-1.18216	0.08321	0.956860
	<i>lrhc</i>	-1.04041	0.76531	0.958404
<i>Operator</i>	<i>hrlc</i>	-0.94782	0.08263	0.96646
	<i>lrhc</i>	-0.53262	0.71697	0.956814
<i>Fleet</i>	<i>hrlc</i>	-0.96219	0.13331	0.969958
	<i>lrhc</i>	-0.75045	1.20378	0.970225

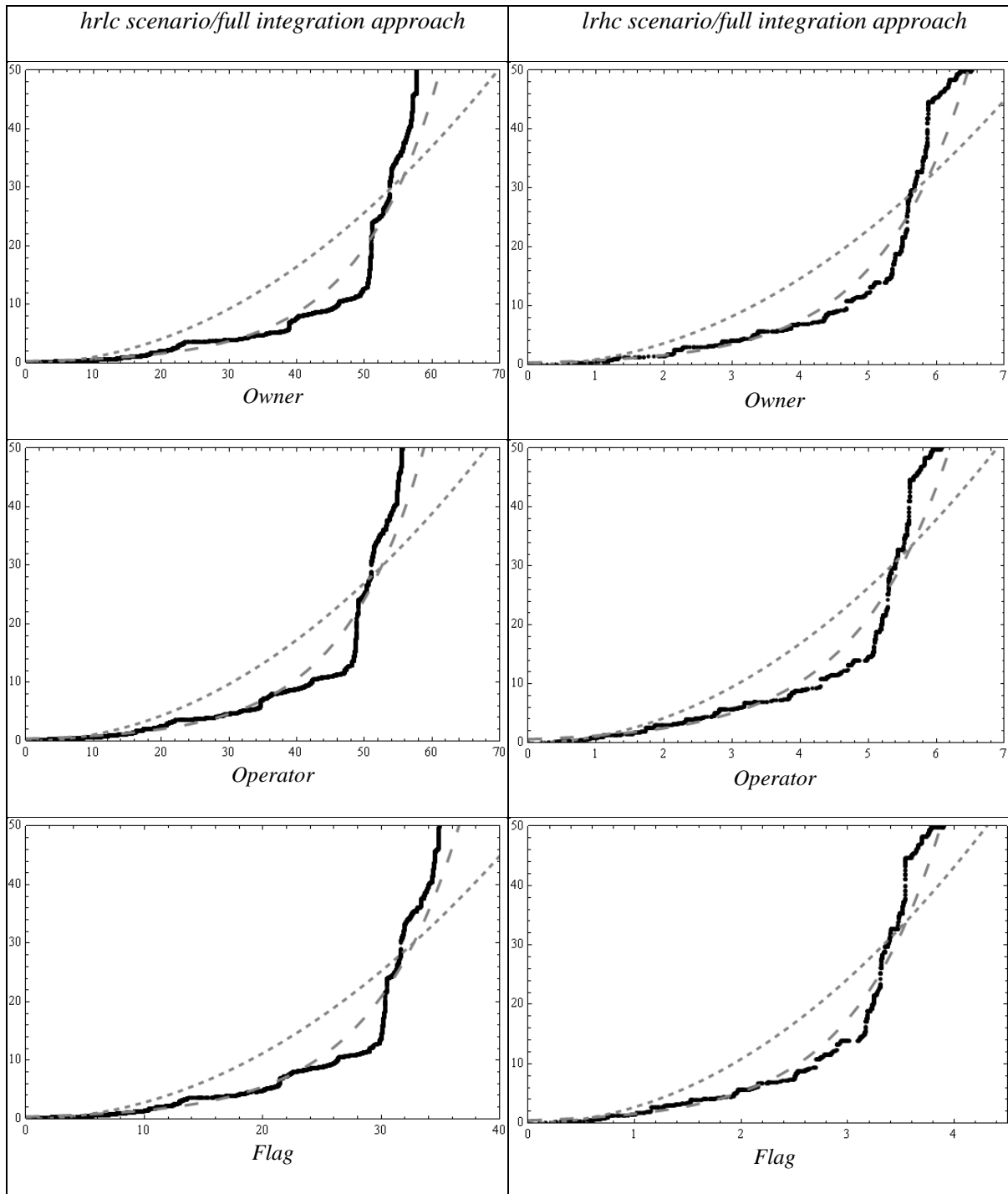
*Source:* Own calculations.



<sup>a</sup> 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*<sup>a</sup>. Source: Own calculations.





<sup>a</sup>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*<sup>a</sup>. Source: Own calculations.

**Table A3:** Emissions, abatement costs, and CO<sub>2</sub> 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 <sub>S</sub> in billion 2007US\$)	Abatement costs AoS (AC <sub>AoS</sub> in billion 2007US\$)	Abatement costs (AC <sub>AoS</sub> + AC <sub>S</sub> in billion 2007US\$)	CO <sub>2</sub> price/ton (in 2007US\$)= MAC <sub>AoS</sub>	CO <sub>2</sub> price/ton (in 2007US\$)= MAC <sub>AoS</sub> =MAC <sub>S</sub>	
Joint target for AoS and shipping (scenario 1)		<i>Owner</i>	286	4249	216	3433	0.89	16.54	17.43	53.38	
		<i>hrhc</i>	<i>Operator</i>	276	4249	210	3439	0.85	16.23	17.09	52.72
		<i>Flag</i>	173	4249	134	3515	0.45	12.53	12.98	44.52	
		<i>Owner</i>	286	4249	279	3370	0.09	20.15	20.24	60.73	
		<i>lrhc</i>	<i>Operator</i>	276	4249	269	3380	0.09	19.58	19.67	59.61
		<i>Flag</i>	173	4249	169	3480	0.04	14.18	14.22	48.26	
AoS without shipping		<i>Owner</i>		4249		3363		20.58		61.59	
		<i>AoS (scenario 2)</i>	<i>Operator</i>		4249		3373		19.97	60.38	
		<i>Flag</i>		4249		3476		14.37		48.68	
		<i>AoS (scenario 3)</i>		4249		3649		7.46		31.79	

Source: Own calculations.

**Table A4:** Emissions, abatement costs, and CO<sub>2</sub> 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 <sub>S</sub> in billion 2007US\$)	Abatement costs AoS (AC <sub>AoS</sub> in billion 2007US\$)	Abatement costs (AC <sub>AoS</sub> + AC <sub>S</sub> in billion 2007US\$)	CO <sub>2</sub> price/ton (in 2007US\$)=MAC <sub>AoS</sub>	CO <sub>2</sub> price/ton (in 2007US\$)=MAC <sub>AoS</sub> =MAC <sub>S</sub>
Joint target for AoS and shipping (scenario 1)	<i>hrhc</i>	<i>Owner</i>	286	4249	227	3547	0.49	11.18	11.70	41.34
		<i>Operator</i>	276	4249	220	3547	0.49	11.15	11.65	41.28
		<i>Flag</i>	173	4249	139	3591	0.27	9.44	9.71	39.98
	<i>lrhc</i>	<i>Owner</i>	286	4249	280	3494	0.06	13.49	13.54	46.72
		<i>Operator</i>	276	4249	270	3497	0.06	13.36	13.43	46.44
		<i>Flag</i>	173	4249	169	3561	0.03	10.62	10.66	39.98
AoS without shipping	<i>AoS (scenario 2)</i>	<i>Owner</i>		4249		3488		13.79		49.01
		<i>Operator</i>		4249		3491		13.65		48.15
		<i>Flag</i>		4249		3557		10.77		40.34
	<i>AoS (scenario 3)</i>		4249		3649		7.46		31.79	

Source: Own calculations

# Eidesstattliche Erklärung

Ich erkläre hiermit an Eides Statt, dass ich meine Doktorarbeit „Essays on Economic Aspects of Regulating Maritime Transport“ selbständig und ohne fremde Hilfe angefertigt habe und dass ich alle von anderen Autoren wörtlich übernommenen Stellen, wie auch die sich an die Gedanken anderer Autoren eng anlehnenden Ausführungen meiner Arbeit, besonders gekennzeichnet und die Quellen nach den mir angegebenen Richtlinien zitiert habe.

Nadine Heitmann

Kiel, Januar 2013