Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport

Tender DG ENV.C3/ATA/2008/0016

DLR

Fearnley Consultants

Nature Associates

Manchester Metropolitan University

MARINTEK SINTEF

NORTON ROSE

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Öko-Recherche

Report
Delft, December 2009

Author(s):
Jasper Faber, Agnieszka Markowska, Dagmar Nelissen, Marc Davidson (CE Delft)
Veronika Eyring, Irene Cionni (DLR)
Espen Selstad (Fearnley Consultants)
Per Kågeson (Nature Associates)
David Lee (Manchester Metropolitan University)
Øyvind Buhaug, Haakon Lindtsad (MARINTEK)
Philip Roche, Emma Humpries (Norton Rose)
Jakob Graichen, Martin Cames (Öko Institut)
Winfried Schwarz (Öko-Recherche)
With assistance from DNV on some issues

CE Delft

Publication Data

CE Delft
Committed to the Environment

CE Delft is an independent research and consultancy organisation specialised in developing structural and innovative solutions to environmental problems.
CE Delfts solutions are characterised in being politically feasible, technologically sound, economically prudent and socially equitable.

Preface

This is the report of a project to provide the European Commission, DG Environment, with Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport. It has been written by a consortium led by CE Delft and comprising of experts from DLR, Fearnley Consultants, MARINTEK, Norton Rose LLP, Öko Institut, Ökorecherche, Per Kågeson and David Lee. They have been assisted by DNV on issues of monitoring, reporting, administrative procedures, and enforcement.

In the course of the project, the authors have benefited from discussions with European Commission staff, numerous stakeholders and experts. We thank them for their time and comments. All errors, of course, are ours.

Jasper Faber

List of abbreviations	
AIS	Automatic Identification System
ASTM	American Society of Testing and Materials
BAF	Bunker Adjustment Factor
BC	Black carbon
BDN	Bunker delivery note
BIMCO	The Baltic and International Maritime Council
CBDR	Common but differentiated responsibilities
CCS	Carbon capture and storage
CDEM	Construction, design, equipment and manning
CDM	Clean Development Mechanism
CESA	Community of European Shipyards' Associations
CFCs	ChloroFluoroCarbons
CH_4	Methane
CLC	Civil Liability Convention
CMTI	Centre for Maritime Technology and Innovation
CNG	Compressed natural gas
CO	Carbon oxide
CO_2	Carbon dioxide
CO_2 eq.	CO_2 eq.
COAs	Contracts of Affreightments
COP	Conference of the Parties
DoC	Document of Compliance
DRI	Direct reduced iron
DWT	Deadweight tonnage/deadweight ton
DX	Direct expansion
EC	European Commission
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Index
EEZ	Exclusive Economic Zone
EMEP	European Monitoring and Evaluation Programme
ESI	Environmental Ship Index
ETA	Estimated Time of Arrival
EU ETS	European Union Emission Trading System
ETS	Emission Trading System
FFA	Forward Freight Agreement
F-gas	Fluorinated greenhouse gas
FP	Framework Programme
FPSO	Floating Production Storage and Offloading
GATS	General Agreement on Trade and Services
GATT	General Agreement on Tariffs and Trade
GDP	Gross domestic product
GHG	Greenhouse gas
GIS	Geographic Information System
GT	Gross tonnage/gross ton
GWP	Global warming potential
HCs	HydroCarbons
HCFC	HydroChloroFluoroCarbons
HFCs	HydroFluoroCarbons
HFO	Heavy fuel oil
HGV	Heavy goods vehicle
IAM	Integrated Assessment Model
IEA	International Energy Agency

List of abbreviations	
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
IWL	Institute Warranty Limits
k€	Thousand (kilo) Euro
kt	Kilotonne
kW	Kilowatt
LDC	Least developed countries
LLDCs	Landlocked developing countries
LLMC	Limitation of Liability for Maritime Claims
LMIU	Lloyd's Marine Intelligence Unit
LNG	Liquid natural gas
Lo-Lo	Lift-on/Lift-off
LPG	Liquefied petroleum gas
LRIT	Long Range Identification and Tracking
LULUCF	Land Use, Land Use Change and Forestry
MACC	Marginal abatement cost curve
MARPOL	International Convention for the Prevention of Pollution From Ships
MCR	Maximum Continuous Rating
MEPC	Marine Environment Protection Committee
METS	Maritime Emissions Trading Scheme
MMSI	Maritime Mobile Service Identity
MoU	Memorandum of Understanding
MS	Member State
Mt	Mega ton
NH_3	Ammonia
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
OCIMF	Oil Companies International Marine Forum
OECD	Organisation for Economic Co-operation and Development
O&M	Operation and Maintenance
OPRF	Ocean Policy Research Foundation
Paris MoU on Port State Control	Paris Memorandum of Understanding on Port State Control
% m/m	Mass percentage
ppm	parts per million
R&D	Research and Development
R&I	Research and Innovation
RoRo	Roll-on/Roll-off
RSW	Refrigerated Sea Water
RTD	Research and Technological Development
SAR	Search and rescue vessel
SCC	Social cost of carbon
SCM	Subsidies and countervailing measures
SEEMP	Ship Energy Efficiency Management Plan
SFC	Specific fuel consumption
SIDS	Small Island Developing States
SO_2	Sulfur dioxide
SOLAS Convention	Safety of Life at Sea Convention
SMA	Swedish Maritime Administration
SRES	Special Report on Emission Scenarios
SSS	Short Sea Shipping
t	Tonne
t/a	Tonne per annum

List of abbreviations	
TEAP	Technology and Economic Assessment Panel
TEU	Twenty-foot equivalent unit
Tg	Tera gram
TJ	Tera joule
tkm	Tonne kilometres
TMSA	Tanker Management Self Assessment
ULCC	Ultra large crude carrier
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
UN-OHRLLS	United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States
VLCC	Very large crude carrier
WTO	World Trade Organization

Contents

Summary

Introduction
The European Union has a target to reduce GHG emissions at least by 20% by 2020. All sectors of the economy need to contribute to achieving these emission reductions, including international maritime shipping.

Preferably, the European Union would like to see the International Maritime Organization or the UNFCCC take action to reduce emissions from shipping. However, if no international agreement is reached within either of these organisations, or if such an agreement is not approved by the European Union by the end of 2011, the European Commission will propose a policy to include international maritime emissions in the effort to reduce emissions.

This report provides the European Commission with technical assistance in the preparation of a policy to reduce CO_2 emissions from maritime transport.

In order to do so, it first establishes emissions estimates along with the marginal costs and abatement potential of emission reducing measures, basic data that had not been available for any policy development previously. It then selects and designs policy instruments that could contribute to achieving the policy objectives and assesses the impact of these policy instruments on the shipping sector and on developing countries.

This summary focuses initially on defining the problem, taking emission estimates into account and estimating of costs of reducing emissions. It develops an analytical framework of the emergence of maritime CO_2 emissions. Using this information, the next section defines the policy objectives and then selects and designs five policy instruments that best meet the policy objectives. The final sections evaluate the impact of these instruments on the shipping sector, on emissions and on developing countries. The conclusions are a comparative discussion of the extent to which the policy instruments will achieve the policy objectives.

Problem definition
Ships emit large quantities of CO_2. Ships sailing to and from EU ports account for a large share of global emissions. Emissions from shipping are projected to rise rapidly, despite potentially significant efficiency improvements.
A substantiation of these statements is provided below.

Global greenhouse gas emissions of maritime transport
Shipping emits significant amounts of CO_2, which is a well-known greenhouse gas, a fraction of which can remain in the atmosphere for very long time periods (millennia) and cause significant warming of climate. In addition, shipping emits small amounts of cooling gases, some of which are greenhouse gases. Furthermore, ships emit a number of other pollutants including SO_2, particles and NO_x. These pollutants - not covered by current climate policies - have complex by more short-lived warming and cooling effects on the atmosphere. However, it has been shown that CO_2 emissions are still a significant problem and commit future generations to irreversible warming. Thus, the focus of this work is on the long-term problem of greenhouse gas emissions of CO_2 from the shipping sector.

This report follows the *2nd IMO Greenhouse Gas Study* that estimates in 2006 global CO_2 emissions from shipping were 1,006 Mt of CO_2, equal to 3.3% of global anthropogenic CO_2 emissions. The uncertainty range of this estimate is 20%.

CO_2 emissions on voyages to and from Europe are a significant share of global emissions

Based on an analysis of ship movement data, this report concludes that emissions from ships on voyages to EU ports amounted to 208 Mt CO_2 in 2006. Ships on voyages between EU ports emitted 112 Mt CO_2 in 2006 (see Table 1).

Table 1 CO_2 emissions on voyages to, from and between EU ports, 2006

Route groups	CO_2 emissions (Mt CO_2)
Voyages arriving at EU ports	208
Voyages departing from EU ports	214
Voyages between EU ports	112
Voyages arriving at or departing from EU ports	310

Source: This report.

These estimates are higher than most other published estimates of emissions on voyages to and/or from EU ports that are based on trade data. There are several reasons why our trade based estimates underestimate emissions:
- 29% of emissions on voyages to the EU are from non-cargo ships, such as passenger ships (ferries and cruise ships), fishing vessels and 'other ships', including dredgers, offshore support vessels, tugs, etc. These emissions are not included in trade based estimates.
- A relatively large share of emissions on routes to European ports are from small ships that are less efficient than larger ships. To the extent that this also applies to cargo ships, this would result in higher emissions per tonne-mile on voyages to European ports.
- Container ships, RoRo and chemical tankers often make several stops in Europe, offloading cargo in every port but often not transporting cargo between these ports.

Emissions on voyages involving EU ports are a significant share of global CO_2 emissions from shipping. Voyages arriving at or departing from EU ports accounted for 31% of global shipping emissions.

Total greenhouse gas emissions from domestic sources in the EU-27 amounted to 5,105 Mt CO_2 eq. in 2006. Hence, emissions from ships on voyages to and from EU ports accounted for 6.1% of these emissions (although emissions from ships sailing domestic voyages may be counted twice in these figures).

CO_2 emissions are projected to increase despite efficiency improvements

All scenarios of future emissions from maritime transport project that emissions are expected to increase in the coming years, despite sometimes significant improvements in fleet average fuel efficiency.

The increase in emissions is driven by many factors. Figure 1 shows an analytical framework. By definition, emissions are the product of transport operation and efficiency. Each of these factors can be broken down into sub factors. A brief discussion of factors involved is Figure 1.

Figure 1   Stylised representation of factors determining maritime emissions
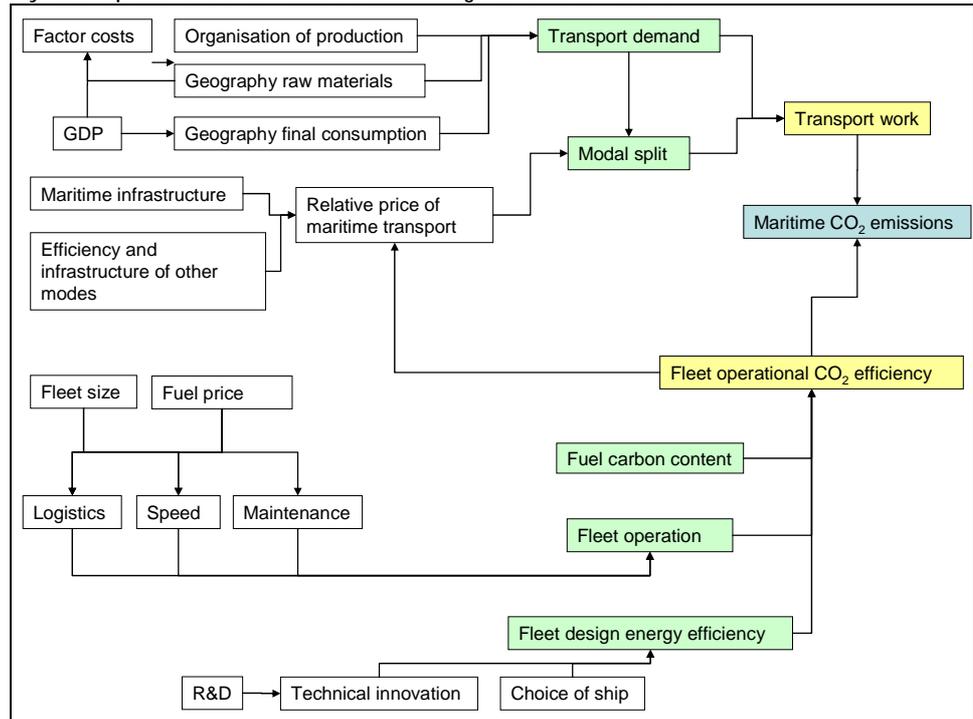
The increase in emissions is driven largely by growing demand for maritime transport, which in turn is driven by the geography of production, raw materials and final consumption. These factors are influenced by wealth and factor costs. The modal split signifies how much transport is supplied by shipping. Its main determinant is the relative price of maritime transport, which in turn depends on the efficiency of shipping and other modes, infrastructure, etc. This is shown in the upper half of Figure 1.

Emissions do not increase as much as demand because of improvements in fleet efficiency, shown in the lower half of Figure 1. For analytical purposes, the fleet CO_2 efficiency can be broken down into the carbon content of the fuel, the operational efficiency and the design efficiency.

Investments in ship efficiency become more cost-effective when fuel prices rise. Rising fuel prices in recent years, forecasts of future price increases and regulation of the sulphur content of maritime bunker fuels will most likely ensure the cost-effectiveness of these investments in the coming years.

Currently, not all cost-effective measures to reduce emissions appear to have been taken. There seems to be scope to reduce maritime emissions by about 10% at negative costs, although due to transaction costs and hidden costs the true potential may be smaller. There are many reasons why these measures are not being taken. In some segments of shipping, split incentives prevent the implementation of cost-effective measures. In others, ship owners and operators may opt to postpone investments when they anticipate future technology improvements. Current fuel prices and environmental concerns seem to be attracting the maritime transport industry's attention to reducing the problem with split incentives through changing standard charter parties. We expect this development to continue if fuel prices increase further.

Even if all apparently cost-effective measures to reduce emissions were implemented, emissions from maritime transport would increase. Provided that demand for transport to and from the EU continues to grow, it is likely that emissions on voyages to and from the EU will increase despite efficiency improvements.

Marginal costs and abatement potential of technical and operational measures

By 2030, CO_2 emissions of shipping can be reduced by 27-47% relative to a frozen technology scenario by implementing technical and operational measures identified in this report. A major share of these emission reductions, 23-45 percentage points, with 33 percentage points being the central estimate, can be achieved at negative marginal abatement costs, again relative to a frozen technology baseline (see Figure 2).

Figure 2   Marginal CO_2 Abatement Costs for the Maritime Transport Sector in 2030 relative to frozen-technology scenario, Range of Estimates, US$ 700/tonne fuel, 9% Interest Rate
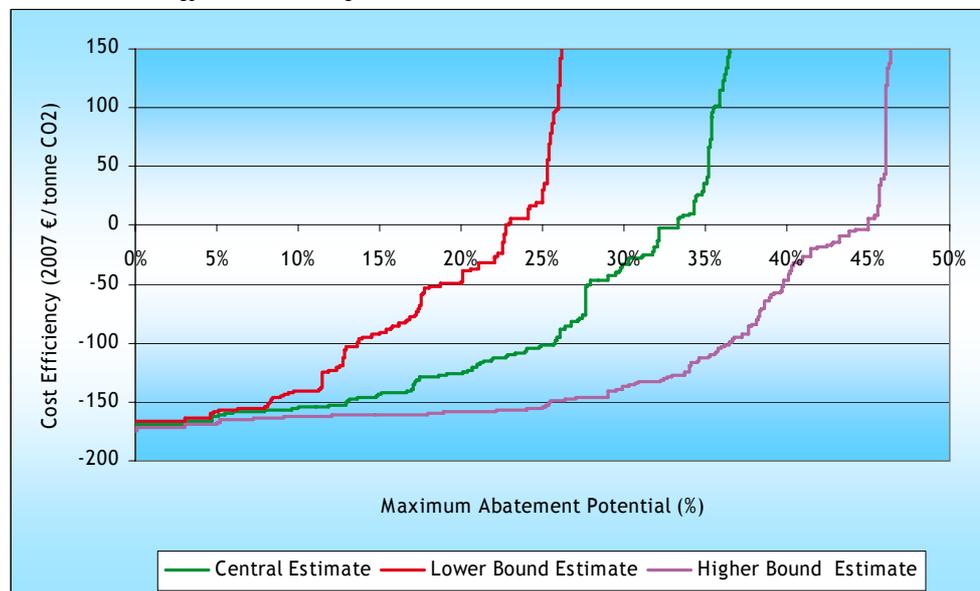
The marginal costs of emission abatement depend on the fuel price. At lower fuel prices, fewer emissions can be abated cost-effectively. At higher fuel prices, more. The fuel price underlying Figure 2 is higher than the current fuel price, which averaged US$ 276 in the first five months of 2009 because crude oil prices are projected to rise to US$ 89.5 in 2030 and because the requirement to use low sulphur fuel will increase the costs of maritime fuels. Interest rate assumptions have a smaller impact on the marginal costs.

A share of the cost-effective measures will be implemented regardless of the choice of a policy instrument. However, market failures and barriers may result in some measures not being implemented. As argued above, we consider it unlikely that the abatement potential of measures that are not implemented due to market failures and barriers will increase over its current estimated 10% of maritime emissions. There are signals in the industry that the split incentive in fuel costs is being addressed, for example. Therefore, we project that by 2030, there will still be measures that can be implemented in an apparently

cost-effective way, but these measures will account for less than 10% of the total emissions.

Figure 3 shows that even if all cost-effective measures to reduce emissions are taken in 2030, emissions will be 39% higher than the 2007 level in the central estimate. If inefficiencies remain at their current estimated level of 10% of emissions, emissions will have increased by 60% in 2030.

Figure 3   Frozen-Technology Baseline and Possible Net Emissions in 2030
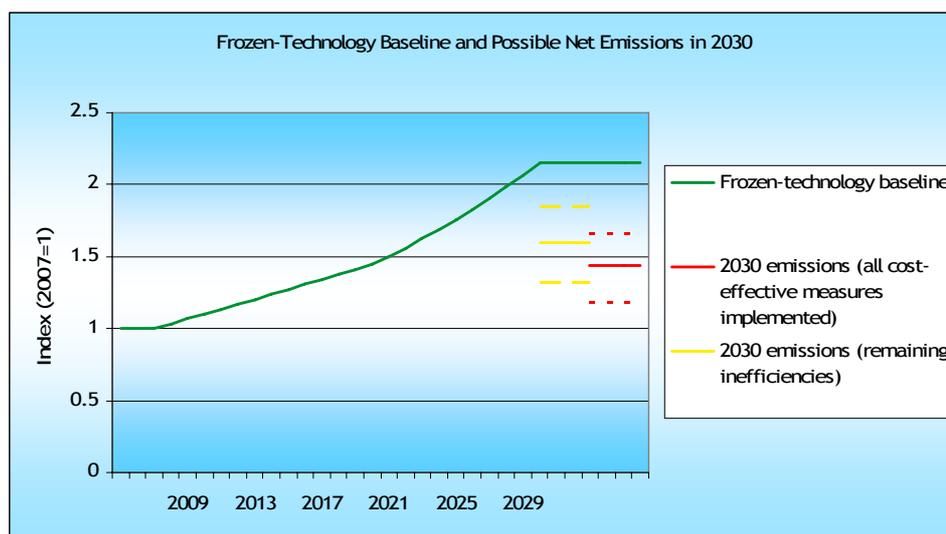
Objectives of European action to reduce CO_2 emissions from international maritime transport

In summary, the evidence shows that CO_2 emissions from maritime transport are significant, both on a global scale and for the EU. In all future maritime emissions scenarios, emissions are forecast to rise despite gains in efficiency. Even if all the cost-effective abatement options identified in this report were implemented, emissions would still continue to increase.

If unabated, the increase in emissions from maritime transport would have to be offset by larger emission reductions in other sectors of the economy in order to meet a climate stabilisation goal. Since this would be associated with welfare costs, the primary policy objective should be to reduce the emissions of maritime transport.

It appears from this report that there is scope to cost-effectively reduce emissions, but not all cost-effective measures seem currently to be implemented due to the existence of split incentives, transaction costs and a time lag.

Even though the removal of these market failures and barriers would not result in a reduction of emissions below current levels or in a trend of decreasing emissions, the continuing existence of cost-effective abatement options diminishes the overall cost-effectiveness of policies aimed at reducing emissions.

Selection of policy instruments to reduce CO_2 emissions from maritime transport

Based on an analysis of the drivers of maritime transport emissions (as shown in Figure 1), this report has identified 27 possible policy instruments to address these emissions. In a broad evaluation, they are assessed on their potential to reduce maritime CO_2 emissions, their cost-effectiveness in doing so, their legal feasibility and the feasibility of their implementation. Four policies are identified that have the potential to cost-effectively reduce emissions from maritime transport. A fifth is added as a reference. These policy instruments are:

1   A cap-and-trade system for maritime transport emissions.
2   An emissions tax with hypothecated revenues.
3   A mandatory efficiency limit for ships in EU ports.
4   A baseline and credit system based on an efficiency index.
5   Voluntary action.

Each of these instruments is detailed and the impact of each assessed.

1   Design of a cap-and-trade system for maritime transport emissions

The design of a cap-and-trade system for maritime transport emissions comprises the following elements:

1   Responsible entity.
2   Geographical scope.
3   The climate unit.
4   Cap.
5   Initial allocation of allowances.
6   Use of revenues (if any).
7   Monitoring emissions.
8   Administration of reporting emissions and surrendering allowances.
9   Compliance and enforcement.
10 Expandability to third countries.
11 Ship size scope.
12 Ship type scope.

Each of these elements is discussed below.

The responsible entity for surrendering allowances in an emissions trading scheme for maritime transport should be the ship owner who can take action to improve the design efficiency of the ship and, in the case that the owner is also the ship operator, the operational efficiency of the ship. He can be unequivocally identified and is already liable for other forms of pollution, such as oil pollution. A disadvantage of making the registered owner the responsible entity would be that he is often a special purpose vehicle with no other assets and no real independence - if the ship is sold, action against that entity to recover the allowances is pointless. Therefore, it is necessary that the system allows for action against the direct source of emissions, i.e. the ship. The accounting entity should be the ship. Hence, a ship owner is required to report emissions and surrender allowances for each ship he owns, with enforcement able to target both the ship owner and the ship.

The geographical scope of a system determines the amount of emissions under the scheme and thus its environmental effectiveness. As ships are moveable objects, any geographical scope can be avoided in principle, thereby reducing the environmental impact. Moreover, there are legal and practical considerations in setting the scope. The environmental effectiveness would be significant when emissions on voyages to EU ports are included in the scheme. We find that avoidance by making an additional port call becomes

prohibitively expensive for ships with a single bill of lading when a voyage is defined as the route from the port of loading to the port of discharge. For ships with multiple bills of lading (container ships, general cargo ships), it is not possible to unequivocally determine a port of loading. Hence, for these ships, some avoidance will inevitably occur. In summary, the geographical scope includes all voyages to EU ports, starting from the port of loading for ships with a single bill of lading and the last port call for ships with multiple bills of lading or non-cargo ships.

In such a geographical scope, all ship types can be included. The more types, the larger the amount of emissions under the scheme and the better its environmental effectiveness and cost-effectiveness. The scheme can include inland shipping if this is considered to be desirable, thereby adding about 4-7 Mt CO_2 emissions to the cap.

The size threshold could be set low, e.g. at 400 GT in line with a MARPOL threshold. Such a threshold would not create additional market distortions and there seems to be little benefit in raising the threshold, as the number of ships would not be reduced more than the emissions.

CO_2 is the only greenhouse gas emitted by maritime transport in large quantities and for which a Global Warming Potential has been established. Therefore, the traded unit can be a tonne of CO_2.

If the emissions trading scheme needs to be implemented soon, a political decision is the only feasible way to set the cap, as the degree of uncertainty in current emissions is quite high. The political decision could be informed by emission estimates presented in this report, by equity considerations and by natural science arguments relating to climate stabilisation scenarios. A more accurate cap could be set if the implementation of the cap-and-trade scheme were to be preceded by a year in which emissions were monitored and reported. The cap could then be based on empirical emissions data collected prior to the implementation of the scheme.

As for the initial allocation, auctioning allowances has major economic advantages:
− It promotes economic efficiency if the auction revenues are used to reduce distortionary taxes.
− It avoids the windfall gains associated with free allocation. And;
− It has positive effects on industry dynamics as it treats new entrants, closing entities, growing and declining entities alike.

Yet, there are two reasons to allocate allowances for free:
1   Ensure equal treatment of industries covered by the EU ETS.
2   Temporarily allocate freely in order to give a sector time to adjust to new circumstances.

It is not possible to set an output-based benchmark for the entire shipping sector as output is very diverse. Neither is it possible to set a historical baseline per ship, as the amount of emissions a ship has under the scope of the ETS may vary significantly from year to year. Therefore, if the financial impact on the sector needs to be reduced, we recommend recycling the allowances: ships could receive free allowances equal to a decreasing share of the reported individual emissions in the previous year.

The revenues from the auction could be hypothecated, although this seems to have legal restrictions. Still, in some cases there could be arguments for using part of the revenue for funding R&D and/or financing climate policy in developing countries.

As for monitoring and reporting, fuel consumption is routinely monitored on board ships. Records are kept of both annual fuel purchases (bunker delivery notes) and fuel consumption per voyage. Most larger vessels have fuel flow meters that are able to record fuel consumption with an accuracy of ± 0.2%. Other vessels may have to rely on a less accurate tank sounding method.

Upon implementation of an emissions trading scheme for maritime shipping, ships could be given two choices:
1 Monitor fuel per voyage.
2 Monitor fuel consumption per annum.

The latter option would be attractive for ships that operate exclusively or predominantly between EU ports. In both cases, ships would have to indicate how they will monitor fuel consumption.

The main costs associated with monitoring and reporting emissions would stem from the verification of the data. These costs are hard to estimate, but are unlikely to be significant.

In order to limit the administrative burden on the ships, reporting and surrendering allowances should be annual.

In general, the enforcement by the EU of any scheme with the aim of reducing carbon emissions would in practice have to be carried out at EU ports as member states exercise exclusive jurisdiction over their ports and ships calling at EU ports are required to comply with the laws of the respective state. Failure to surrender allowances matching the ship's emissions would result in banning that ship from calling in EU ports.

Member states will transpose EU legislation into national legislation with the ship being accountable for reporting to the appointed authority in that member state. The ship owner will take steps to independently verify the emissions reported. In most jurisdictions, the administrative authority would need to be given specific statutory power to demand compliance and to detain vessels that do not comply.

Enforcement of any EU action to reduce CO_2 emissions from international shipping would be flag neutral and enforced through port based state control for foreign flagged vessels and possibly the Flag State Authority for vessels falling under national jurisdiction. These are already established systems across the EU so compliance and enforcement would become just another requirement under their inspection regimes. Therefore, as long as there are no major non-compliance issues, any increase in cost by the addition of another requirement would be minor. Any potential significant costs that might arise would be in relation to any detentions and legal challenges, which cannot be quantified at this stage.

To make it possible to gradually extend the scheme and finally turn it into a global system, an international convention with the participation of other Annex 1 countries may be considered as an alternative to including maritime transport emissions in the EU ETS directive. Trade between the Maritime

Emissions Trading Scheme (METS) and the EU ETS could be made possible by establishing a link between them.

2   An emissions tax with hypothecated revenues

The design of an emissions tax for shipping comprises the following design elements:

1   Responsible entity.
2   Geographical scope.
3   Tax basis.
4   Level of the tax.
5   Use of revenues.
6   Monitoring emissions.
7   Administration of reporting emissions.
8   Compliance and enforcement.
9   Expandability to third countries.
10 Ship size scope.
11 Ship type scope.

Many of the design elements are common to both the emissions tax and to the cap-and-trade scheme described above. The reasons for making design choices are often also the same. As a consequence, there is overlap between this section and the previous one.

The responsible entity for surrendering allowances in an emissions trading scheme for maritime transport should be the ship owner who can take action to improve the design efficiency of the ship and, in the case that the owner is also the ship operator, the operational efficiency of the ship. He can be unequivocally identified and is already liable for other forms of pollution, such as oil pollution. A disadvantage of making the registered owner the responsible entity would be that he is often a special purpose vehicle with no other assets and no real independence - if the ship is sold, action against that entity to recover the allowances is pointless. Therefore, it is necessary that the system allows for action against the direct source of emissions, i.e. the ship. The accounting entity should be the ship. Hence, a ship owner is required to report emissions and surrender allowances for each ship he owns, with enforcement able to target both the ship owner and the ship.

The geographical scope of the tax basis determines the amount of emissions under the scheme and thus its environmental effectiveness. As ships are moveable objects, any geographical scope can be avoided in principle, thereby reducing the environmental impact. Moreover, there are legal and practical considerations in setting the scope. The environmental effectiveness would be significant when emissions on voyages to EU ports are included in the scheme. We find that avoidance by making an additional port call becomes prohibitively expensive for ships with a single bill of lading when a voyage is defined as the route from the port of loading to the port of discharge. For ships with multiple bills of lading (container ships, general cargo ships), it is not possible to unequivocally determine a port of loading. Hence, for these ships, some avoidance will inevitably occur. In summary, the geographical scope includes all voyages to EU ports, starting from the port of loading for ships with a single bill of lading and the last port call for ships with multiple bills of lading or non-cargo ships. This scope does not have a large chance of successful legal action.

In such a geographical scope, all ship types can be included. A larger scope implies greater environmental effectiveness. The scheme can include inland shipping if this is considered to be desirable, thereby adding about 4-7 Mt CO_2 emissions would be added to the cap.

The size threshold could be set low, e.g. at 400 GT in line with the MARPOL threshold. Such a threshold would not create additional market distortions and there seems to be little benefit in raising the threshold.

CO_2 is the only greenhouse gas emitted by maritime transport that is emitted in large quantities and for which a Global Warming Potential has been established. Therefore, the tax should be levied on the amount of CO_2 emitted in the scope of the scheme.

A precise calculation of the socially optimal CO_2 tax rate for maritime shipping is impossible because of uncertainty with respect to data on the marginal costs of emissions and marginal benefits of emission reduction. An attempt to calculate the recommended tax rate based on the theory of socially optimal tax results for the current period in a range of 7-45 Euro, with central estimate of 25 Euro.

The tax will not result in large emission reductions in the shipping sector. Consequently, in order to be environmentally effective, the revenues of the tax have to be spent at least partially on emission reductions. Emission reductions in non-Annex 1 countries seem the best way to improve the environmental effectiveness.

As for monitoring and reporting, fuel consumption is routinely monitored on board ships. Records are being kept of both annual fuel purchases and fuel consumption per voyage. Most larger vessels have fuel flow meters that are able to record fuel consumption with an accuracy of ± 0.2% while other vessels may have to rely on sounding tanks with a lower level of accuracy.

Upon implementation of an emissions trading scheme for maritime shipping, ships could be given two choices:
1   Monitor fuel per voyage.
2   Monitor fuel consumption per annum.

The latter option would be attractive for ships that operate exclusively or predominantly between EU ports. In both cases, ships would have to indicate how they will monitor fuel consumption.

The main costs associated with monitoring and reporting emissions would stem from the verification of the data. These costs are hard to estimate, but are unlikely to exceed US$ 10,000 (approximately € 6,700) per ship.

We propose that the tax be paid through national tax regimes or local tax bodies such as customs. Failure to pay taxes over a period would result in banning non-compliant ships from calling in EU ports.

3   A mandatory efficiency limit

The design of a mandatory efficiency standard comprises the following design elements:

− Choice of the indicator.
− Geographical scope.
− Ship size scope.
− Ship type scope.
− Baseline.
− Legal feasibility.

Each of these is discussed below.

There are two potential indicators for a ship's efficiency: the Energy Efficiency Operational Indicator (EEOI) and the Energy Efficiency Design Index (EEDI), both developed by IMO. Other indices are conceivable, but developing them would require a large amount of work.

While the EEDI may be developed into a good indicator for a ship's design efficiency, it is currently not mature since its formula has only recently been established and is undergoing trials.

The EEOI is not a suitable basic parameter for a mandatory policy for the following reasons:

− The value of the EEOI varies greatly over the business cycle, and depends furthermore on the density of cargo, origin and destination, weather, etc. This means that in some trades, times or locations, a mandatory value would easily be met whereas in other trades, times or locations, the same value would be unattainable. This can be considered to be inequitable.
− It is hard if not impossible to compare the EEOI across ship types, even the most important ship types, in terms of CO_2 emissions: bulkers, tankers, container ships and RoRo ships.
− The IMO has endorsed the use of the EEOI as a voluntary measure to evaluate the performance of ships by ship owners and operators, not as a metric for a ship's performance in a mandatory policy, although a mandatory application of some sort has not bee ruled out completely.

As the efficiency limit can only be enforced in EU ports, the geographical scope would be confined to EU ports. Since the EEDI of a ship is independent of its operation, adopting this scope would, in fact, cover ships sailing anywhere in the world that visit EU ports. While the scope of emissions under this policy would be large, so would the scope for avoidance. Because ships are moveable objects, it is possible to avoid the system by deploying ships with an EEDI over the baseline outside the EU, and deploy compliant ships in the EU. Such avoidance would relocate emissions, but would not significantly reduce them.

The EEDI is currently being tested for cargo ships. The formula for calculating the EEDI currently does not allow its calculation for non-cargo ships such as ferries, dredgers, fishing vessels, etc. These vessel types account for 29% of emissions on voyages arriving at EU ports.

As trials are being conducted with the EEDI in the IMO, we cannot currently recommend a limit value for this policy.

The policy instrument may be open to legal challenge depending on how this index evolves and the practical effect it has on ships trading to EU ports. If compliance with the index can be effected at little cost or disturbance to the ship's trading pattern, then such a challenge may not emerge. If compliance requires major modifications that involve time in shipyards and leads to ships being banned permanently from EU ports due to their inherent design and inability to comply with the EEDI, then this may lead to legal challenge from ship owners and the users of such tonnage.

4   A baseline-and-credit trading scheme

The design of a baseline-and-credit trading scheme comprises the following design elements:
−   Choice of indicator.
−   Traded unit.
−   Baseline – principle.
−   Baseline – value.
−   Scope – geographical scope.
−   Scope – ship size.
−   Scope – ship types.
−   Administrative set-up.

Each of these elements is discussed below.

There are two potential indicators for a ship's efficiency: the Energy Efficiency Operational Indicator (EEOI) and the Energy Efficiency Design Index (EEDI), both developed by IMO. Other indices are conceivable, but developing them would require a large amount of work.

While the EEDI may be developed into a good indicator for a ship's design efficiency, it is currently not mature since its formula has only recently been established and is undergoing trials.

The EEOI is not a suitable basic parameter for a mandatory policy for the reasons indicated above.

The traded unit would be based on the Energy Efficiency Design Index, which is currently being developed by IMO's MEPC. Credits would be generated or surrendered in proportion to the difference of a ship's EEDI with the baseline value for that ship and in proportion to the miles sailed from the last port of loading to an EU port.

The baseline would depend on ship type and ship size, in conformity with the current discussion in MEPC. The value of the baseline would gradually be reduced in order to improve the design efficiency of the fleet. The rate at which the baseline would be reduced would need to be assessed in a separate study.

The geographical scope of a system determines the amount of emissions under the scheme and thus its incentive to improve design efficiency. As ships are moveable objects, any geographical scope can be avoided in principle, which weakens the incentive. Moreover, there are legal and practical considerations in setting the scope. The incentive would be large when emissions on voyages to EU ports are included in the scheme. Avoidance in a baseline-and-credit scheme can take two forms. First, the system can be avoided by making an additional port call outside the scope of the system. As argued in the section on the cap-and-trade scheme, such avoidance can be limited by determining a

voyage as the port of loading to the port of discharge for ships with a single bill of lading. Second, the system can be avoided in the same way as the mandatory EEDI limit can be avoided, i.e. by deploying ships with an EEDI over the baseline outside the EU, and deploying more efficient ships in the EU. This type of avoidance cannot be effectively limited without interfering with the free movement of ships. It would lead to an oversupply of credits and therefore to a small incentive to improve efficiency.

All ship types for which a baseline can be established can be included in the scheme. This includes all cargo ships. A size threshold could be set to exempt the smallest ships and thus reduce the administrative burden. In order not to distort markets, the threshold should be set in conformity with thresholds currently being used in maritime law, viz. at 400 GT or 500 GT.

The administrative set-up of a baseline-and-credit scheme could be very similar to the EU ETS administrative set-up.

5   Voluntary action

Voluntary action policy consists of the EU and/or its member states promoting the use of a Ship Energy Efficiency Management Plan by ships.

Impacts on the maritime sector

Policies that increase the costs of emitting CO_2 and/or reward efficiency are likely to increase the implementation of measures that are cost-effective under these policies. Since a mandatory efficiency limit or a baseline-and-credit scheme can only be based on the design efficiency of ships, these policies only provide incentives for the implementation of cost-effective measures in a ship's design. These account for about half of the total abatement potential of measures to reduce emissions.

The amount of abatement in policies that reward both operational and technical measures is approximately twice the amount of abatement in policies that reward technical options only. Hence, the environmental effectiveness of an emissions trading scheme or an emissions tax can be greater than the effectiveness of a mandatory EEDI value or a baseline-and-credit trading scheme.

In 2030, unless new technologies become available, little additional impact on emissions from the shipping sector seems likely from any of the policies discussed here, as long as the assumptions used in this impact assessment on fuel price and allowance price or tax level become a reality. The impact these policies could have on emissions in the shipping sector would be in reducing some of the market barriers and market failures that currently prevent the implementation of some cost-effective measures. This, however, cannot be quantified.

The policies discussed here would impact CO_2 emissions mainly through the cap or the use of the tax revenues. Hence, policies without a cap or revenues would have much less of an impact on CO_2 emissions.

The policies will have a positive impact on the rate of innovation as they will increase the benefits of technologies that abate CO_2 emissions. However, some innovations are not directly market driven, as they require a change in institutions. Examples from this report include improved communication systems between ports and ships to reduce port congestion and allow ships to sail at an optimal speed to ports and changed charter contracts in order to allow all parties to reap the benefits of slow steaming. While policies that

increase the costs of CO_2 emissions may increase pressure on the actors involved, institutional changes are needed to make these innovations possible.

Impact on the cost structure of the maritime sector

A general cost structure of shipping (presented in Figure 4) will see costs associated with CO_2 emissions become part of the voyage costs.

Figure 4   Cost structure for running a ship
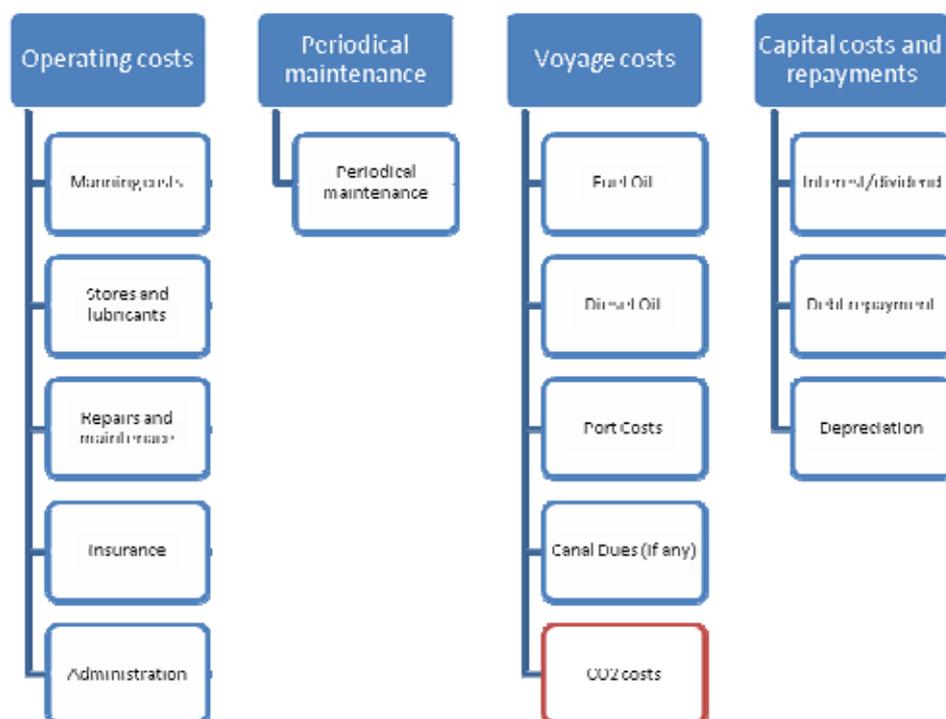
An emissions trading scheme or an emissions tax adds to the voyage costs of a ship. The quantitative impact depends on the value of other cost items. These items vary for various ship types and sizes. Under the assumptions of fuel prices, allowance prices and tax rates used throughout this impact assessment, the CO_2 costs represent 9-121% of fuel costs in 2030, with a central assumption of 33%. For the central assumption, we find that for six different ship types, total costs increase by 8-17% and operational costs by 16-23%.

In a baseline-and-credit scheme, the average costs will increase as ships on average have to meet the baseline. Since the indicator is the EEDI and only reflects design efficiency, changes to the design will be needed to meet the baseline. This means that the capital costs will increase. In order to achieve the same environmental effect as the cap-and-trade scheme, total costs would increase by a higher percentage because a policy based on a design index excludes operational measures, many of which would be more cost-effective.

In a mandatory EEDI limit value, the capital costs will increase. The amount by which depends on the limit value, which is not specified in this report. As indicated above for the baseline-and-credit scheme, the costs increase for achieving reductions comparable to the reductions in a cap-and-trade scheme would have to be higher because of excluding operational options. It is clear, however, that most measures to improve the design efficiency of a ship have

negative marginal costs. This means that although the capital costs increase, the annual capital costs are less than the fuel savings.

Market circumstances dictate whether these costs can be passed on. When demand for shipping is high, freight rates are well above operating costs as they are determined by marginal demand. Since demand will not change when shipping is included in an emissions trading scheme or an emissions tax is levied, freight rates will not change. Hence, in these circumstances costs are borne by the shipping companies, leading to lower scarcity rents and thus lower profit margins. Conversely, when demand for shipping is low, freight rates are set by marginal costs. These change when the policies are implemented. So in such a situation, the costs will be passed on to the shipper and ultimately to the consumer.

In circumstances where costs are passed on, we estimate import values to increase by 0.4 to 2.7% under the assumptions used throughout this impact assessment. The highest increase in value is expected for ores and coal (because a relatively high share of the value of these goods can be attributed to maritime transport costs), and the lowest for crude oil. Impacts on consumer prices are smaller because of value added in the importing country, which is not affected by a climate policy for maritime transport.

The administrative burden on ship owners of the emissions trading scheme, the emissions tax and the baseline-and-credit scheme all mainly stem from the requirement to verify data that is already routinely monitored. It is hard to calculate an accurate cost figure, but we estimate them to be low compared to costs of operating a ship.

The increased costs of ship operations would result in reduced demand in times when costs are passed on. The limited evidence available on price elasticities in the maritime transport sector suggests a rather inelastic situation, with an expected reduction in transport demand of 2 to 5% in the period up to 2030 relative to a baseline increasing by more than 2 to 3% per annum.

Impacts on modal split

When the costs of shipping increase, this may cause a shift to other modes of transport (see Figure 1). This modal shift is confined to transport routes where alternatives via other modes exist. If it does occur, it will most likely happen in unitised short sea shipping, including RoRo and LoLo. For intercontinental shipping other modes of transport hardly exist, while elasticity estimates of short sea bulk transport suggest that these are not very sensitive to price, which this section interprets as being caused by little competition with other modes of transport. Model results estimate that unitised (Container, RoRo and General cargo) intra-European shipping accounted for 77.6 Mt of CO_2 in 2006 (39% of total emissions intra-European emissions and 21% of all emissions on voyages to and from Europe).

Modal shift results in higher emissions in most cases, yet this is not necessarily true in every case. Small vessels (up to approximately 1,800 dwt) have emissions that are comparable to road transport and higher than rail transport. So modal shift only results in higher emissions on routes where relatively large ships compete with road transport.

On routes where unitised cargo is transported and maritime transport competes with road transport and rail, modal shift may occur if road and rail transport are not subjected to cost increasing climate policies. However,

shipping may have a larger potential to reduce emissions than other modes of transport. Furthermore, if the cost increase in road and rail transport is higher than in maritime transport, modal shift is unlikely to occur, or may occur in a way that increases the share of maritime transport.

Impacts on islands, least developed countries and landlocked regions

EU policies addressing emissions from maritime transport can affect non-EU countries in different ways. On the one side, transport costs are likely to rise slightly, which might adversely affect national economies, especially in countries heavily dependent on maritime transport. On the other side, reduced greenhouse gas emissions from shipping will reduce the negative impacts of climate change and might spur innovation and efficiency enhancements in the shipping sector. These positive effects are hard to assess and are not quantified in this report.

This report has assessed the impacts on trade of small island developing states, least developed countries and landlocked developing countries with the EU. It finds that for these three groups, the impact will be low to very low under realistic assumptions. Only under very specific circumstances could EU policy that addresses emissions from international maritime transport affect these countries in a noticeable way. Despite this, the effect on individual countries with specific circumstances might be higher.

Impact on tourism

EU maritime climate policy is not expected to adversely affect cruise shipping in developing countries. Cruise activities in European seas could be affected, however, and the climate policy could induce a marginal shift from cruise tourism to land based tourism.

Research, development and innovation

Reducing the emissions from maritime transport requires innovations in the shipping sector. The form of the MACC derived in chapter 3 suggests that innovation will become very expensive beyond a level that is cost-effective at expected fuel prices in 2030. Hence, a further reduction of per vessel emissions would require an increased supply of cost-effective technologies. As these technologies may have long lead times, it may be considered important to step up the current R&D effort in order to increase the chances of technologies becoming available.

An essential element of an R&D policy would be the adoption of climate instruments. Without them, the level of technology development required will remain uncertain, thus reducing the incentive to invest in R&D.

This chapter outlines a number of options to reduce emissions that require more study and may merit funding. In the short to medium term, per vessel emission reductions can be expected to result from research into and innovations of alternative sources of energy and ship efficiency improvements. In the longer term, more radical improvements will be needed that take into account the ship concept and design.

Measures to reduce the climate impact of refrigerant emissions

While not a large share of total greenhouse gas emissions from shipping, refrigerant emissions deserve special attention as they can be abated at low marginal costs. These emissions can be regulated through Flag State regulation, which would also make the policy instrument choice different than for CO_2 emissions.

The 2008 assessment of the impact of the application of Art 3 and 4 F-Gas Regulation, which was subject of a study for the European Commission, estimated that this measure can reduce the overall HFC emissions from the maritime sector by 40% or ~ 813 kt CO_2 eq.. The abatement cost was estimated at € 22 per t CO_2 eq., and the absolute annual cost at € 2,000 to € 4,000 per ship. This measure has the advantage that it can be applied to the totality of ships in EU registers whatever their year of construction (including those from 2002-2010) and their types, including passenger ships. In addition, the level of absolute cost per ship is similar for all ships.

In this study, the emission reduction potential of the recommended option 'natural refrigerants', which excludes sub option 2b from reefer ships and fishing vessels, is estimated at 676 kt CO_2 eq. with an average abatement cost of ~ € 19.50 per t CO_2 eq. and sharp differences in annual additional cost per ship type ranging from € 100 to € 23,000.

HFC emissions from ships built between 2002 and 2010 and from reefer ships, medium and large sized freezer trawlers with direct refrigeration systems built before 2002 and from passenger ships of all age classes are not covered by the option (sub option) natural refrigerants.

Application of Art 3 and 4 to the maritime sector must be considered the more effective and coherent overall option, compared to the overall option 'natural refrigerants', if the two options are considered as alternatives.

For some ship types 'natural refrigerants' is the better solution. Therefore, a combination of the two options should be considered as an effective measure to reduce projected 2020 HFC emissions.

Conclusions

Table 2 summarises the extent to which the policy instruments achieve the policy objectives. We conclude that the cap-and-trade scheme for maritime transport and the emissions tax with hypothecated revenues are best capable of reaching the primary policy objective of reducing CO_2 emissions of maritime transport. The cap-and-trade system is feasible to implement, as demonstrated above. The emissions tax with hypothecated revenues may be harder to implement as it requires unanimity amongst member states not only on the implementation of the tax but also on the hypothecation of revenues.

Table 2   Summary table of achievements of policy objectives by policy instruments

Policy instrument	Primary policy objective: reduce CO_2 emissions of maritime transport	Secondary policy objective: remove the market failures and barriers that prevent cost-effective abatement options from being implemented
A cap-and-trade system for maritime transport emissions	The emissions are capped. An increase of emissions of maritime transport over the cap will be compensated by a reduction of emissions in another sector. The price of allowances will provide an incentive to reduce emissions in the maritime transport sector, but by 2030, the impact on shipping emissions is likely to be small. Some avoidance will occur in some segments of shipping.	CO_2 emissions become valuable, thus attracting the attention of the ship owner. Monitoring and reporting requirements draw ship owners attention to emissions and to emissions abatement measures.
An emissions tax with hypothecated revenues	The emissions tax creates an incentive to reduce CO_2 emissions. By 2030,there will be a limited impact on shipping emissions, but the use of the revenues to support mitigation efforts elsewhere would reduce overall emissions. Some avoidance will occur in some segments of shipping.	CO_2 emissions become valuable, thus attracting the attention of the ship owner. Monitoring and reporting requirements draw ship owners attention to emissions and to emissions abatement measures.
A mandatory efficiency limit for ships in EU ports	In principle, the efficiency of ships would be improved, but emissions can continue to rise if demand growth outpaces efficiency improvement rate. The effect can be significantly reduced by avoidance of the system.	In principle, the efficiency limit would create an incentive to improve the EEDI of non-compliant ships through buying more newly built fuel-efficient ships or improving the EEDI of existing ships through technical retrofits. It also creates an incentive to avoid the system by deploying compliant ships in Europe and non-compliant ships in other parts of the world. It would not increase attention for measures not reflected in the EEDI.
A baseline-and-credit system based on an efficiency index	In principle, the efficiency of ships would be improved, but emissions can continue to rise if demand growth outpaces efficiency improvement rate. The effect can be significantly reduced by avoidance of the system.	A baseline-and-credit scheme would be more flexible than a mandatory limit and create incentives to improve the EEDI of all ships through buying more newly built fuel-efficient ships or improving the EEDI of existing ships through technical retrofits. However, it also creates an incentive to avoid the system by deploying compliant ships in Europe and non-compliant ships in other parts of the world. The system would not increase attention for measures not reflected in the EEDI.
Voluntary action	No or very limited impact beyond business-as-usual emissions.	The energy efficiency management plan might draw attention of ship owners implementing it to take cost-effective options to reduce emissions.

1 Introduction

The European Union has a target to reduce GHG emissions 20% by 2020.

In March 2007 the European Council called for action to reduce the emissions from international maritime transport and to work towards the inclusion of international maritime emissions in a post 2012 agreement (to be negotiated within the framework of the UNFCCC during 2008 and 2009).

The European Commission's 6th Environmental Action Plan identified the need to take actions to reduce greenhouse gas (GHG) emissions from maritime transport, if no such action is agreed within the International Maritime Organization. To date there has been very limited progress towards reducing emissions in the IMO.

The European Parliament has repeatedly called for the inclusion of international maritime transport in the ETS.

The Council and the Parliament included the following recital in EU Directive 2009/29/EC (23 April 2009):

> The European Council of March 2007 made a firm commitment to reduce the overall greenhouse gas emissions of the Community (…) All sectors of the economy should contribute to achieving these emission reductions, including international maritime shipping and aviation. (…) In the event that no international agreement which includes international maritime emissions in its reduction targets through the International Maritime Organisation has been approved by the Member States or no such agreement through the UNFCCC has been approved by the Community by 31 December 2011, the Commission should make a proposal to include international maritime emissions according to harmonised modalities in the Community reduction commitment, with the aim of the proposed act entering into force by 2013. Such a proposal should minimise any negative impact on the Community's competitiveness while taking into account the potential environmental benefits.

In order to support the international negotiations and, in case there is no global agreement to reduce GHG emissions from ships, for the Commission to be in a position to propose European action, the Commission has retained the services of a consortium led by CE Delft to provide technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport. This report is one of the deliverables of that study.

1.1 Maritime transport and society

Maritime transport provides essential services to the EU. It is an important transport mode for external trade. In 2008, over 70% of external trade in weight was carried over sea (see Figure 5). Measures in value, maritime transport carried over 50% of trade (see Figure 6).

Figure 5   EU-27 external trade by volume transport mode
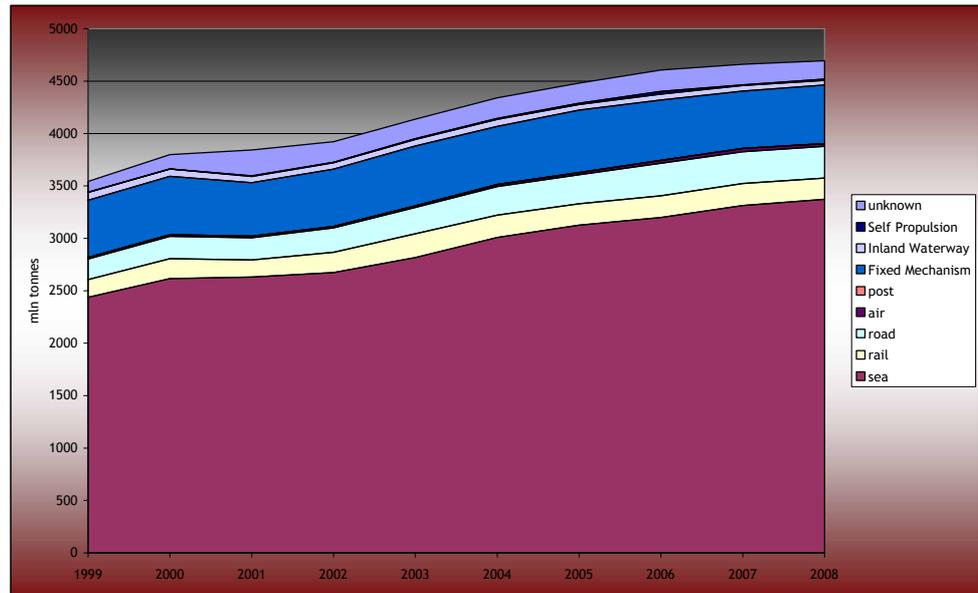
Source: EUROSTAT.

Figure 6   EU-27 external trade by value and transport mode
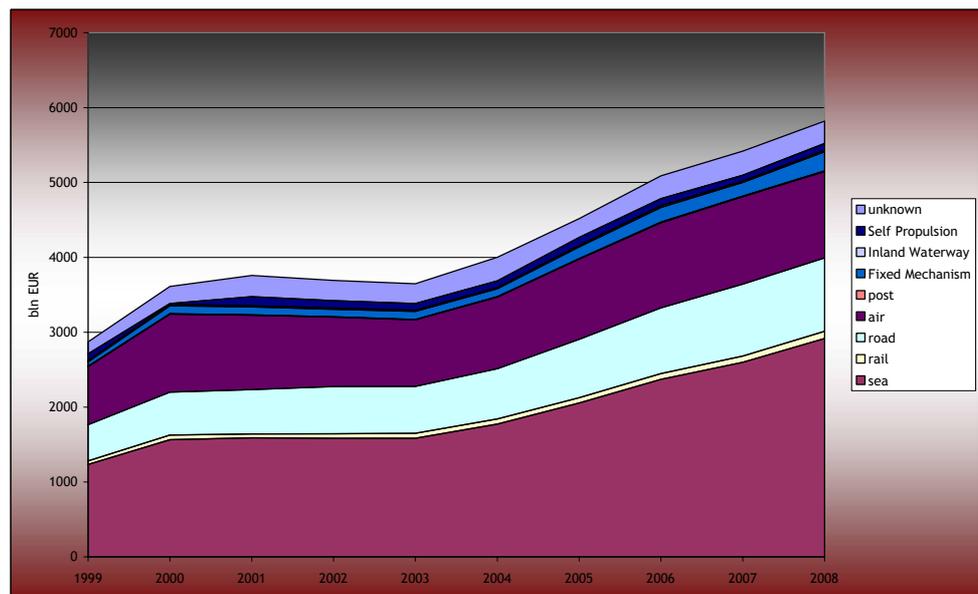
Source: EUROSTAT.

In addition to external trade, shipping provides transport services to trade within the Community. According to the European Commission (2009), short sea shipping carries 40% of intra-European freight. The same source states that more than 400 million sea passengers pass through European ports each year. In several regions, ferries are an important transport link.

1.2 Existing policy frameworks addressing maritime GHG emissions

On a global level, policies addressing maritime GHG emissions have been discussed both within the IMO and within the UNFCCC.

The inclusion of international shipping emissions in a global climate policy framework has proved to be a difficult issue. In the run-up to the Kyoto Protocol, different options were studied to allocate emissions to countries and thus include them in the national totals, but no agreement could be reached (CE et al., 2004; CE et al., 2006a). Instead, the Kyoto Protocol calls on Annex 1 countries to limit or reduce emissions 'working through the International Civil Aviation Organization and the International Maritime Organization' (KP, Article 2.2).

After years without progress the work on emissions from international maritime transport has taken a new pace with the negotiations of a post-2012 climate agreement. The negotiation text for the United Nations climate change conference COP 15 in Copenhagen includes seven different options to address these emissions (UNFCCC, 2009). None of these options include an allocation of emissions to individual countries anymore. While one proposal is to leave international maritime transport out of a future climate regime all six other proposals aim at a sectoral agreement targeting operators directly, either through IMO or through the UNFCCC. The EU put a regime forward, where the UNFCCC determines the necessary contribution of the maritime sector towards a global climate agreement but leaves all implementing measures to the auspices of the IMO. The EU proposes a global sectoral emissions target for the year 2020 of 20% below 2005 levels (EU Council, 2009).

To date, the Annex 1 countries have not been successful in limiting or reducing greenhouse gas emissions from international maritime transport working through IMO. The main reason seems to be differing views between Annex 1 countries and non-Annex 1 countries on the interpretation of Article 2.2 and on the applicability of the IMO's principle of non-discriminatory regulation of all ships engaged in international trade to a climate policy instrument (CE, 2008).

IMO did complete it's GHG work plan, by adopting 'interim guidelines on the method of calculation and voluntary verification of the Energy Efficiency Design Index (EEDI) for new ships' and 'guidance on the development of a Ship Energy Efficiency Management Plan (SEEMP) for new and existing ships' (IMO 2009). Both are 'intended to be used for trial purposes on a voluntary basis until MEPC 60 in March 2010' (IMO, 2009). From MEPC 60, discussions will be held on the 'application and enactment' of these measures (IMO, 2009). Moreover, the MEPC agreed on a work plan to consider market based instruments. The work plan culminates in 2011.

In the EU, the European Commission's 6th Environmental Action Plan identified the need to take actions to reduce greenhouse gas (GHG) emissions from maritime transport, if no such action is agreed within the International Maritime Organization. The European Council called for action to reduce the emissions from international maritime transport and to work towards the inclusion of international maritime emissions in a post 2012 agreement (to be negotiated within the framework of the UNFCCC during 2008 and 2009). In October 2007 it further urged Parties under the UNFCCC to set clear and

meaningful targets for the maritime sector within the framework of a future global climate agreement.

1.3 Outline of the report

The next two chapters provide essential information to assess the impacts of potential policies. Chapter 2 quantifies maritime GHG emissions and chapter 3 assesses the mitigation potential and the costs of various measures to reduce emissions. Chapter 4 defines the problem of maritime GHG emissions. In five subsequent chapters, policies are identified, selected and designed. Chapter 5 identifies a comprehensive list of policy options to limit or reduce maritime GHG emissions and selects four different policy options for further design and impact assessment. The first of these, a cap-and-trade scheme for maritime transport, is designed in chapter 6. Chapter 7 describes an emissions tax. Chapter 8 designs a policy for a mandatory efficiency limit and chapter 9 a baseline-and-credit scheme to improve the efficiency of ships. Chapter 10 describes voluntary action. The next two chapters assess a number of impacts for the different policy options. Chapter 12 assesses impacts on the shipping sector, chapter 13 impacts on other sectors, regions and on the economy in general. Chapter 14 evaluates measures to reduce emissions of cooling gases. Chapter 15 concludes.

Annexes to this report are presented in a separate volume.
Their topics are:

Annex A	Technical Appendix MACC.
Annex B	EU's competencies to regulate international shipping emissions.
Annex C	Taking responsibility: setting a CO_2 emissions cap for the aviation and shipping sectors in a 2-degree world.
Annex D	Emissions of black carbon from shipping and effects on climate.
Annex E	Impact of NO_x and other ozone prescursor emissions from ships on the chemical composition and climate.
Annex F	Ship aerosol impacts on climate and human health.
Annex G	Greenhouse Gas Emissions from Port Congestion.
Annex H	Potential for evasion.
Annex I	Ship-to-ship transfers.
Annex J	Ad-hoc paper on bunkers in possible US cap-and-trade schemes.

2 GHG emissions from shipping

Shipping emits significant amounts of CO_2, which is a well-known greenhouse gas, a fraction of which can remain in the atmosphere for very long time periods (millienia) and cause significant warming of climate. In addition, ships emit a number of other pollutants including SO_2, particles and NO_x. These pollutants - not covered by current climate policies - have complex by more short-lived warming and cooling effects on the atmosphere. However, it has been shown that CO_2 emissions are still a significant problem and commit future generations to irreversible warming. The non-CO_2 pollutants are dealt with in a number of ad hoc reports in support of this work (Eyring and Lee, 2009a/b; Lee and Eyring, 2009; Lee et al., 2009) and the predominance of CO_2 discussed in the scientific literature (Eyring et al., 2009; Fuglestvedt et al., 2009). Thus, the focus of this chapter is on the long-term problem of greenhouse gas emissions of CO_2 from the shipping sector.

2.1 Methodological introduction

The principal existing approaches to produce spatially resolved emissions from shipping can be characterised as either top-down or bottom-up. These methods are described in detail in Eyring et al. (2009a) and briefly explained below.

2.1.1 Top-down approaches

In a top-down approach emissions are calculated without respect to location by means of quantifying the fuel consumption by power production first and then multiplying the consumption by emission factors. The resulting emission totals are distributed over the globe by using spatial proxies. There are generally two different top-down approaches to calculate the fuel consumption.

One approach uses total fuel consumption from worldwide sales of bunker fuel by summing up by country. Bunker fuel sales figures require a combination of fuels reported under different categories (e.g. national or international bunker fuel). This can be challenging at a global scale because most energy inventories follow accounting methodologies intended to conform to International Energy Agency (IEA) energy allocation criteria (Thomas et al., 2002) and because not all statistical sources for marine fuels define international marine fuels the same way (Olivier and Peters, 1999).

The other approach models fleet activity and estimates fuel consumption resulting from this activity (summing up per ship/segment). The fuel consumption is often based on installed engine power for a ship, number of hours at sea, bunker fuel consumed per power unit (kW), and an assumed average engine load. Global ship emission totals are derived by combining the modelled fuel consumption with specific emission factors (Corbett et al., 1999; Corbett and Köhler, 2003; Endresen et al., 2003, 2007; Eyring et al., 2005; Buhaug et al., 2009). Input data for these models is collected from different sources and maritime data bases. Uncertainties in the calculated emission totals in the activity based approach arise from the use of average input parameters in the selected ship type classes, for example in input parameters like marine engine load factor, time in operation, fuel

consumption rate, and emission factors, which vary by size, age, fuel type, and market situation.

2.1.2 Bottom-up approaches

In a bottom-up approach emissions are directly estimated within a spatial context so that spatially resolved emissions inventories are developed based on detailed activities associated to locations. Bottom-up approaches estimate ship and route specific emissions based on ship movements, ship attributes, and ship emissions factors. The locations of emissions are determined by the locations of the most probable navigation routes, often simplified to straight lines between ports or on predefined trades.

Although bottom-up approaches can be more precise, large scale bottom-up inventories can also contain a degree of uncertainty because they estimate engine workload, ship speed, and most importantly, the locations of the routes determining the spatial distribution of emissions. The quality of regional annual inventories in bottom-up approaches is also limited when selected periods within a calendar year studied are extrapolated to represent annual totals. Bottom-up approaches have been mostly limited to smaller scale or regional emissions inventories due to the significant efforts associated with routing. Moreover, because they often use straight lines as routes between ports, they may overestimate ship emissions, as straight lines on a map usually are not the shortest path between two points on the globe. As such, locations of emissions may not be assigned correctly at larger scales.

A bottom-up inventory for Europe has been developed by Entec UK Limited (European Commission and Entec UK Limited, 2005a). The inventory estimates emissions on the basis of kilometres travelled by individual vessels and uses weighted emission factors for each vessel type as opposed to fuel based emission factors. The underlying vessel movement data for the year 2000 are taken from Lloyd's Marine Intelligence Unit (LMIU) and data on vessel characteristics by Lloyd's Register Fairplay.

The Waterway Network Ship Traffic, Energy and Environment Model (STEEM) is the first network that quantifies and geographically represents inter-port vessel traffic. STEEM applies advanced geographic information system (GIS) technology and solves routes automatically at a global scale, following actual shipping routes. The model has been applied with a focus for geographically characterization of ship emissions for North America, including the United States, Canada and Mexico (Wang et al., 2008).

The first global bottom-up approach has been developed by Paxian et al. (2009) and is used in this project to determine regional emissions as well as emissions per ship size and ship type. Ship movements and actual ship engine power per individual ship from Lloyd's Maritime Intelligence Unit (LMIU) ship statistics of six months in 2006 and further mean engine data from literature serve as input.

2.2 Model description

The existing top-down approaches do not allow the allocation of emissions to countries as they calculate energy use and emission totals without respect to location by means of quantifying the worldwide fuel consumption by power production first and then multiplying the consumption by emission factors (Corbett and Köhler, 2003; Endresen et al., 2003, 2007; Eyring et al., 2005; Buhaug et al., 2009). Therefore, a bottom-up method is needed where fuel use and emissions are directly estimated within a spatial context and can be linked to ship movement data. Such a bottom-up approach has been developed by Paxian et al. (2009), hereafter referred to as SeaKLIM algorithm. A brief model description is given below. For further details please refer to Paxian et al. (2009).

The SeaKLIM algorithm uses ship movements and actual ship engine power per individual ship from LMIU ship statistics of six months in 2006 and further mean engine data from literature serves as input (see also section 1.3). The SeaKLIM algorithm automatically finds the most probable shipping route for each combination of start and destination port of a certain ship movement by calculating the shortest path on a predefined model grid while considering land masses, sea ice, shipping canal sizes and climatological mean wave heights. For each movement with a given start and end harbour a distance field (km) is calculated that provides the distance a ship navigates on each model grid box between start and end port following the shortest path. An example for the distance field that is automatically determined by the SeaKLIM algorithm for a ship starting in Europe and arriving in Australia is given in Figure 7. The resulting present-day ship activity closely corresponds with observations (see Figure 1 as well as Figure 3 of Paxian et al., 2009). The global fuel consumption of 221 Mt in 2006 lies in the range of previously published inventories when undercounting of ship numbers in the LMIU movement database (40,055 vessels) is considered. Extrapolated to 2007 and ship numbers per ship type informed by the recent International Maritime Organization (IMO) estimate (100,214 vessels), a fuel consumption of 349 Mt is calculated which is within 5% of the IMO result of 333 Mt.

Figure 7   Resulting distance field (km) of the SeaKLIM algorithm for an example shipping route (left) and the 0.5°x0.5° standardized and weighted ship density (millionth of global total) for present-day (2006, upper right).
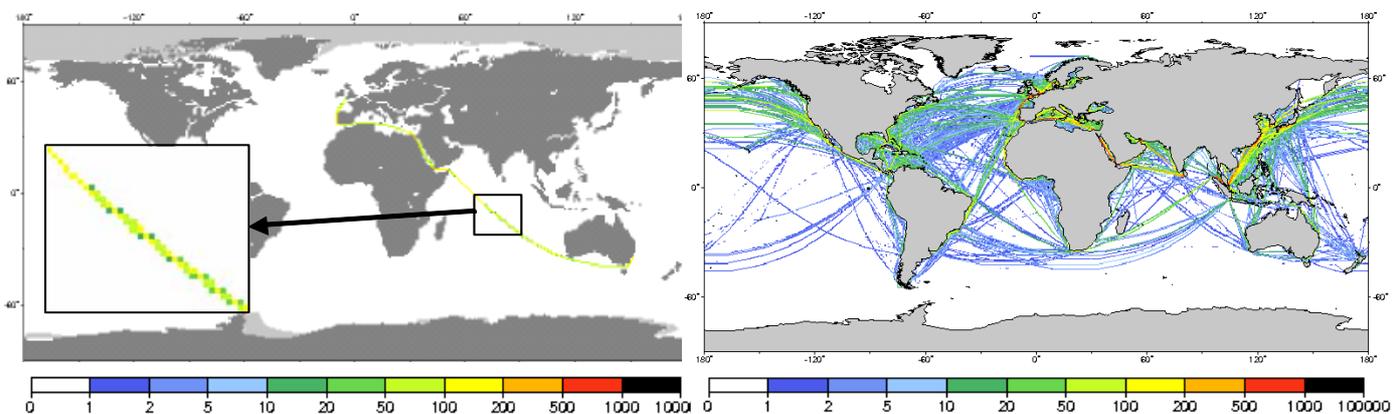
Source: Paxian et al. (2009), Figure 1.

For the purpose of this project, several improvements and extensions over the method described in Paxian et al. (2009) have been made in order to allow the calculations that were required for this project to be made:

1. The focus of the Paxian et al. (2009) study was on global emissions rather than regional estimates. Therefore, as part of this project the SeaKLIM algorithm had to be extended to allow the calculation of emissions for arriving/departing ships for certain regions (see Table 1), certain ship type classes (see Table 2), certain ship types (see Table 3) as well as for emissions calculations between the LMIU regions.

2. There are significant uncertainties associated with the main engine power of each ship. For this study, LMIU provided an updated file for the main engine power for each ship that is registered in the LMIU movement database. This file included 16,494 instead of 16,642 missing values out of 90,840 ships that are registered. However, from the 90,840 ships that were registered in 2006, only 40,055 are included in the LMIU movement database, and from those ships that are included in the LMIU movement database, 2,527 ships have missing entries for the main engine power in the new file. In addition to using this new file, compared to Paxian et al. (2009) two further changes have been made: (a) the main engine power has been multiplied with the number of engines as instructed by Lloyds, and (b) instead of using the average main engine power for missing values in this file, a new method was developed that considers the actual ship size. For the ships with missing engine power the vessel's dead weight tonnage (DWT), the vessel type and the vessel subtype was extracted from the Lloyds file that included the vessel information. The vessels were divided into 10 subgroups considering type and subtype. Within each of these groups the vessels were further selected by classes related with the vessels DWT to match the IMO classification (Buhaug et al., 2009). Once the class of the ship had been determined the IMO main engine power was assigned for this particular ship. After this method was applied, the main engine power of only 338 ships could not be corrected (because size, subsize or DWT was missing from the LMIU file on vessels). In this case the mean value for the ship class was used as in Paxian et al. (2009).

3. All intermediate stops not important for trading but only for passing like the Strait of Dover, Gibraltar, Suez/Port Said and the Panama Canal, have been skipped in the algorithm by Paxian et al. (2009). This is only possible if the corresponding ship continues to navigate in the same direction after leaving this port, i.e. the start port of the first movement and the end port of the second movement lie in different LMIU regions on both sides of the intermediate port. This skipping can be redone for four times until the final ship movement is determined from start port and sailing date of the first movement to end port and arrival date of the last movement in this row. This skipping method has been improved in this project. First of all, the selection of regions of start ports (before the skipped port) and of the end ports (after the skipped port) is redefined. Then, the choice of any particular category of routes (by regions, by country, etc.) was postponed with respect to the evaluation of the correct start and end port through the 'skipping algorithm' in order to allow the emission calculations by region.

4. As a reference for the total we use the fuel consumption and emission totals that were calculated in the 2nd IMO GHG study (Buhaug et al., 2009). In other words, we use the SeaKLIM algorithm only to calculate the regional shares and the shares for the various ship size categories, but we scale the resulting fuel consumption and emissions to the IMO totals by applying the factor ($Fuel_{IMO(2006)}/Fuel_{SeaKLIM(2006)}$).

The final algorithm that was then used in this study, with the changes described above, to calculate a total fuel consumption of 237 Mt instead of 221 Mt as in *Paxian et al.* (2009). This shows that overall the total fuel consumption is not particularly sensitive to the above outlined changes, which proves the robustness of the algorithm against these changes. With this revised highly flexible SeaKLIM algorithm, global, national and European energy use and emissions can be calculated considering a variety of different allocation methods. Allocation methods that are considered for this project include ship emissions estimates for particular regions (see Table 3) as well as ship size categories (see Table 4) and ship types (see Table 5).

Table 3   Overview of regions for which emissions are calculated. They are divided into LMIU regions (regions as defined by Lloyd's MIU) and non-LMIU regions. Only for LMIU regions it is possible to calculate emissions between the regions.

No	Area	Area Details (including LMIU area code if available)
LMIU regions		
1	South America	SAA, SAP
2	North America	USP, USG, USA, CAN
3	Central America	CAR, CAM (Caribbean, Central America)
4	North East Asia	CHI, JPN (China, Korea, Japan and Russia)
5	Europe	NEU, BLK, SCN, UKE, IBE, SEU, EMD
6	Africa	NAF, EAF, WAF
7	Middle Eastern Gulf	RED, ARA (Middle Eastern Gulf plus Red Sea)
8	Oceania	AUS (Australia, New Zealand, New Guinea, etc.)
9	Indian subcontinent	IND (India, Pakistan and Burma)
10	Far East Asia	SEA (Singapore, Vietnam, Thailand, Malaysia, Indonesia)
Non-LMIU region		
11	EU-27	European Union

Most LMIU regions are self-evident. Figure 8 shows the difference between the LMIU region Europe and the non-LMIU region EU-27. The countries that have been colored red belong to the EU-27. All these countries belong to the LMIU region Europe, which comprises also the yellow countries. Note that the eastern ports of Russia are not part of LMIU region Europe but belong to the LMIU region North East Asia.

Figure 8   Comparison of the EU-27 (in red) and the LMIU region Europe (all countries in red and yellow)
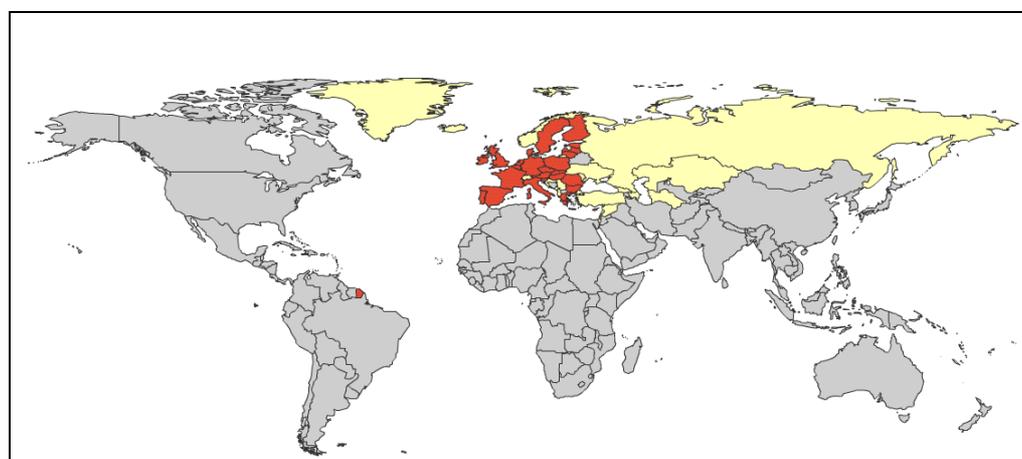
Note: Eastern ports of Russia and ports in French Guiana are not part of LMIU region Europe.

Table 4   Overview of ship size categories for which emissions are calculated

No	Lower limit	Upper limit	Notes
1	> 0 GT	400 GT	The size threshold for MARPOL
2	> 400 GT	500 GT	The size threshold for SOLAS
3	> 500 GT	5000 GT	A size threshold in CLC
4	> 5000 GT	No upper limit	

Table 5   Overview of ship type categories for which emissions are calculated

No	Ship Type
1	Container
2	Tanker
3	General Cargo
4	Bulk Carrier
5	Refeer
6	RoRo
7	Passenger
8	Fishing
9	Rest
10	Total

With regard to regional differentiation, the algorithm allows the calculation of emissions on routes between LMIU regions, in particular it allows the calculation of emissions between European ports (Region 5 in Table 3) as well as on routes to and/or from European ports.

2.3   Input data

2.3.1   Ship Movement Data

Spatially resolved ship movements from three databases of Lloyd's Maritime Intelligence Unit (LMIU) are used. These three databases are linked by unique LMIU ship IDs and LMIU port IDs (see further details in Paxian et al. (2009)).

1. The ship movement database available for this study contains movements of the international commercial fleet larger than 100 GT leaving the start port in February, April, June, August, October or December in 2006. Purchasing the full year of data from LMIU was not possible due to financial limitations. However, the six months of ship movements are considered representative for the whole year of 2006 and thus extrapolated. The dataset includes the ship IDs, start and end ports, arrival and sailing dates (d) and partly also times (h) of 1,001,123 ship movements from 40,055 vessels.
2. The ship database contains information on ship name, size, main engine power, average speed, flag and type of 90,840 ships.
3. The port database includes names and locations in geographical coordinates of 8,541 ports. Besides main engine power (see section 1.2) no further engine data were available from LMIU.

Table 6 shows a comparison of the ship numbers per ship type that are included in the LMIU movement database (half a year in 2006) in comparison to the recent global top-down study from Buhaug et al. (2009). This comparison shows that ship movements of non-trading vessels like tugs, pleasure craft, fishing and small coastal vessels are undercounted in the LMIU ship movement database because these non-IMO vessels are registered but not monitored in the movement database. In contrast, container ships, bulk carriers and reefers

are well covered in the LMIU database, whereas general cargo, tankers and roll-on-roll-off ships are covered only to around 60%. This undercounting of certain ships leads to biases in the derived regional emissions.

Table 6   Ship number per ship type of this study from LMIU ship movement database (2006) in comparison to Buhaug et al. (2009) for 2007

Ship type	Ship numbers from six months LMIU movement database in 2006	Ship numbers from Buhaug et al. (2009) in 2007	Percentage
General cargo	8,988	17,234	52.2
Tanker	7,751	12,905	60.1
Container	4,744	4,137	114.7
Bulk carrier	6,233	7,391	84.3
Reefer	1,080	1,238	87.2
Roll-on-Roll-off	1,480	2,445	60.5
Passenger	1,221	6,912	17.7
Fishing	2,332	23,848	9.8
Miscellaneous	6,226	24,101	25.8
All ships	40,055	100,214	40.0

Source: From Paxian et al. (2009), their Table S2.

2.3.2   Ship Characteristic and Engine Data

Since no further engine data are available from LMIU, we use mean ship characteristic for ship speed, auxiliary engine power and main and auxiliary engine load factors from Wang et al. (2007) grouped into nine different ship classes (see Table S3 in Paxian et al., 2009). From Eyring et al. (2005) we derive further information on specific fuel oil consumption and emission factors for main and auxiliary engines. Finally, Entec UK Limited (European Commission and Entec UK Limited, 2005b) provides CO_2 emission factors and main and auxiliary engine load factors, engine running hours, specific fuel oil consumption and emission factors for harbor activities. CO emission factors in harbors are not included.

2.3.3   Model Grid Data: Land Masses, Sea Ice, Shipping Canals and Sea State

Several input datasets describe the model grid characteristics. The distribution of land masses is derived from a 0.5°x0.5° land-sea mask of the Data Collection of the International Satellite Land Surface Climatology Project Initiative II (ISLSCP2, 2009). Three grid boxes are defined representing the shipping canals Panama, Suez and Kiel. These canals only allow certain ship sizes to pass and furthermore act as delay areas for passing ships due to reduced ship speeds compared to open sea voyages. Therefore, shipping canal data such as average canal ship speed and ship length, breadth and draft restrictions are gathered from canal authorities (see Supporting Information of Paxian et al. 2009, their Table S1). Finally, significant wave heights (m) are obtained from ECMWF ERA 40 data (ECMWF, 2009). A 2.5° sea state climatology for 1958-2001 is derived and scaled to the 0.5° model grid in order to present further delay areas for shipping routes.

2.4 Model results: 2006 fuel use and CO_2 emissions from shipping

The improved SeaKLIM algorithm calculates a total fuel consumption of 237.25 Mt in 2006 and 745.6 Mt CO_2. As described above we calculate the regional totals (see section 1.4.1), the emissions between Europe and other regions of the world (see section 1.4.2) as well as the emissions for different ship size categories (see section 1.4.4) and ship types (section 1.4.5) with the SeaKLIM algorithm and scale the results to the IMO totals. This means that we multiply the resulting values with the ratio of the fuel consumption/CO_2 emissions that are calculated by IMO and the SeaKLIM model for 2006. The fuel consumption and CO_2 emissions for total shipping therefore agree with the IMO estimate in 2006 (321 Mt fuel and 1,008 Mt CO_2). Since we cannot calculate emissions between the EU and other regions of the world, in section 1.4.3 we present an estimate based on the ratio of the regional emission totals for the EU and for Europe. The results that are described below are taken from Eyring et al. (2009b).

2.4.1 Regional Totals
The SeaKLIM algorithm was first run to calculate the emission totals for the regions that are listed in Table 5. These calculations are carried out (a) for all ships leaving a certain region and (b) for all ships arriving in a certain region and a summary of the results is presented in Table 7. Overall, the fuel consumption and CO_2 emissions for ships arriving and leaving a certain region are very similar, but e.g. for Europe the latter are slightly higher. The largest contribution comes from Europe (276.7 Mt CO_2 = 27% of total) followed by North East Asia (193.6 Mt, 19%), North America (120.2 Mt = 12% of total)and Far East Asia (115.8 Mt = 12% of total). All other regions (Central America, South America, Africa, Middle Eastern Gulf, Indian subcontinent and Oceania) have a contribution to the total of 7% or less. Figure 9 displays the regional totals and percentage to the total fuel consumption and CO_2 emissions, and Figure 10 displays the geographical distribution of CO_2 emissions for the LMIU regions.

Figure 9 Fuel consumption and CO_2 emissions for ships arriving in the various LMIU regions scaled to IMO totals for the year 2006 (see Table 3). Also given is the percentage contribution to the total.
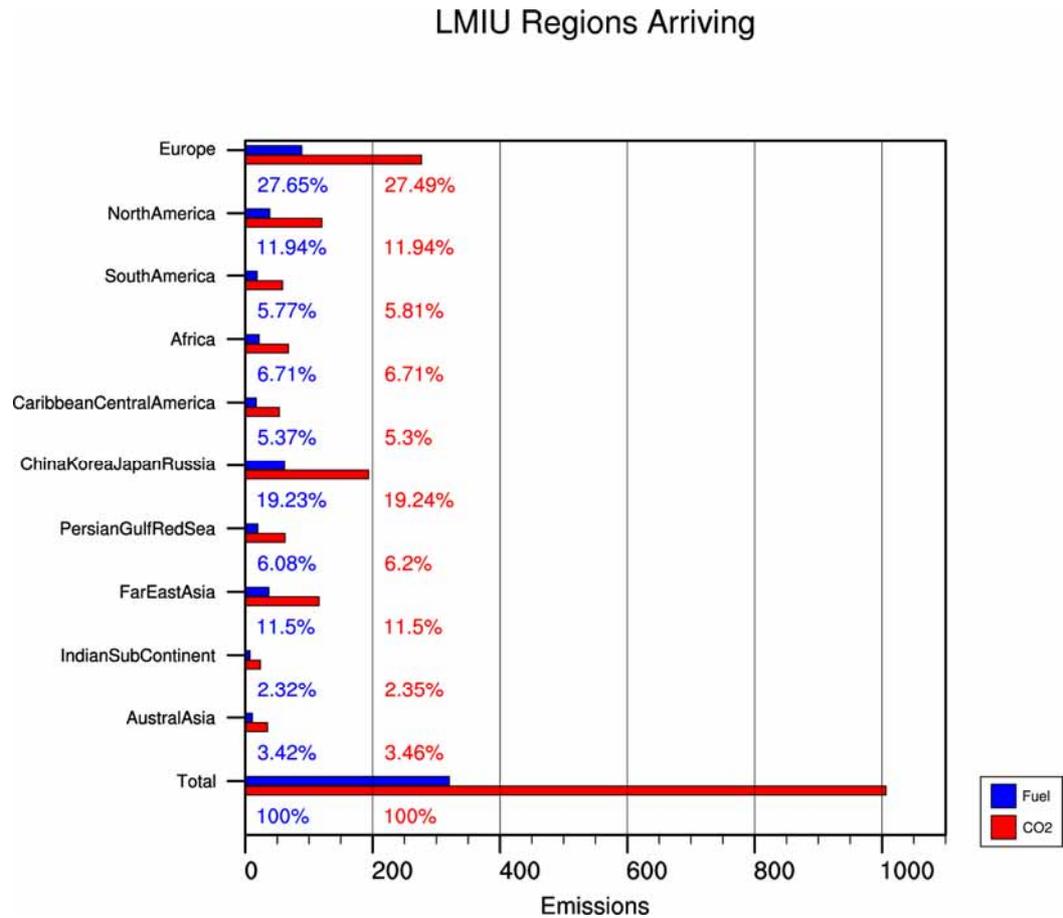
Figure 10   Geographical distribution of CO₂ emissions for the LMIU regions
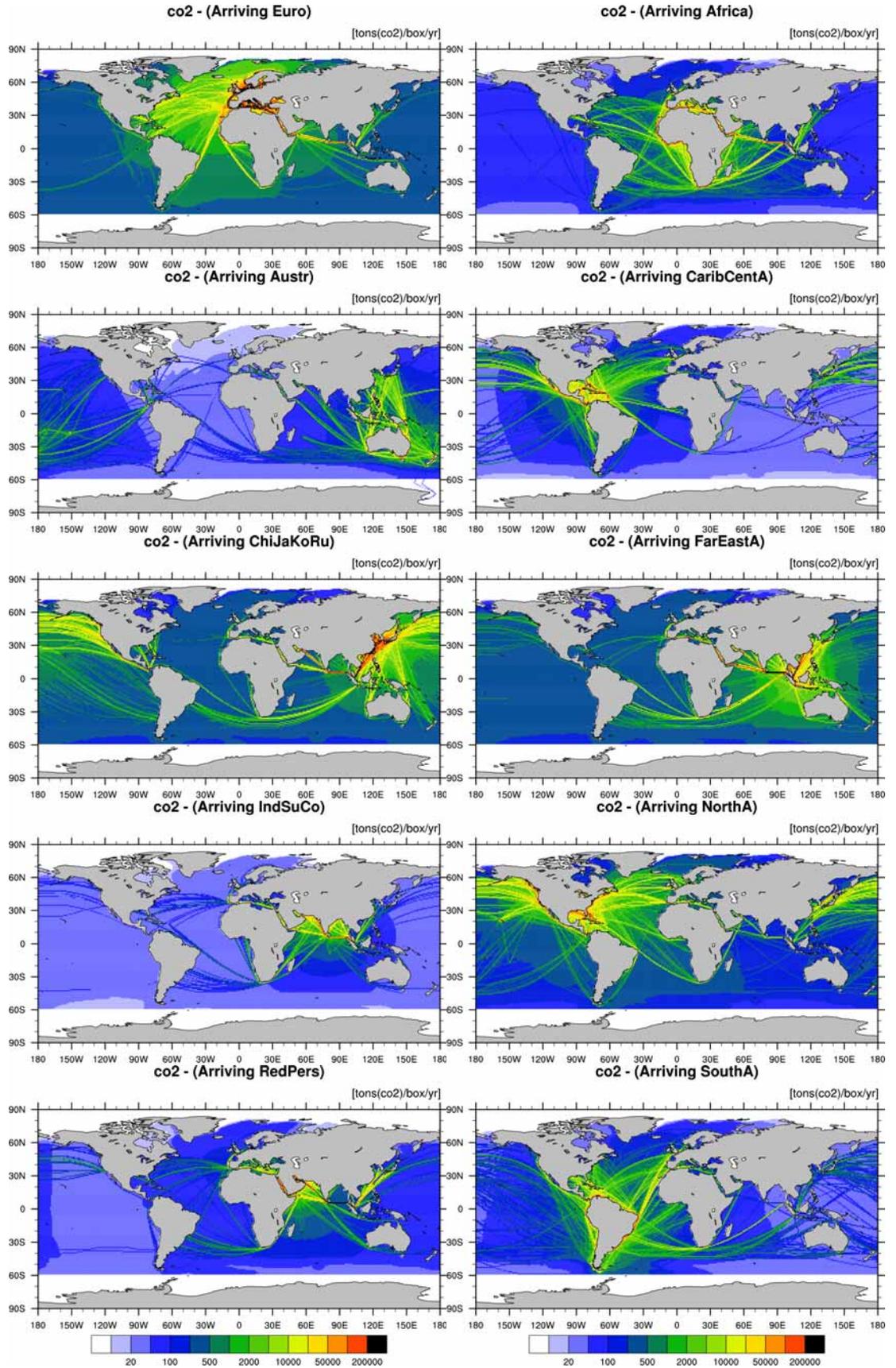
Table 7   Fuel use and CO_2 emissions on voyages to and from world regions, 2006

Region	Arriving ships			Departing ships		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of global CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of global CO_2 emissions (%)
LMIU regions						
Europe	88.6	276.7	27%	90.9	284.1	28%
North America	38.3	120.2	12%	37.5	117.5	12%
Central America	17.2	53.3	5%	16.6	51.6	5%
South America	18.5	58.5	6%	20.2	64.2	6%
Africa	21.5	67.6	7%	21.9	69.2	7%
Middle Eastern Gulf	19.5	62.4	6%	20.5	66	7%
Indian subcontinent	7.5	23.6	2%	7.07	22.3	2%
Far East Asia	36.8	115.8	12%	36	113.1	11%
North East Asia	61.6	193.6	19%	58.8	184.6	18%
Oceania	11.0	34.8	3%	11.3	36	4%
Totals	320.4	1,006.5	100%	320.8	1,008.6	100%
Non-LMIU region						
EU-27[*]	66.9	208.4	21%	68.6	213.6	21%

* EU-27: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom of Great Britain and Northern Ireland.

2.4.2   Emissions on voyages to and from European ports

In addition to the regional totals, the SeaKLIM algorithm is used to calculate emissions between regions. The focus of this project was on the calculation of emissions between Europe and other regions of the world. Table 8 summarizes the results, and in particular it shows the fuel consumption and CO_2 emissions for ships that arrive in Europe from all other nine LMIU regions as well as for the intra-European movements. The same calculation is repeated for all ships departing. As for the regional totals for Europe (see Table 7), the emission totals and the total fuel consumption is slightly higher for the ships departing from Europe than it is for ships arriving in Europe. The sum over the various regions tallies with the estimates that are given in Table 7 for the European totals. In terms of the regional totals, the difference between arrival and departure is not large. The main share of emissions on voyages arriving at European ports is on movements that started in a European port (i.e. intra-European movements) (197.7 Mt = 71%), followed by 8% for ships arriving from Africa, 6% for ships arriving from North America, and 4% for ships arriving from Far East Asia. All other contributions are below 4%.

Table 8   Fuel use and CO_2 emissions on voyages to and from European ports, 2006

Region of origin or destination	Ships arriving in Europe from this region			Ships leaving Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	5	15.9	6%	5.6	17.7	6%
Central America	1.9	5.7	2%	1.8	5.3	2%
South America	3.3	10.5	4%	4.3	13.9	5%
Africa	6.7	21.2	8%	5.9	18.5	7%
Middle Eastern Gulf	1.7	5.5	2%	2.5	7.8	3%
Indian subcontinent	0.8	2.6	1%	0.8	2.6	1%
Far East Asia	3.7	11.6	4%	4.3	13.3	5%
North East Asia	1.3	4	1%	2	6.2	2%
Oceania	0.6	1.9	1%	0.2	0.6	0%
Euro	63.5	197.7	71%	63.5	197.5	70%
Total Europe	88.5	276.6	100%	90.9	283.4	100%

2.4.3   Emissions on voyages to and from EU ports

The SEAKLIM model results on emissions to and from European ports (see section 2.4.2) can be used to calculate emissions to and from EU ports. Table 9 shows that emissions on routes to the EU total 208 Mt CO_2 and on routes to Europe 277 Mt CO_2. Hence, emissions to the EU are around 75% of emissions to Europe. Assuming that this share applies to all route groups, except for emissions between EU ports, which are reduced by the square of 75%, we estimate emissions on different route groups to the EU to be as shown in Table 9. This calculation could be improved by calculating the intra-EU emissions as in section 1.4.3. However, this is not yet possible with the SeaKLIM algorithm without further model development.

Table 9   Fuel use and CO_2 emissions on voyages to and from EU ports, 2006

Region of origin or destination	Ships arriving in EU ports from this region			Ships leaving EU ports to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	3.8	12.0	6%	4.2	13.3	6%
Central America	1.4	4.3	2%	1.4	4.0	2%
South America	2.5	7.9	4%	3.2	10.5	5%
Africa	5.1	16.0	8%	4.5	13.9	6%
Middle Eastern Gulf	1.3	4.1	2%	1.9	5.9	3%
Indian subcontinent	0.6	2.0	1%	0.6	2.0	1%
Far East Asia	2.8	8.7	4%	3.2	10.0	5%
North East Asia	1.0	3.0	1%	1.5	4.7	2%
Oceania	0.5	1.4	1%	0.2	0.5	0%
Rest of Europe	11.8	36.8	18%	11.8	37.4	17%
EU-27	36.2	112.1	54%	36.2	112.1	52%
TOTAL	66.9	208.4	100%	68.6	214.3	100%

2.4.4   Emissions for different ship size categories

The SeaKLIM algorithm was also used to calculate ship emissions and fuel consumption for the various ship size categories that are listed in Table 4. The results are summarized in Table 10 and in Figure 11. In addition the geographical distribution for CO_2 for the different size categories for total shipping is shown in
Figure 12 and for Europe in Figure 13. The majority of the total fuel is consumed by ships with sizes greater than 5,000 GT (87%). Similarly, this size category is the largest contributor for the European fuel consumption (78,9%), though it is notable that there is a slight shift to the smaller size category (500 to 5,000 GT) for the European fuel consumption and CO_2 emissions.

Table 10   Fuel use and CO_2 emissions for different ship size categories, totals and ships arriving in Europe, 2006

	Global shipping			Voyages to European ports		
Size (GT)	Total fuel use (Mt)	Total CO_2 emissions (Mt)	Percentage of global CO_2 emissions (%)	Fuel use for ships arriving in Europe (Mt)	CO_2 emissions for ships arriving in Europe (Mt)	Percentage of CO_2 emissions on voyages to Europe (%)
<400	5.1	15.3	1.5%	2.5	7.5	2.7%
400 to 500	1.3	4.1	0.4%	0.4	1.3	0.5%
500 to 5,000	34.3	106.7	10.6%	15.9	49.7	18.0%
>5,000	279.8	880.5	87.5%	69.7	218.2	78.9%
Total	320.5	1,006.6	100.0%	88.5	276.7	100.0%

Figure 12   Geographical distribution of total CO$_2$ emissions for the four different ship size classes
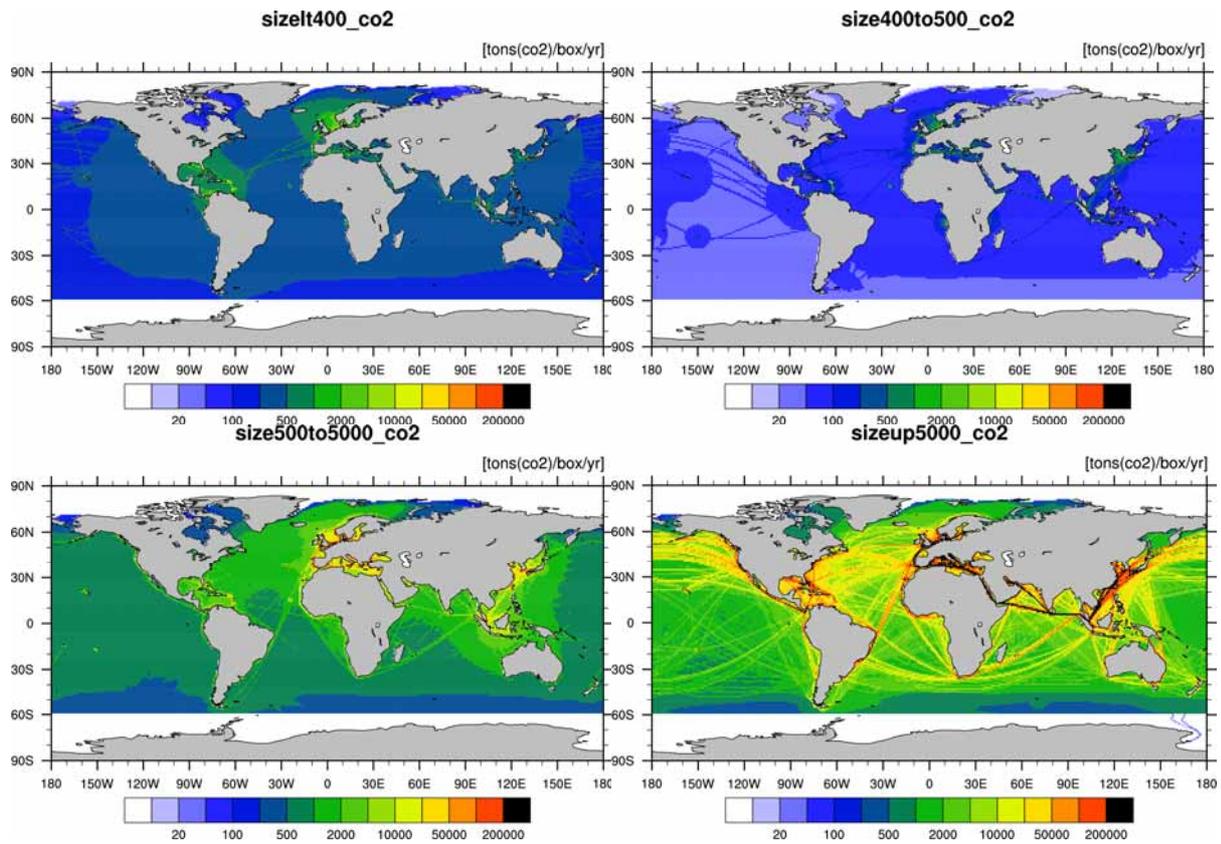
Figure 13   Geographical distribution of CO_2 emissions for ships arriving in Europe
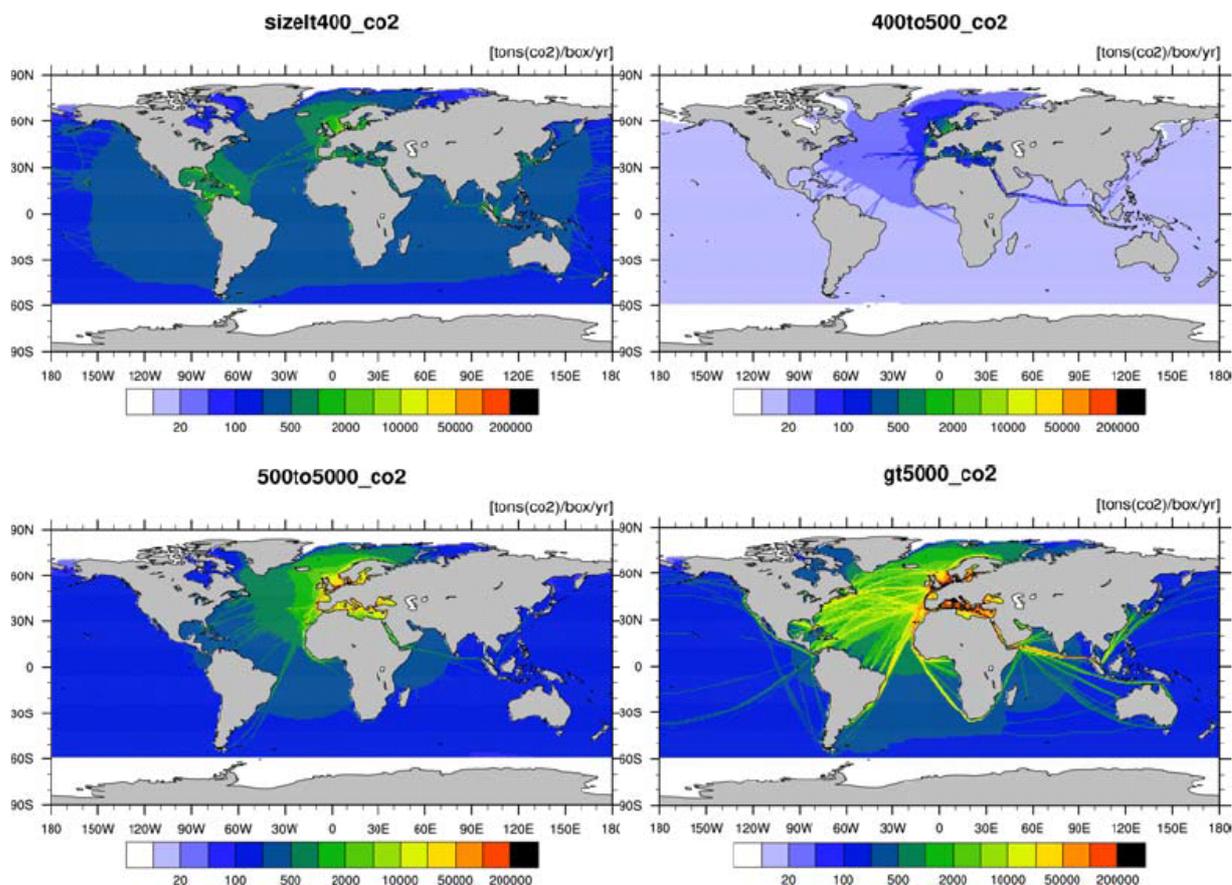
2.4.5   Emissions for different ship types

In this section we summarize results that have been calculated for different ship type categories (see Table 5). This calculation has been carried out for total emissions, for the ships arriving in Europe as well as for the intra-European traffic.

For movements that either arrive or depart in European ports, Figure 14 shows the contribution from the various LMIU regions (see Table 3) to European ports in terms of fuel consumption and CO_2 emissions for the various ship type categories (Container. Tanker, General Cargo, Bulk Carrier, Reefer, RoRo, Passenger, Fishing, and Rest). In all categories the contribution from Europe to European fuel consumption and CO_2 emissions is highest. However, significant differences exist for all other regions. For example, the CO_2 emissions from Europe to the Far East are dominated by the container ship type category (77.6%), followed by tankers (9.4%) and bulk carriers (8.7%). All other ship type categories contribute less than 2%. The percentage contributions is similar for the other direction (Far East Europe), i.e. 69.2% for container and 8.4% for tankers), but in this case the contribution in the bulk carrier category is higher than in the Europe – Far East case (16.2%). In contrast, in the passenger and fishing ship type category, CO_2 emissions are clearly dominated by intra-European traffic, with negligible contribution from other LMIU regions as expected. Only the passenger traffic to and from Africa contributes significantly with around 9% of the overall CO_2 emissions from this region.

Figure 14   Traffic from Europe to the other LMIU regions (see Table 3) for various ship type categories (see Table 5). The percentage fuel consumption (blue) and CO$_2$ emissions (red) to the total intra-Europe traffic in each ship type category is given in addition in percent in each panel. Note that the Europe-Europe fuel consumption and CO$_2$ emissions are the same for ships arriving and ships departing, but for clarity this contribution is only plotted once.
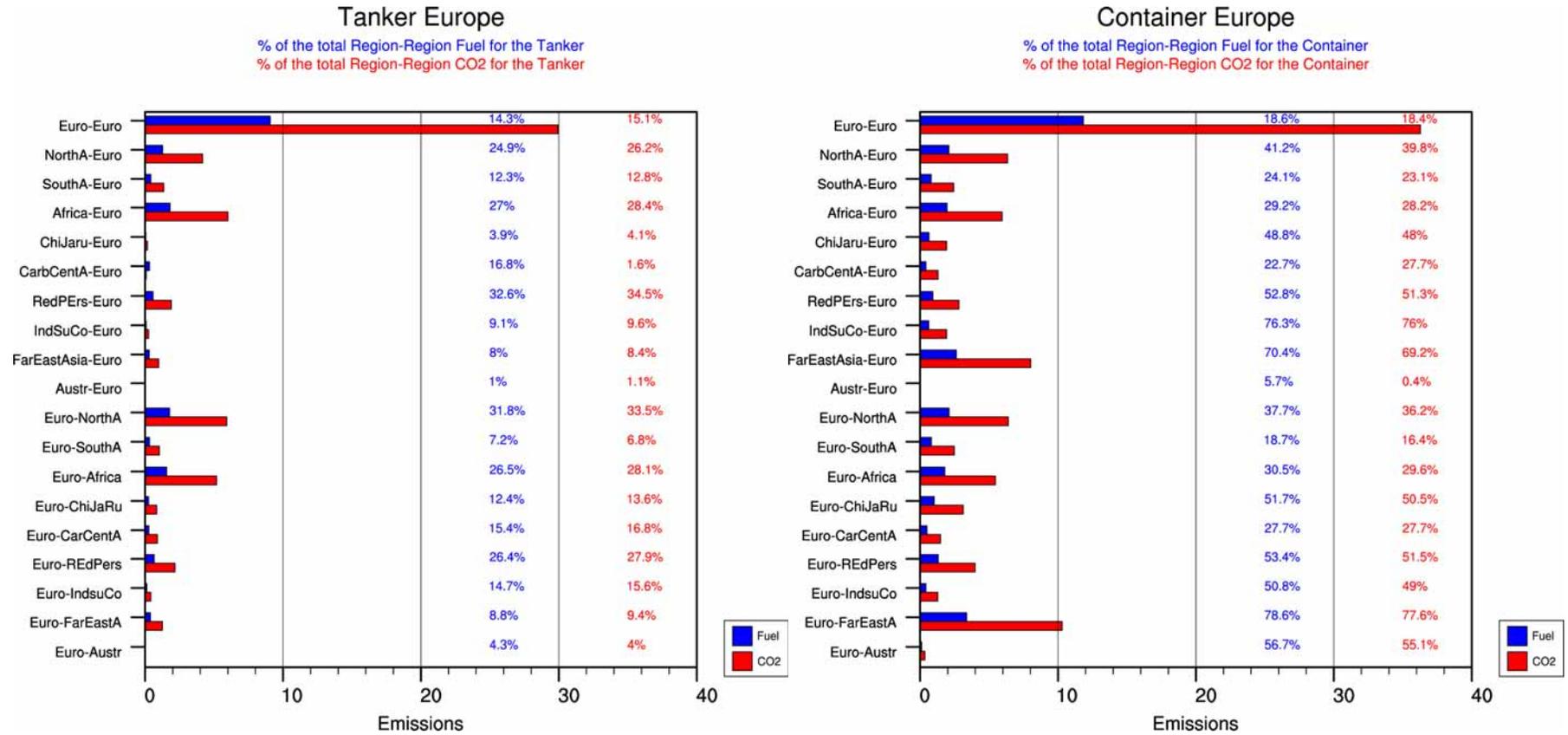
GeneralCargo Europe

% of the total Region-Region Fuel for the GeneralCargo
% of the total Region-Region CO2 for the GeneralCargo

	Fuel	CO2
Euro-Euro	12.7%	12.9%
NorthA-Euro	4.5%	4.5%
SouthA-Euro	4.9%	4.8%
Africa-Euro	8.9%	8.9%
ChiJaru-Euro	3.9%	4.1%
CarbCentA-Euro	3.4%	4.3%
RedPErs-Euro	3.5%	3.2%
IndSuCo-Euro	4.6%	4.3%
FarEastAsia-Euro	1.8%	1.9%
Austr-Euro	2.6%	3.1%
Euro-NorthA	3.9%	3.8%
Euro-SouthA	3.7%	3.4%
Euro-Africa	9.9%	10%
Euro-ChiJaRu	2.8%	2.8%
Euro-CarCentA	2.3%	2.5%
Euro-REdPers	5.5%	5.6%
Euro-IndsuCo	4.9%	5.1%
Euro-FarEastA	1.9%	2%
Euro-Austr	7.1%	8.8%
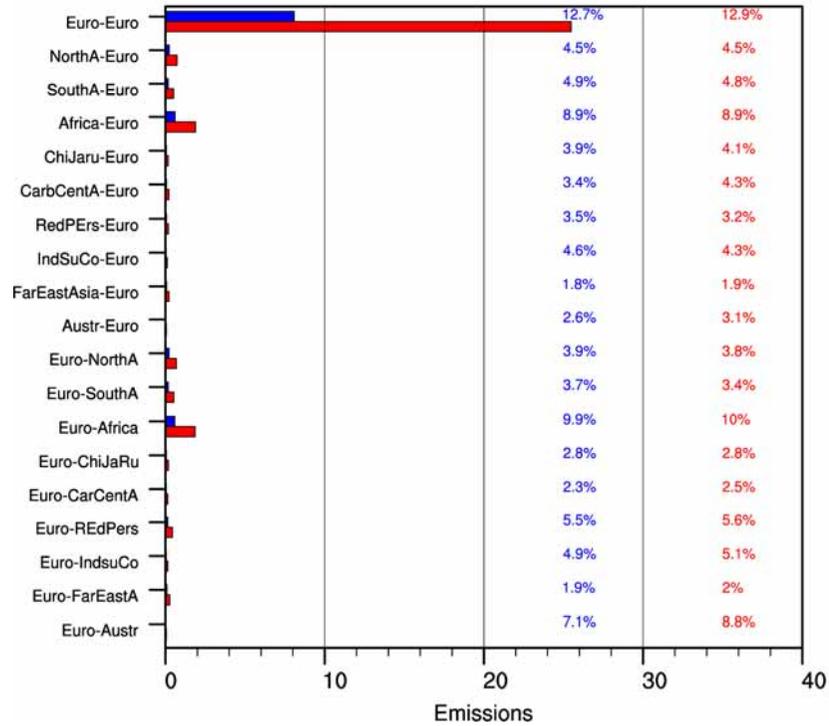
BulkCarrier Europe

% of the total Region-Region Fuel for the BulkCarrier
% of the total Region-Region CO2 for the BulkCarrier

	Fuel	CO2
Euro-Euro	5.6%	5.9%
NorthA-Euro	19%	19.8%
SouthA-Euro	48.2%	49.9%
Africa-Euro	16.9%	17.4%
ChiJaru-Euro	20.7%	22%
CarbCentA-Euro	9.7%	12.7%
RedPErs-Euro	6.1%	6.4%
IndSuCo-Euro	7%	7.5%
FarEastAsia-Euro	15.2%	16.2%
Austr-Euro	81.1%	85.5%
Euro-NorthA	16.5%	17.1%
Euro-SouthA	60.5%	57.3%
Euro-Africa	9%	9.5%
Euro-ChiJaRu	17.2%	17.9%
Euro-CarCentA	6.9%	7.9%
Euro-REdPers	8.8%	9.4%
Euro-IndsuCo	24.6%	25.6%
Euro-FarEastA	8.2%	8.7%
Euro-Austr	21.3%	22%

Emissions

Refeer Europe

Region	Fuel %	CO2 %
Euro-Euro	1.6%	1.4%
NorthA-Euro	2.7%	2.5%
SouthA-Euro	8.6%	7.6%
Africa-Euro	3.5%	3%
ChiJaru-Euro	0.3%	0.3%
CarbCentA-Euro	41%	46.2%
RedPErs-Euro	0.1%	0.1%
IndSuCo-Euro	0%	0%
FarEastAsia-Euro	0%	0%
Austr-Euro	4.8%	5.3%
Euro-NorthA	2.4%	2.1%
Euro-SouthA	7.5%	6%
Euro-Africa	4.4%	3.9%
Euro-ChiJaRu	1.1%	1%
Euro-CarCentA	40.1%	37.7%
Euro-REdPers	0.6%	0.5%
Euro-IndsuCo	0.3%	0.3%
Euro-FarEastA	0.3%	0.2%
Euro-Austr	6.4%	5.9%

Fuel / CO2

Emissions

Roro Europe

Region	Fuel %	CO2 %
Euro-Euro	8.3%	8%
NorthA-Euro	5.1%	4.8%
SouthA-Euro	0.4%	0.4%
Africa-Euro	4.9%	4.7%
ChiJaru-Euro	17.6%	16.9%
CarbCentA-Euro	0.7%	1.2%
RedPErs-Euro	3.1%	2.7%
IndSuCo-Euro	1.3%	1.1%
FarEastAsia-Euro	3.6%	3.5%
Austr-Euro	0%	0%
Euro-NorthA	5.6%	5.3%
Euro-SouthA	0.6%	0.6%
Euro-Africa	5.8%	5.4%
Euro-ChiJaRu	12.4%	11.8%
Euro-CarCentA	2.3%	2.3%
Euro-REdPers	4.4%	4.2%
Euro-IndsuCo	2.1%	2%
Euro-FarEastA	1.8%	1.7%
Euro-Austr	0%	0%

Fuel / CO2

Emissions

Passenger Europe

Region	Fuel	CO2
Euro-Euro	30%	29.6%
NorthA-Euro	1.3%	1.2%
SouthA-Euro	0.7%	0.6%
Africa-Euro	8.5%	8.3%
ChiJaru-Euro	0.4%	0.3%
CarbCentA-Euro	3.7%	4%
RedPErs-Euro	0.8%	0.7%
IndSuCo-Euro	0.7%	0.6%
FarEastAsia-Euro	0.1%	0.1%
Austr-Euro	0%	0%
Euro-NorthA	1.1%	1.1%
Euro-SouthA	1%	8.8%
Euro-Africa	9.5%	9.4%
Euro-ChiJaRu	0%	0%
Euro-CarCentA	3.2%	3.1%
Euro-REdPers	0.2%	0.1%
Euro-IndsuCo	1.3%	1.3%
Euro-FarEastA	0%	0%
Euro-Austr	0%	0%

Emissions

Fishing Europe

Region	Fuel	CO2
Euro-Euro	2%	1.9%
NorthA-Euro	0.1%	0.1%
SouthA-Euro	0.1%	0.1%
Africa-Euro	0.1%	0.1%
ChiJaru-Euro	0.7%	0.7%
CarbCentA-Euro	0.1%	0.2%
RedPErs-Euro	0%	0%
IndSuCo-Euro	0%	0%
FarEastAsia-Euro	0%	0%
Austr-Euro	0%	0%
Euro-NorthA	0.1%	0.1%
Euro-SouthA	0.1%	0.1%
Euro-Africa	0.3%	0%
Euro-ChiJaRu	0.1%	0.1%
Euro-CarCentA	0.2%	0.2%
Euro-REdPers	0%	0%
Euro-IndsuCo	0.3%	0.3%
Euro-FarEastA	0%	0%
Euro-Austr	1.4%	1.5%

Emissions

Table 11   Fuel use and CO_2 emissions for Container ships arriving in and departing from Europe, 2006

Region of origin or destination	Container ships arriving in Europe from this region			Container ships departing from Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	2.1	6.3	9%	2.1	6.4	9%
Central America	0.4	1.3	2%	0.5	1.5	2%
South America	0.8	2.4	4%	0.8	2.5	4%
Africa	1.9	5.9	9%	1.8	5.5	8%
Middle Eastern Gulf	0.9	2.8	4%	1.3	4.0	6%
Indian subcontinent	0.6	1.9	3%	0.4	1.3	2%
Far East Asia	2.6	8.0	12%	3.4	10.3	14%
North East Asia	0.6	1.9	3%	1.0	3.1	4%
Oceania	0.03	0.09	0%	0.1	0.3	0%
Euro	11.8	36.3	54%	11.8	36.3	51%
Total Europe	21.7	67.1	100%	23.2	71.1	100%

Table 12   Same as Table 11, but for Tankers

Region of origin or destination	Tankers arriving in Europe from this region			Tankers departing from Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	1.3	4.2	9%	1.8	5.9	12%
Central America	0.3	0.7	2%	0.3	0.9	2%
South America	0.4	1.4	3%	0.3	1.0	2%
Africa	1.8	6.0	13%	1.6	5.2	11%
Middle Eastern Gulf	0.6	1.9	4%	2.2	2.2	5%
Indian subcontinent	0.07	0.2	0%	0.1	0.4	1%
Far East Asia	0.3	1.0	2%	0.4	1.2	3%
North East Asia	0.05	0.2	0%	1.8	5.9	12%
Oceania	0.01	0.02	0%	0.01	0.02	0%
Euro	9.1	29.9	66%	9.1	29.9	63%
Total Europe	13.9	45.5	100%	14.4	47.6	100%

Table 13   Same as Table 11, but for General cargo ships

Region of origin or destination	General cargo ships arriving in Europe from this region			General cargo ships departing from Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	0.2	0.7	2%	0.2	0.7	2%
Central America	0.06	0.18	1%	0.04	0.14	0%
South America	0.16	0.5	2%	0.16	0.5	2%
Africa	0.6	1.9	6%	0.6	1.9	6%
Middle Eastern Gulf	0.06	0.18	1%	0.14	0.4	1%
Indian subcontinent	0.04	0.11	0%	0.04	0.1	0%
Far East Asia	0.07	0.22	1%	0.08	0.3	1%
North East Asia	0.23	0.72	2%	0.22	0.7	2%
Oceania	0.01	0.05	0%	0.01	0.05	0%
Euro	8.1	25.5	86%	8.1	25.5	86%
Total Europe	9.5	29.5	100%	9.4	29.7	100%

Table 14   Same as Table 11, but for bulk carriers

Region of origin or destination	Bulk Carriers arriving in Europe from this region			Bulk Carriers departing from Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	1.0	3.2	11%	0.9	3.0	10%
Central America	0.2	0.6	2%	0.1	0.4	1%
South America	1.6	5.2	18%	2.6	8.6	29%
Africa	1.1	3.7	13%	0.5	1.8	6%
Middle Eastern Gulf	0.1	0.4	1%	0.2	0.7	2%
Indian subcontinent	0.06	0.2	1%	0.2	0.7	2%
Far East Asia	0.6	1.9	7%	0.4	1.2	4%
North East Asia	0.3	0.8	3%	0.3	1.1	4%
Oceania	0.5	1.5	5%	0.04	0.14	0%
Euro	3.6	11.7	40%	3.6	11.7	40%
Total Europe	9.0	29.1	100%	8.9	29.3	100%

Table 15   Same as Table 11, but for Reefer ships

Region of origin or destination	Refeer ships arriving in Europe from this region			Refeer ships departing from Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	0.1	0.4	6%	0.1	0.4	6%
Central America	0.8	2.1	30%	0.7	2.0	29%
South America	0.3	0.8	11%	0.3	0.9	13%
Africa	0.2	0.6	9%	0.3	0.7	10%
Middle Eastern Gulf	0.00	0.00	0%	0.01	0.04	1%
Indian subcontinent	0.00	0.00	0%	0.00	0.01	0%
Far East Asia	0.00	0.00	0%	0.01	0.03	0%
North East Asia	0.00	0.01	0%	0.02	0.06	1%
Oceania	0.03	0.09	1%	0.01	0.04	1%
Euro	1.0	2.8	40%	1.0	2.8	40%
Total Europe	2.4	7.0	100%	2.5	7.0	100%

Table 16   Same as Table 11, but for RoRo ships

Region of origin or destination	RoRo ships arriving in Europe from this region			RoRo Ships departing from Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	0.3	0.8	4%	0.3	0.9	5%
Central America	0.01	0.05	0%	0.04	0.1	1%
South America	0.01	0.04	0%	0.03	0.09	0%
Africa	0.3	1.0	5%	0.3	1.0	5%
Middle Eastern Gulf	0.05	0.15	1%	0.1	0.3	2%
Indian subcontinent	0.01	0.03	0%	0.02	0.05	0%
Far East Asia	0.1	0.4	2%	0.08	0.2	1%
North East Asia	0.2	0.7	4%	0.2	0.9	5%
Oceania	0	0	0%	0	0	0%
Euro	5.3	15.8	84%	5.3	15.8	82%
Total Europe	6.3	18.9	100%	6.4	19.3	100%

Table 17   Same as Table 11, but for Passenger ships

Region of origin or destination	Passenger Ships arriving in Europe from this region			Passenger Ships departing from Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	0.07	0.2	0%	0.06	0.19	0%
Central America	0.07	0.2	0%	0.06	0.16	0%
South America	0.02	0.07	0%	0.04	1.32	2%
Africa	0.6	1.8	3%	0.6	1.7	3%
Middle Eastern Gulf	0.01	0.04	0%	0.00	0.01	0%
Indian subcontinent	0.01	0.01	0%	0.01	0.03	0%
Far East Asia	0.00	0.01	0%	0.00	0.00	0%
North East Asia	0.01	0.01	0%	0.00	0.00	0%
Oceania	0.00	0.00	0%	0.00	0.00	0%
Euro	19.0	58.5	96%	19.0	58.5	95%
Total Europe	19.8	60.8	100%	19.8	61.9	100%

Table 18   Same as Table 11, but for the Fishing fleet

Region of origin or destination	Fishing ships arriving in Europe from this region			Fishing ships departing from Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	0.00	0.01	0%	0.01	0.03	1%
Central America	0.00	0.01	0%	0.00	0.01	0%
South America	0.00	0.01	0%	0.00	0.01	0%
Africa	0.01	0.03	1%	0.02	0.05	1%
Middle Eastern Gulf	0.00	0.00	0%	0.00	0.00	0%
Indian subcontinent	0.00	0.00	0%	0.00	0.01	0%
Far East Asia	0.00	0.00	0%	0.00	0.01	0%
North East Asia	0.01	0.03	1%	0.00	0.01	0%
Oceania	0.00	0.00	0%	0.00	0.01	0%
Euro	1.24	3.85	97%	1.24	3.85	97%
Total Europe	1.26	3.95	100%	1.28	3.98	100%

Table 19   Same as Table 11, but for all other ships (Rest)

Region of origin or destination	All other ships (Rest) arriving in Europe from this region			All other ships (Rest) departing from Europe to this region		
	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)	Fuel use (Mt)	CO_2 emissions (Mt)	Percentage of total CO_2 emissions (%)
North America	0.06	0.18	1%	0.05	0.14	1%
Central America	0.03	0.1	1%	0.03	0.09	1%
South America	0.02	0.07	0%	0.03	0.09	1%
Africa	0.06	0.2	1%	0.24	0.74	5%
Middle Eastern Gulf	0.02	0.06	0%	0.02	0.05	0%
Indian subcontinent	0.01	0.02	0%	0.01	0.02	0%
Far East Asia	0.03	0.08	1%	0.02	0.05	0%
North East Asia	0.05	0.15	1%	0.05	0.14	1%
Oceania	0.03	0.08	1%	0.01	0.02	0%
Euro	4.4	13.3	93%	4.4	13.3	90%
Total Europe	4.7	14.3	100%	4.8	14.7	100%

Figure 15 gives an overview of contributions from various ship type categories to total (left), European (ships arriving, right) and intra-European (lower panel) fuel consumption and CO_2 emissions. In each case, the percentages from each ship type category in terms of fuel consumption and CO_2 emissions are given. While total CO_2 emissions are dominated by the container ship type category (33.3%), followed by tankers (20.8%), and bulk carriers (15.1%), the highest contribution to total CO_2 emissions for the intra-European traffic comes from the passenger fleet (29.6%), followed by container ships (18.4%), tankers (15.1%) and general cargo (12.9%). For the European regional totals (i.e. all ships arriving in Europe from all other regions worldwide), the contribution from containers is smaller than for the worldwide fleet (i.e. 24.3%), while the contribution from the passenger fleet is higher (22%).

Figure 15   Contribution of various ship type categories to total (left), European (ships arriving, right) and intra-Europe (lower panel) fuel consumption and CO_2 emissions. The percentages from the ship type categories to the total in each figure are given in addition (blue: fuel consumption; red: CO_2 emissions)
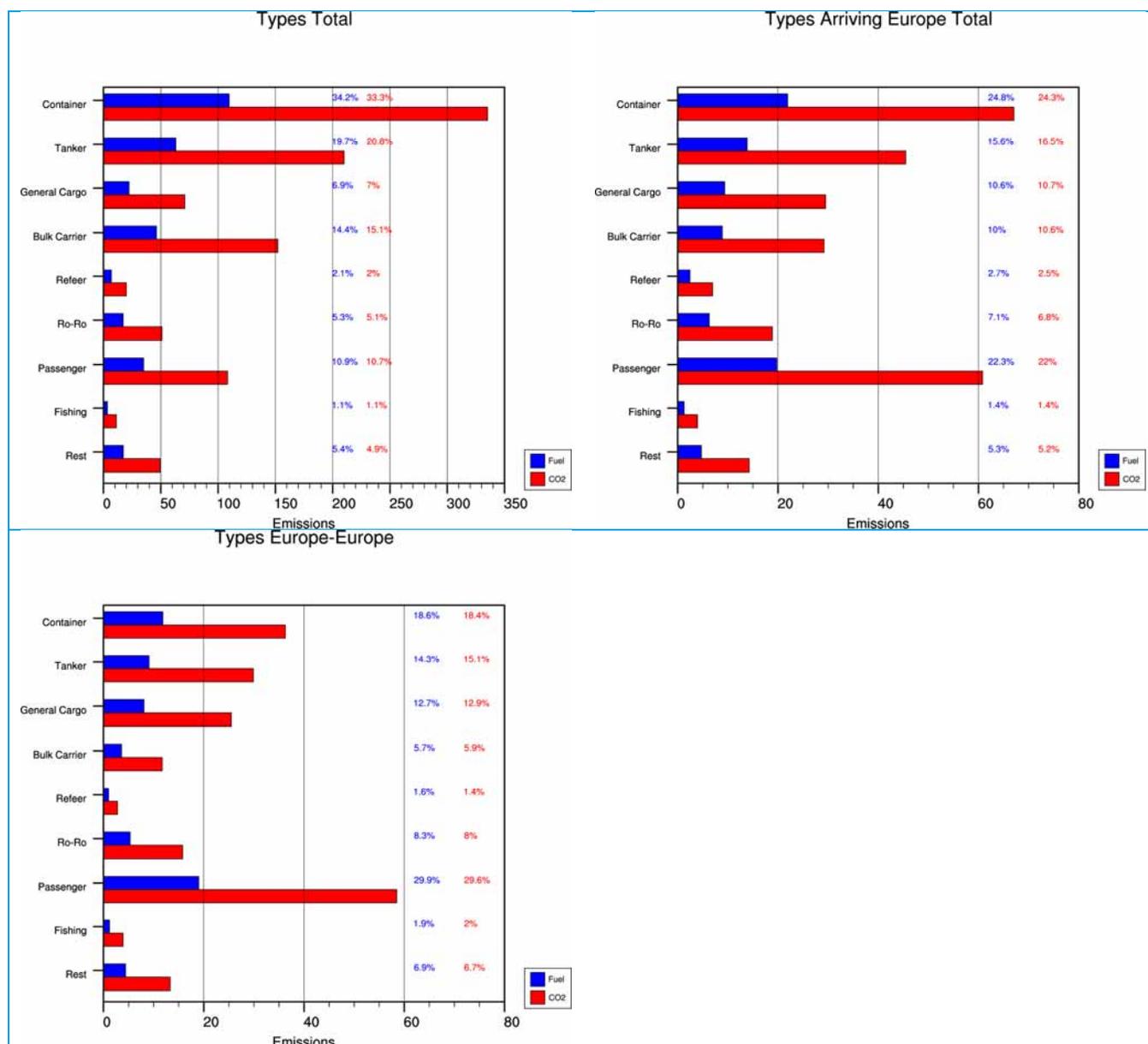
2.5   Discussion and uncertainties in emission estimates

The emissions calculations presented in this section are based on a global bottom-up method. An automatic path-finding algorithm between start and end port on a 0.5°x0.5° model grid developed by Paxian et al. (2009) has been further improved and extended to allow the calculation of fuel consumption and emissions for several policy relevant allocation criteria. The results yield a better spatial resolution than global top-down approaches and represent the first global bottom-up approach. The totals of fuel consumption and emissions lie in the range of recent global top-down and regional bottom-up approaches. This algorithm is used to calculate fuel consumption as well as CO_2 emissions

for ten LMIU regions and for an additional six regions that include the European Union. Fuel consumption and CO_2 emissions can be calculated for ships arriving in these regions, as well as for ships leaving these regions. In addition, fuel consumption and emissions can be calculated between the ten LMIU regions.

Overall, the results are reasonable: see also section 2.6 for comparison to other studies. However, the quality of the results strongly depends on the input data and the completeness of the movement database. Table 6 shows that while the number of container ships, bulk carriers and reefers are well represented in the half year of 2006 LMIU movement database, general cargo, tankers and roll-on-roll-off ships are covered only to around 60%, and smaller ships like passenger, fishing and miscellaneous ships are not well represented. In addition, a bias in the coverage of the movement database (e.g. higher coverage of movements over Europe than over China) cannot be excluded and might influence the results. These uncertainties in the input data cannot be overcome as part of this project. Effective monitoring and reliable emission modelling on an individual ship basis is expected to improve if data from the Long Range Identification and Tracking (LRIT) technology and the Automatic Identification System (AIS) are more widely used. LRIT is a satellite-based system with planned global cover of maritime traffic from 2008. AIS transponders automatically broadcast information, such as their position, speed, and navigational status, at regular intervals to shore-side receivers. Since 2004, all ships greater than 300 GT on international voyages are required by the IMO to transmit data on their position using AIS. The LRIT information ships will be required to transmit the ship's identity, location and date and time of the position.

The LMIU movement data that were bought for the purpose of this project included only half a year of 2006 because of financial limitations. Improvements could be achieved by improved information for engine data per individual ship and by an underlying ship movement database that covers at least a whole year of movements to avoid averaged values per ship type and extrapolations. It would be desirable if the movement data could be made freely available for research purposes in order to allow the analysis of several years leading to more robust results.

The path-finding algorithm itself could be improved by a model grid with higher resolution and an optimisation following shipping routes' costs in addition to distances. In general, the SeaKLIM algorithm finds the shortest path and thus always calculates a lower bound for the fuel consumption of a certain port combination. The method that was used in this study shows the flexibility to integrate all these improvements.

2.6 Comparison with other emission estimates

This section compares the model results presented in section 2.4 with three other estimates of emissions on routes to, from and between EU ports.

The first estimate is generated by the POLES model (JRC/IPTS 2009). The POLES (Prospective Outlook for the Long term Energy System) model is a global sectoral simulation model for the development of energy scenarios until 2050. The dynamics of the model is based on a recursive (year by year) simulation process of energy demand and supply with lagged adjustments to prices and a feedback loop through international energy prices.

POLES has a maritime transport module (Hidalgo, 2007) that has been used to calculate emissions on voyages between various regions in the world for 2005 and projected emissions for the years 2010 through 2030.

Table 20 CO_2 emissions from maritime transport, 2005 (Mt CO_2)

Region of destination	Emissions (Mt CO_2)	Share of world total
EU-27	132	20%
North America	39	6%
Central America	184	28%
South America	9	1%
Europe	157	24%
Commonwealth of Independent States	11	2%
Africa	74	11%
Middle East	11	2%
China	40	6%
North East Asia	23	4%
South East Asia	46	7%
Oceania	47	7%
South West Asia	8	1%
WORLD	648	20%

Source: POLES.

POLES estimates global maritime emissions in 2005 to be 648 Mt CO_2. This is lower than the consensus estimate in Buhaug et al. (2009), although the latter estimate is for 2007, not 2005. POLES estimates emissions on voyages to the EU-27 to be 132 Mt CO_2, 20% of the global emissions; the figures for Europe are 157 Mt and 24%, respectively. Both the absolute emissions and the share of emissions is lower than the results of the DLR model, according to which emissions on voyages to Europe amount 300 Mt CO_2, representing 27.5% of global emissions, albeit in 2006 rather than 2005.

Much more can be said on the comparison of POLES with the DLR model. Many of the differences can probably be attributed to differences in region borders. POLES, for example, considers China to be one region, whereas the in the DLR model China is part of the region North East Asia, which also includes Japan, Korea and some Russian ports. It is beyond the scope of this report to analyse all the differences, as this report focuses on Europe.

The second estimate we consider here has been published by Entec (2005). It is an activity based estimate, based on Lloyds MIU ship movement data. CE et al., 2006b have performed an analysis of this report. The results are shown in Table 21.

Table 21   Indication of CO$_2$ emissions (2000) (excluding fishing, including ferries)

	Global CO$_2$ emissions of maritime transport (Mt)	CO$_2$ emissions in EMEP region (Mt)
Operators		
All operators	756.7	153.3
EU based operators		
EU flagged ships	196.6	71.4
EU based shippers		
Operations		
All operations	756.7	153.3
All operations to and from EU ports	152.4	
In ports	30.2	10.2
Territorial waters	-	38.3
Exclusive economic zones	-	120.6

Source: Entec, 2005.

Notes: EU includes Croatia; EMEP is the Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe. The EMEP region includes the Baltic Sea, North Sea, Mediterranean and the North Atlantic.

Entec (2005) estimates emissions on voyages to and from EU ports to be 152.4 Mt CO$_2$ in 2000, or 20% of the global emissions. Assuming that emissions on voyages *to* the EU are the same as emissions on voyages *from* the EU, emissions on voyages to the EU are 76 Mt CO$_2$, or 10% of the global emissions. Both the amount and the share are considerably lower than the results of the DLR model and the POLES model estimate.

A peculiarity in the Entec data is that emissions in the EMEP region are almost the same as emissions on voyages to and from the EU. This means that emissions on voyages to and from the EU outside the EMEP region would be approximately the same as emissions on voyages not departing from or arriving in EU ports but sailing through the EMEP region. Figure 16 suggests that ships sailing through the EMEP region but not calling at EU ports would be predominantly ships sailing to or from Norwegian, Russian, Icelandic, Turkish, Albanian and North African ports, as well as ships sailing to North American destinations from the Suez Canal. Their emissions would be as large as emissions of ships calling at EU ports outside the EMEP region, e.g. from Suez to the Gulf or Asia, and from the boundary of the EMEP region to North, Central and South America, Africa and Australia. While this is not entirely impossible, we consider it implausible considering the lengths of the voyages to and from EU ports concerned and the relatively small number of ships sailing to non-EU European destinations and to the US.

Figure 16   EMEP region

Source: EEA (http://dataservice.eea.europa.eu/atlas/viewdata/viewpub.asp?id=1959).
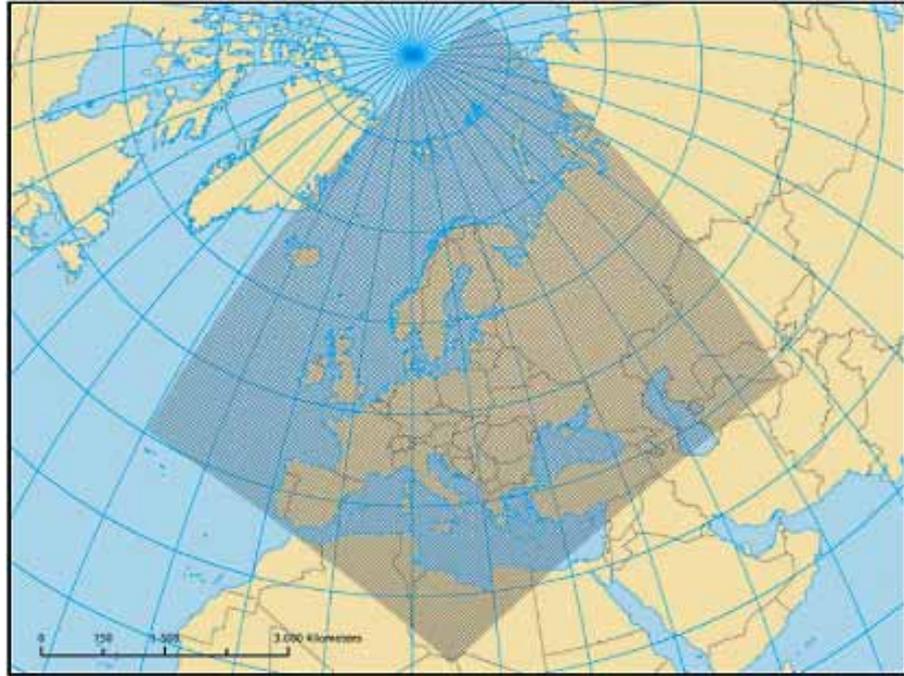
A third estimate has been prepared for this project using EUROSTAT trade data. The methodology that was used to estimate the emission baseline is shown schematically in Figure 17 and will be discussed in the following section.

Figure 17   A schematic overview of the methodology
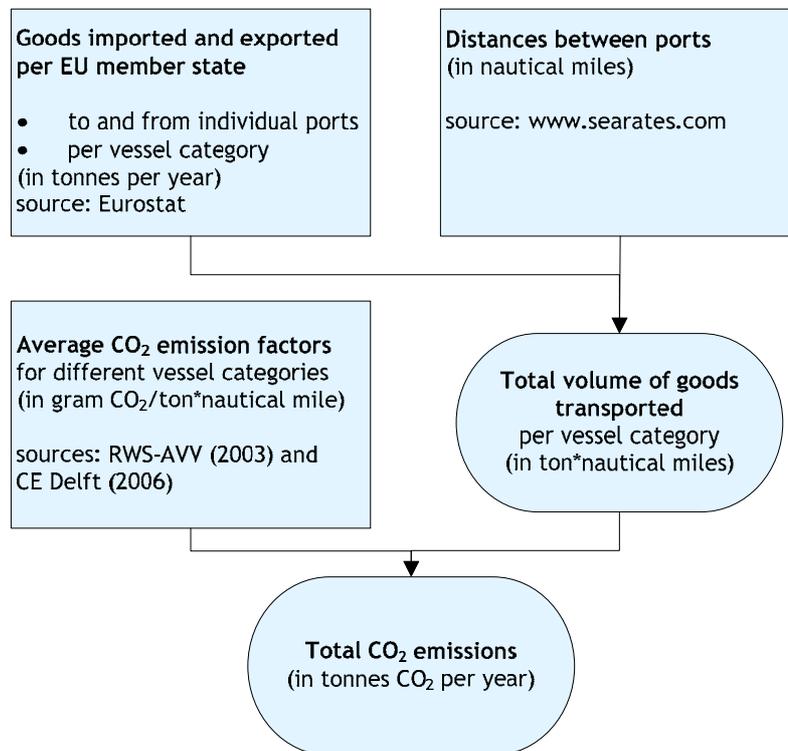
Starting point of the estimation is the identification of the amount of goods transported (in tones) per vessel type and the distance over which the cargo is transported (in nautical miles). This is being done by making use of Eurostat data. The data for the year 2006 was used in the analysis, which is the most recent year currently available in the Eurostat database.

To estimate the emission factors of the vessel types (g CO_2/tonne-mile) we made use of two different sources: 1) emission factors deduced from the emission registration- and monitoring protocol for seagoing ships in Dutch coastal waters (RWS-AVV, 2003) and 2) the average CO_2 index determined for various ship types in a field trial, as described in MARINTEK (2006)[1]. Both are shown in Table 22, together with the emissions factors used in our calculations.

Table 22   Average emission factor per vessel type

Vessel type	Average emission factor based on RWS-AVV 2003) (g CO_2/ nautical tonne-mile)	Average emission factor based on MARINTEK (2006) (g CO_2/nautical tonne-mile)	Average emission factor used (g CO_2/nautical tonne-mile)
Liquid bulk	9	15	12
Dry bulk	8	15	11
Large freight container	24	30	27
RoRo	95	-	95
Other cargo	8	15	11

Source: Own analysis based on RWS-AVV (2003) and MARINTEK (2006).

Application of the emission factors to the tonne-miles per vessel type gives the CO_2 emission from maritime transport of cargo for the year 2006.

The emission estimates for 2006 are presented in Table 23.

Table 23   Emission estimates based on trade data, 2006

Ship type	Intra-EU	Non-EU to and from EU
Large Containers	2.94	47.48
Liquid bulk carriers	4.04	42.32
Dry bulk carriers	2.18	17.30
Other cargo nes	0.92	7.68
RoRo (mobile non-self propelled units)	2.37	1.24
RoRo (mobile self propelled units)	3.32	0.00
Total	15.77	116.03

Source: This report.

---

[1]   Unfortunately, the number and variety of vessels participating in this trial, was not large enough to consider this trial as representative for all vessels accessing the EU. However, these data give a good first indication of emission factors that can be expected.

Assuming that the emissions on voyages arriving in EU ports are the same as emissions on voyages departing from EU ports, we estimate emissions on voyages to the EU to be 74 Mt CO_2 in 2006. This is lower than the other estimates presented above. Part of this difference can be attributed to the fact that only cargo vessels are included and not fishing vessels, dredging vessels and yachts, for example. Moreover, the estimate could be lower if trading patters for Europe have lower average load factors than the world average.

According to these estimates, 22% of emissions on voyages to the EU are on intra-EU voyages. This is considerably lower than the share estimated by the DLR model.

A fourth estimate of regional emissions presented here are by Chiffi and Fiorello (2009). They use a model based on trade data, which they convert to voyage data using average vessel statistics from EU ports. For each voyage, 50% of the emissions are assigned to the country of origin and 50% to the destination country. Thus they estimate emissions on voyages related to EU ports to be 77 Mt in 2005.

Table 24 presents a summary of emission estimates in this and the preceding section.

Table 24   Summary of emissions estimates

Source identifier	Year	CO_2 emissions (Mt CO_2)		
		Voyages to EU ports	Intra-EU voyages	Voyages from non-EU ports to EU ports
DLR	2006	208	112 (54%)	96 (46%)
POLES	2005	132	n.a.	n.a.
Entec	2000	76	n.a.	n.a.
CE Delft	2006	74	16 (22%)	58 (78%)
EX-TREMIS	2005	77	n.a.	n.a.

Source: This report, sections 2.4 and 0.

Table 24 shows that emission estimates vary widely, and that the estimates presented in section 2.4 are much higher than all other available estimates. We note that estimates based on trade-data (POLES, CE Delft and EX-TREMIS) are consistently lower than estimates based on ship movements (DLR, ENTEC). We furthermore note that the share of voyages between EU ports shows a considerable variation. Trade-data estimates show a much smaller share of emissions between EU ports than ship activity based data.

There several reasons why activity based data are should be consistently higher than trade-based estimates:
— As section 2.4.5 shows, non-cargo ships (passenger, fishing and 'other' ships) accounted for 16.7% of global maritime CO_2 emissions in 2006 according to the SEAKLIM results. According to Buhaug et al. (2009), ships in the categories ferry, cruise, yacht, offshore, service and miscellaneous accounted for 24% of global emissions in 2007. Both numbers show that non-cargo ships account for a significant amount of emissions, which are not included in trade-based estimates.
— Section 2.4.5 shows that non-cargo ships account for an even larger share of emissions of ships arriving in EU ports, 28.6%. So for estimates of European emissions, trade-based estimates ignore an even larger share of

emissions. If the emissions estimates from POLES, CE Delft and EX-TREMIS were increased by 40% to account for non-cargo ships, the difference with the DLR figures would be reduced but not eliminated. POLES emissions would increase to 185 Mt CO_2 (23 Mt CO_2 or 11% less than the DLR model results). The CE Delft and EX-TREMIS emission figures would increase to 104 Mt CO_2 and 108 Mt CO_2 respectively, or about 50% of the DLR model results.

— Section 2.4.4 shows that a relatively large share of emissions on routes to European ports are from small ships. These are less efficient than larger ships. To the extent that this also applies to cargo ships, this would result in higher emissions per tonne-mile on voyages to European ports.

— Container ships, RoRo and chemical tankers often make several stops in Europe, offloading cargo in every port but often not transporting cargo from one of these ports to another. For example, if a container ship sails from Malaysia via Colombo and Salalah to Europe, its first stop is often Gioia Tauro in Italy, where it may offload containers, but not load new ones, after which it carries on to Rotterdam, Felixstowe or Bremerhaven. This intra-EU leg is quite long compared to the leg from Salalah to Gioia Tauro. It would not be reported as an intra-EU voyage in trade-based estimates. Hence, intra-European emissions are substantial relative to emissions from a non-European port to Europe

— There are a relatively high number of RoPax ferries, fishing vessels and coasters in Europe, because of which intra-European emissions are high. If these vessels carry cargo, the amount is often limited.

— Trade-based estimates like EX-TREMIS and CE Delft are based on Eurostat statistics on cargo offloaded at major EU ports. Smaller ports would probably have relatively more short sea shipping and smaller ships, leading to relatively more emissions on intra-EU voyages.

For these reasons, we conclude that activity based estimates are a better way to determine emissions on voyages to and/or from EU ports than trade based estimates, because the latter will systematically underestimate emissions.

The other activity based estimate presented in Table 24 (Entec, 2005) is also lower than our activity based estimate. Part of it is linked to the different base year. Eurostat data shows that the gross weight of goods handled in all EU ports increased by 3.4% per annum in the period 2002-2007 and the number of ships and total gross tonnage increased by 1.6% and 3.6% respectively in the period 2004-2007. Hence, it is to be expected that the emissions according to the Entec model would have been higher in 2006 than in 2000. However, even if emissions would have increased by, say 4% per annum, they would only have grown to 96 Mt in 2006. Entec (2005) does not provide a lot of detail on the emissions calculations and the assumptions, so we cannot explain the remaining difference. However, we note a number of possible causes:

— Entec (2005) only covers ships larger than 500 GT, while this study covers all ships over 100 GT in the Lloyds MIU database; section 2.4.4 shows that emissions of ships smaller than 500 GT account for 3.2% of emissions on voyages to EU ports. This can explain a small share of the difference.

— Entec (2005) uses the Lloyd's MIS as a source for engine power. As not all engine sizes are specified in this database, and Entec (2005) does not specify whether and how missing data are estimated, this could be a source of underreporting.

— Entec (2005) assumes constant engine load factors which do not depend on vessel speed.

We furthermore note that in the last five years the understanding of activity based modeling has dramatically improved due to a collaborative effort of different modelers (see Buhaug et al., 2009). Moreover, in recent years it has for the first time been possible to check crucial assumptions on days at sea and vessel speeds with AIS data that report the position of ships with great accuracy. The DLR model has been able to take this improved understanding into account. For these reasons, we believe the results of the DLR model are better than the results in Entec (2005).

In summary, we conclude that there are good reasons that emission estimates for different route groups deviate from trade data for these route groups. Moreover, since the DLR model is based on one of the most comprehensive databases of ship movements, and since total global emissions are in line with other, independent estimates, and since the geographical representations of the emissions are credible, we conclude that the DLR model results are the best available estimate for emissions on routes to and from European ports.

2.7 Projections of emission growth

This report has not developed a scenario or scenarios for future development of emissions, as it was beyond its scope. Rather, it bases its projections and scenarios on other studies that have analysed this issue in much greater detail. This section identifies the main reports. See also section 4.1.2 for a more detailed discussion.

Buhaug et al. (2009) have developed emission scenarios for global maritime emissions, based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES). IPCC SRES has four so-called storylines which are driven by population, economy, technology, energy, land-use and agriculture. In an open Delphi process, Buhaug et al. (2009) developed shipping specific correlations of trade volume growth with GDP growth; market driven technological developments; market-driven operational developments and fuel use. Their projected annual growth rates are presented in Table 25.

Table 25   Projected annual growth in maritime CO_2 emissions, (IMO), 2007-2050

SRES storyline	Base	High	Low
A1FI	2.7%	5.1%	-0.4%
A1B	2.7%	5.2%	-0.4%
A1T	2.7%	5.2%	-0.4%
A2	2.2%	4.4%	-0.6%
B1	2.1%	4.3%	-0.7%
B2	1.9%	3.9%	-0.8%

Source: Buhaug et al., 2009.

In the so-called base case, Buhaug et al. (2009) project emissions to increase annually at 1.9 to 2.7% on average. They have not made separate estimates for different world regions.

The EX-TREMIS reference system projects emission growth rates for ships sailing to and from EU ports. For the period 2006-2020, it assumes that growth rates per country are the same as the actual growth rates of transport volume in the period 1997-2005 (Chiffi et al., 2007). For the decade starting in 2021, an approximately 1 percentage point lower growth rate has been assumed.

Thus the reference system projects emissions to increase with average annual rates as shown in Table 26.

Table 26   Projected annual growth rates of emissions (EX-TREMIS)

Period	Emissions average annual growth rate
2005-2020	2.4%
2021-2030	1.6%
2005-2030	2.1%

Source: Chiffi et al., 2007.

POLES has a highly variable average annual growth rate in emissions of ships sailing to EU ports. We haven't been able to identify the cause of this variability.

Table 27   Average annual growth rates of maritime emissions (POLES)

Period	Emissions average annual growth rate
2005-2010	4.6%
2010-2015	2.2%
2015-2020	1.3%
2020-2025	3.4%
2025-2030	4.1%
2005-2030	3.1%

Source: POLES.

In summary, most scenarios project maritime emissions to continue to rise in the forthcoming decades, despite gains in efficiency (on which a detailed discussion is given in section 4.1.2). Average annual growth rates vary from -0.8% for a low economic growth, fast technological progress scenario to 5.2% for high growth scenarios. Specific growth rates for the EU are in the same range as global projections. Most base cases projections, including business-as-usual efficiency improvements, have average annual emission growth rates of 2-3% with little difference between scenarios for global maritime transport or maritime transport to and/or from EU ports.

A more detailed set of scenarios for maritime transport emissions on voyages to and from Europe would take into account economic growth in the EU and its trading partners, new sea routes such as the widened Panama Canal and possibly arctic sea routes, demand for petroleum and other raw materials under climate policies, and other factors.

2.8   Conclusion

We estimate emissions on voyages to and from ports in the EU-27 countries to be 311 Mt of CO_2 in 2006 with an uncertainty margin of ± 20%. The uncertainty margin is equal to the margin in Buhaug et al. (2009), on which the total global emissions have been based. These emissions were divided over route groups as indicated in Table 28.

Table 28   This study's estimate of emissions of maritime transport to the EU-27, 2006

Region of origin or destination	Ships arriving in EU ports from this region		Ships leaving EU ports to this region	
	Fuel use (Mt)	CO_2 emissions (Mt)	Fuel use (Mt)	CO_2 emissions (Mt)
North America	3.8	12.0	4.2	13.3
Central America	1.4	4.3	1.4	4.0
South America	2.5	7.9	3.2	10.5
Africa	5.1	16.0	4.5	13.9
Middle Eastern Gulf	1.3	4.1	1.9	5.9
Indian subcontinent	0.6	2.0	0.6	2.0
Far East Asia	2.8	8.7	3.2	10.0
North East Asia	1.0	3.0	1.5	4.7
Oceania	0.5	1.4	0.2	0.5
Rest of Europe	11.8	36.8	11.8	37.4
EU-27	36.2	112.1	36.2	112.1
Total	66.9	208.4	68.6	214.3

Source: This report.

It was beyond the scope of this to develop scenarios or forecasts of future emission growth. Scenarios from other studies for the period up to 2030 project average annual emission growth rates of 2 to 3%, depending on economic growth and technological development. There seems to be little difference between EU specific projections and global projections.

Using these projections and applying them to route groups involving EU ports, emissions in 2030 are projected to be 499 to 631 Mt CO_2 (see Table 29). Note that these projections take business-as-usual efficiency improvements into account.

Table 29 CO_2 emissions on different route groups, 2006 and projections for 2020 and 2030 (Mt CO_2)

Route groups	2006	2020		2030	
Average annual emission growth rate		2%	3%	2%	3%
Voyages arriving at EU ports	208	274	315	335	423
Voyages departing from EU ports	214	282	324	344	435
Voyages between EU ports	112	148	169	180	228
Voyages arriving at or departing from EU ports	310	409	469	499	630

Note: Average growth rates are based on literature survey not on original scenario development of this report.

3 Emission reduction measures

3.1 Introduction

The different measures that contribute to the abatement of emissions of CO_2 in maritime transport can be illustrated in a marginal abatement cost curve (MACC). A MACC depicts the maximum abatement potential of measures that do not exclude each other, sorted by their marginal costs. We derived such a MACC for the year 2030.

The abatement potential of the measures are related to a certain emission level of the Maritime Transport Sector in 2030, the so-called baseline emissions. The baseline emissions that are used in this analysis constitute a frozen-technology baseline. This is a hypothetical baseline, assuming that between the base year 2007 and 2030 no new technologies are implemented in the fleet. Under this baseline, the fleet will be larger in 2030 in order to meet the demand growth, but each ship that is added to the fleet has the same fuel efficiency as the 2007 fleet average for a ship of this type and size. Using a frozen technology baseline has the advantage that we do not have to make assumptions about the business-as-usual improvements in efficiency and – more importantly – about the measures that will be implemented in order to achieve these improvements.

Note that the emission projections that are presented in section 2.7 do not constitute a frozen-technology baseline. Therefore, when estimating the net emissions in 2030, the abatement potential derived in this chapter cannot be applied to the emission level derived in section 2.7. This would lead to an underestimation of the possible net 2030 emissions. See section 4.1.2 for a more detailed discussion of emission forecasts and efficiency gains.

Deriving the MACC, 29 different technical and operational measures, allocated to the following twelve groups, were taken into account:
1   Propeller/propulsion system upgrades.
2   Propeller maintenance.
3   Retrofit hull improvement.
4   Hull coating and maintenance.
5   Air lubrication.
6   Main engine retrofit measures.
7   Waste heat recovery.
8   Auxiliary systems.
9   Wind energy.
10 Solar energy.
11 Voyage and operations options.
12 Speed reduction.

The groups were chosen so that measures from different groups do not exclude each other. Measures from the same group exclude each other or are, most probably, not used together.

Most of the measures that are accounted for are retrofit measures. This is due to the fact that for retrofit measures more cost data are available.

The MACC gives the marginal costs and the maximum abatement potential for the different groups. Although the marginal costs and the maximum abatement potential have been calculated for the individual measures, an estimation per group is being used. This is due to the fact that uncertainty, particularly about the costs of the abatement measures, is still very high. For the same reason, we distinguished between three estimates for every measure group: a low bound, a high bound, as well as a central estimate.

In the following we will first present the MACC for a price of US$ 700/tonne for bunker fuel and an interest rate of 9%. Subsequently, we will briefly go into the changes of the MACC that are implied by a change of the price of bunker fuel or by a change of the interest rate. Further, the present MACC will be compared with the MACC derived by DNV (DNV, 2009) and the MACC as presented in the latest GHG study from the IMO (Buhaug et al., 2009). Finally, the underlying methodology and data will be described. A list of the individual measures can be found in annex A. Here also some of the measures are described in greater detail.

3.2   The Marginal CO_2 Abatement Cost Curve

In Figure 18 the marginal CO_2 abatement cost curve for 2030 is given for a fuel price of US$ 700/tonne and an interest rate of 9%. The curve on the left-hand and the curve on the right-hand side depict the low and the high estimate of the marginal costs and together give the range in which the marginal cost curve falls. Within this range, the curve in the middle constitutes a central estimate of the marginal costs.

In interpreting the marginal abatement cost curve, several factors are important:
−   This MACC is relative to a frozen technology scenario, i.e. a scenario in which each ship that is added to the fleet or that is taken out of the fleet has the same characteristics as the average vessel in the ship type and size category to which this ship belongs.
−   The frozen-technology emission and fleet growth factors are taken from Buhaug et al. (2009) for the global fleet. Emission reduction options here are presented as percentages of the total frozen technology forecast. These percentages can be applied to the fleet under the scope of an EU policy provided that:
    •   The fleet under the scope of an EU policy is similar to the world fleet. From chapter 2 we know that there are a number of differences. However, as ship types that are relatively overrepresented in Europe (small ships and passenger ships, for example) in general have a fairly average scope for reducing emissions, this assumption does not change the results significantly.
−   The choice of the frozen technology scenario could theoretically impact the results, as demand may increase more or less in different scenarios. The relative abatement potential are unlikely to change significantly, however, because a different scenario choice would affect both the absolute emissions in 2030 and the absolute abatement potential in a very similar way. Hence, the relative abatement potential would remain the same.
−   The choice of the frozen-technology scenario does not influence the marginal costs of abatement measures.

Two things are striking about these curves. First, most of the measures have negative marginal costs. This result is driven by the level of the assumed fuel price as can be seen in the sensitivity analysis below. Second, the curves are characterized by a steep tail at the right-hand side. This is due to the fact that measures have been considered that are developed yet but are still very expensive, as for example solar energy.

The maximum abatement potential of the measures that are taken into account lies within a range of 27–47% of the projected total emissions of the vessel types included. The marginal costs of many of the measures is negative. The range of the maximum abatement potential of these measures is 23-45% with 33% for the central estimate[2].

Since this marginal abatement cost curve accounts for many different ship types and the marginal costs of the measures do highly vary over the ship types a measure group cannot be singled as the most efficient group.

Figure 18   Marginal CO_2 Abatement Costs for the Maritime Transport Sector in 2030 relative to frozen-technology scenario, Range of Estimates, US$ 700/ tonne fuel, 9% Interest Rate
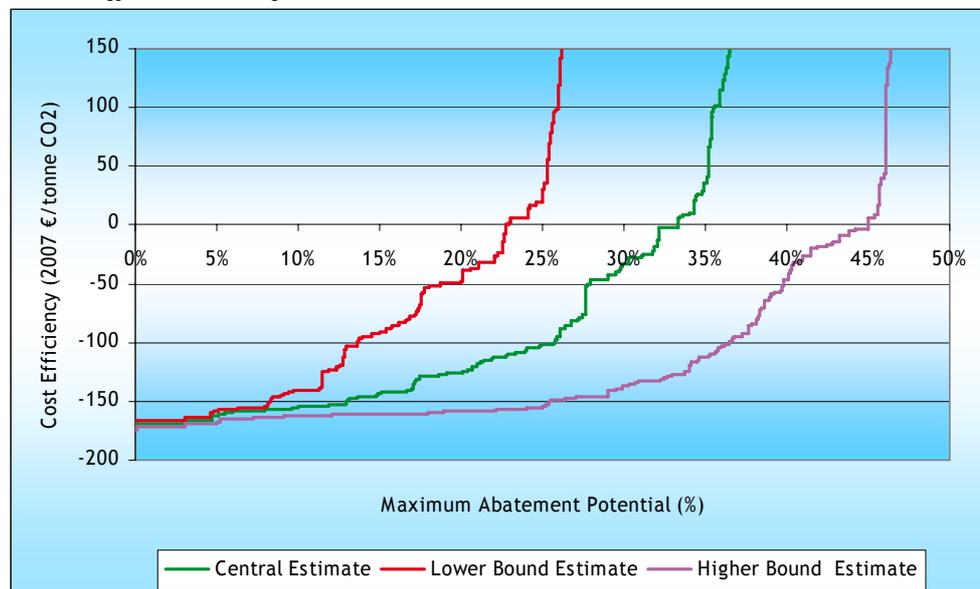
3.3   Implications for the 2030 Emissions

In the previous section the maximum CO_2 abatement potential of the Maritime Transport Sector has been derived for the year 2030. What are the implications of these results for the 2030 emissions of the sector?

The 2030 net emission level is determined by the level of the baseline emissions (gross emissions) and the scope to which emission abatement measures will be applied. The latter depends on the marginal costs of the abatement measures, on the scope to which inefficiencies in the shipping market will be corrected for in 2030, on the level of the bunker fuel price and the interest rate, and on the environmental regulation in place.

---

[2]   Note that these percentages are related to the total emissions of that part of the fleet that is considered here. If the whole fleet was taken into account, the total abatement potential would be 25-43%, the cost-effective abatement potential 21-41% with a central value of 30%.

The abatement potential derived is related to a certain emission level of the Maritime Transport Sector in 2030, the so-called baseline emissions. The baseline emissions that are used in this analysis Marginal CO_2 Abatement Costs for the Maritime Transport Sector in 2030 relative to frozen-technology scenario, Range of Estimates, US$ 700/tonne fuel, 9% Interest Rate constitute a frozen-technology baseline. This is a hypothetical baseline, in which each ship that is added to the fleet has the same fuel efficiency as the 2007 fleet average for a ship of this type and size and each ship that is scrapped also has the average fuel efficiency of such a ship. The frozen-technology emission baseline used in this analysis is derived from the latest GHG report of the IMO (Buhaug et al., 2009) and is thus related to the global and not to the European fleet[3]. Assuming that the structure of the global and the European fleet are the same in 2007 and develop the same until 2030, the baseline can also be applied to the European fleet (see graph below for a schematic illustration).

This report has used a frozen technology baseline based on the A1B1 scenario. Scenarios of the A1 family have higher economic growth than the other scenario families, resulting in higher trade growth, higher fleet growth and higher emissions growth than most other scenarios. Hence, this frozen-technology baseline has higher emissions in 2030 than frozen-technology baselines belonging to different scenario families. However, using a lower baseline, e.g. the B1 or B2 frozen-technology baseline, and combining that with the MACC would probably not result in decreasing emissions, as the amount of emissions that can be effectively abated depends on the size of the fleet and on the rate of new buildings, both of which are lower in the B1 and B2 scenarios.

If the fuel price rises to USD 700 per tonne of maritime fuel, the actors in the shipping sector are rational and all the markets in the shipping sector are perfect markets, economic theory predicts that all the measures whose marginal costs are negative will be implemented. When the CO_2 emissions of the sector are regulated in 2030, those with marginal costs lower than the CO_2 price will be applied. This means that independent of the emission price at least a reduction of about 23% of the 2030 emissions could be expected.

In reality, market failures are present and actors may not be perfectly rational. As will be discussed in section 4.2, not all the measures that are currently cost-effective are being implemented. Hence, assuming that all cost-effective measures would be implemented in 2030 would be unrealistic. The abatement potential thus not only depends on the CO_2 price but also on inefficiencies in the shipping market. To which extent these inefficiencies are corrected for in 2030 is difficult to predict and also depends on whether or not policies are implemented.

Note that not all the measures as illustrated in Figure 3 that have negative marginal costs are currently not applied due to inefficiencies in the shipping market. Some of these measures, as for example very large towing kites, are not commercially available yet.

The following figure illustrates the frozen-technology emission baseline and the possible net emissions in 2030 for two cases. First, the net emissions are given for the case that all the measures are being applied that have negative marginal costs, and second, the net emissions are given for the case that due

---

[3] Note that the emission projections presented in the section 2.7 do not constitute a frozen-technology baseline.

to inefficiencies in the shipping market not all the measures with negative marginal costs are taken. The inefficiencies are quantified by assuming that 10% of the net emissions would be reduced further in the absence of these inefficiencies.

Figure 19   Frozen-Technology Baseline and Possible Net Emissions in 2030
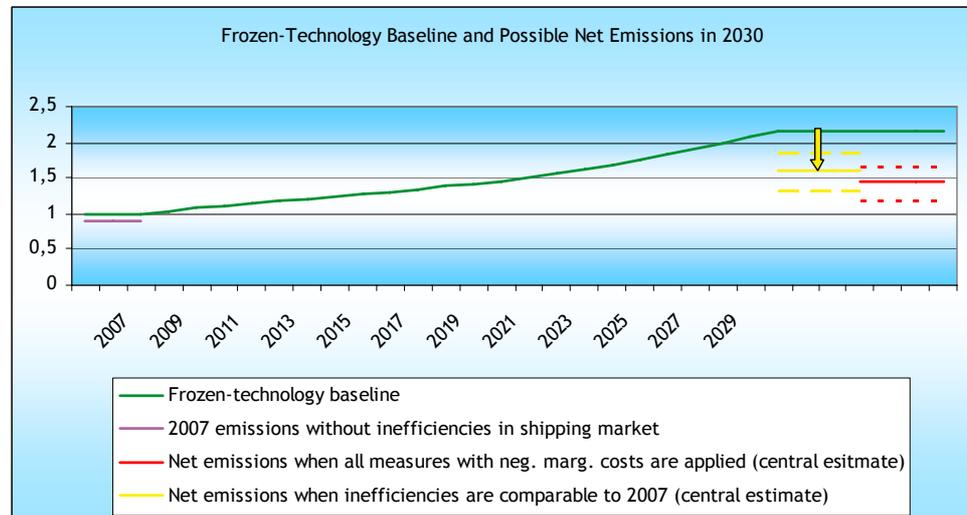
While a different frozen technology baseline would change the results quantitatively, it would not change the conclusion that emissions are forecasted to grow even if all cost-effective abatement measures would be implemented by 2030.

This illustrates that if the European fleet is comparable to the global fleet in 2007 and develops comparable to it, and if all the measures are applied that have negative marginal costs, the actual 2030 emissions of the European fleet will, due to the growth of the fleet be higher than the emissions in the base year 2007.

The sensitivity of the results as to bunker fuel price and interest rate will be discussed in the following section.

3.4   Sensitivity Analyses

Since the bunker fuel price is a crucial determinant of the marginal costs of the measures, we performed a sensitivity analysis with two alternative bunker fuel prices, namely for US$ 350/tonne and for US$ 1,050/tonne. For the central estimates the curves then run as shown in Figure 20.

Figure 20 clearly shows that the marginal abatement cost curve shifts upwards with a decreasing fuel price, leading to a lower share of emissions that can be abated by measures with negative marginal costs. More precise, for US$ 700/tonne and for US$ 1,050/tonne 33 and 36% of the emissions can cost-effectively be abated whereas for US$ 350/tonne only about 25% .

But not only the abatement potential of the measures with negative marginal costs does change with the fuel price; also the total abatement potential does. Here it changes from 38% for US$ 1,050/tonne fuel to 33% for US$ 350/tonne.

This is due to the fact that the total abatement potential varies with the order the measures are added to the curve and this order changes with the underlying fuel price. In other words, within each group, the optimal technology depends on the fuel price. This finding suggests that if fuel prices stay low for a long time and then increase suddenly, the shipping sector could be locked-in apparently inefficient technologies.

A second sensitivity analysis we carried out is with respect to the variation of the interest rate. For a fuel price of US$ 700/tonne fuel and the central estimate the following figures shows the marginal abatement cost curve for not only for an interest rate of 9% but also for 4 and 14%.

Figure 21   Marginal CO$_2$ Abatement Costs for the Maritime Transport Sector in 2030,
Alternative Interest Rates, US$ 700/tonne fuel, Central Estimate Only
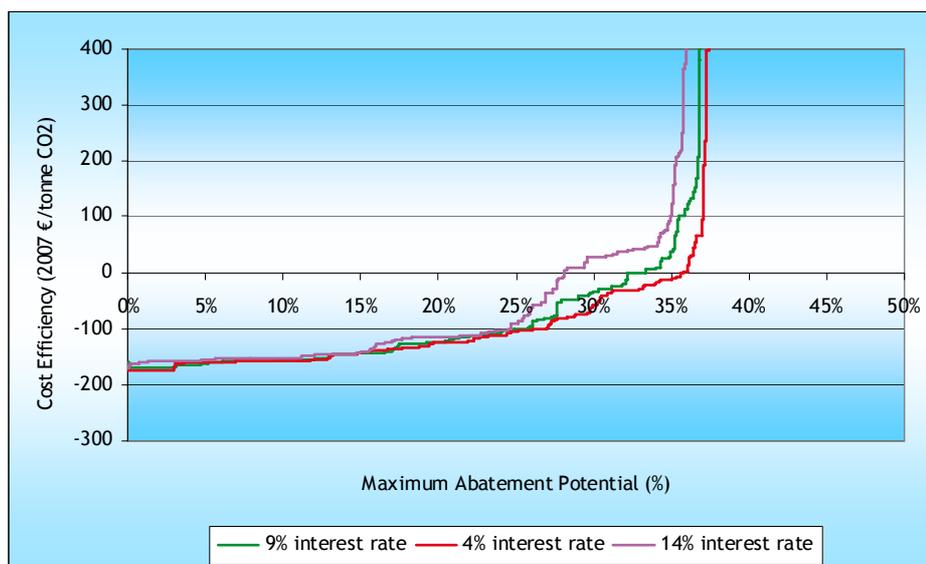
A higher interest rate leads to higher annual capital costs of the measures
which, in turn, leads to lower marginal costs of the measures. The annual
recurring costs of the measures are not affected by this variation. Therefore
the measures are affected differently, depending on the ratio of the
non-recurring and the recurring costs of the measures.

Figure 21 shows that the marginal costs of the measures here are not strongly
affected by the change of the interest rate. The abatement potential varies
not strongly. This holds mainly for the measures that are associated with the
reduction of the first 25% of the total emissions. For these measures it holds
that the fuel expenditure saving induced by the measures dominates their
marginal costs.

3.5   Comparison with other Marginal CO$_2$ Abatement Cost Curves

In the latest GHG report from the IMO (Buhaug et al., 2009) a MACC for the
Maritime Transport sector has been published and DNV too (DNV, 2009)
presented such a curve in 2009 (see Figure 22 and Figure 23).

DNV comes to the conclusion that in 2008 the total abatement potential is in
the order of 25% , with 20% stemming from options with negative marginal
costs. DNV regards this 20% as theoretical maximum and estimates that 15%
cost-effective reduction of the total emissions is realistic.

In the IMO study it is, on the grounds of the MACC, being concluded that in
2020 the total abatement potential lies in the range of 17-35% of the total
emissions, that 11-30% can be abated cost-effectively with a central estimated
value of about 20%.

It is difficult to compare these curves and the respective conclusions with each
other. This is for two reasons. First, the underlying bunker fuel price does
differ in the two studies. Whereas DNV assumes for 2008 a fuel price of
US$ 300/tonne for heavy fuel oil and US$ 500/tonne for marine diesel, in the

IMO study a uniform fuel price of US$ 500/tonne is being used for 2020. One might be tempted to argue that a downward shift of the 'DNV curve' should then be similar to the 'IMO curve', but this is not the case. This is due to the different time horizon; the structure of the fleet in 2020 will differ from that in 2008 since the different ship types will not grow equally in terms of numbers.

As to the MACC presented here, this curve is actually an expanded and more refined version of the curve presented in the IMO report. The curve is expanded in the sense that more measures have been taken into account[4]. The curve is more refined in two ways. On the one hand, it is less aggregated. While in the IMO report the marginal costs and the maximum abatement potential of a measure group was given as an average of the whole fleet, here these numbers were calculated for 53 different ship type/ship size classes. This disaggregation is reflected in an increased smoothness of the curve. On the other hand the interaction of the different measures that are applied to the same ship type/ship size class is modeled with a higher precision. In the IMO report it has been taken into account that the reduction potential of a measure is reduced when another measure has been applied before, however it had been neglected that this reduction also affects the marginal costs of this measure negatively. In addition, the time horizon and the underlying fuel price does also differ from that of the two other curves. Here the marginal abatement costs are determined for 2030 and the underlying bunker fuel price is US$ 700/tonne.

Figure 22   Marginal CO_2 Abatement Cost Curve as presented by DNV
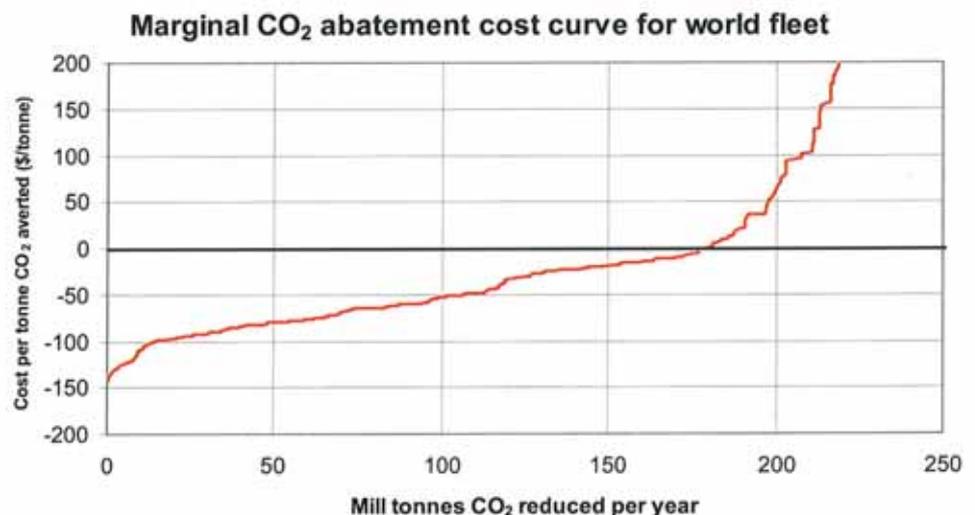
Source: DNV, 2009.

---

[4]   The extra measures are solar energy, waste heat recovery, a speed reduction of 20%, and Flettner rotors.
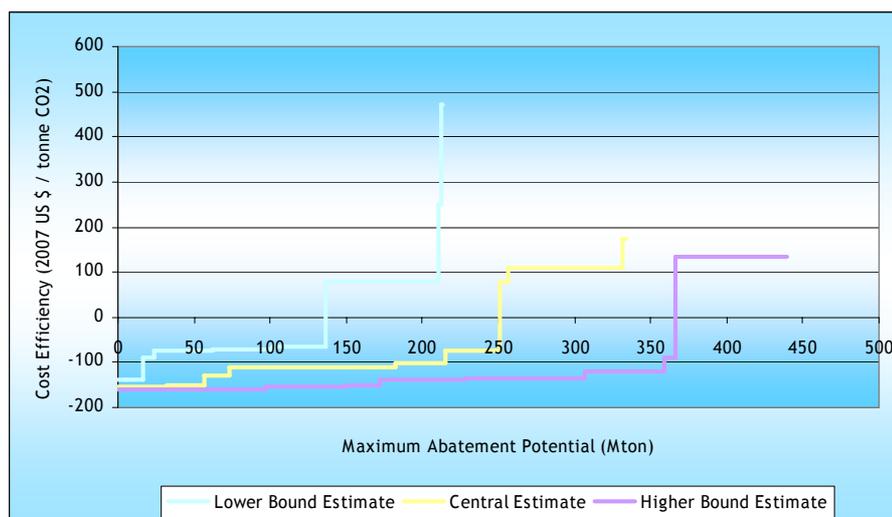
Source: Buhaug et al., 2009.

In a broader sense, many MACCs for 2030 show a considerable cost-effective emission reduction potential relative to frozen-technology emission baselines (see e.g. Ecofys et al., 2009). The main reasons are that in general, not all cost-effective options are implemented for reasons identified in section 4.2.1; and that a frozen-technology baseline does not take into account business-as-usual emission reductions.

3.6   Methodology

The marginal costs of an abatement measure are defined as its net costs for reducing a unit of CO$_2$ emissions in a certain year. The net costs are the costs due to the application of the measure less the fuel expenditure savings that are achieved by implementing the measure.

As to the costs of an abatement measure, we differentiate between non-recurring costs and annual recurring costs. The non-recurring costs are translated into annual costs by calculating an annuity. The number of years over which the investment is thereby spread depends on the expected lifetime of a measure. In Table 30, an overview is given of the expected lifetime and the related assumption that is being made with respect to the years over which the investment is spread.

Table 30   Number of years over which the non-recurring costs of the abatement measures are spread, depending on the expected life time of a measure

Expected Life Time of a Measure	Non-recurring costs are spread over … years
≤ 10 years	Actual expected life time
11–30 years	10 years
≥ 30 years	30 years

For a measure with an expected lifetime of 10 years or less, the spread is carried out over the actual expected lifetime. For those measures whose expected lifetime is between 10 and 30 years, the investment is spread over

10 years, thus implicitly assuming a reinvestment after 10 years. For those measures whose expected lifetime is 30 years or more, the investment is spread over 30 years.

The maximum abatement potential of a measure is the abatement level when all the vessels to which a measure can be applied actually make use of it. Since non-retrofit measures can only be applied to newly built ships, the number of new ships that enter the market between the year of market introduction of the measure and the year under consideration have to be determined in order to assess their abatement potential. For retrofit measures, we assume that they are only applied to those ships whose remaining lifetime allows the investment to be fully spread over the years underlying the annuity calculation. As an example: When a measure has an expected lifetime of five years, its non-recurring costs are spread over five years. In the year of introduction of a measure onto the market, the last four vintages of a ship class will then not apply that retrofit measure.

The marginal costs and the abatement potential are in the first instance derived for the individual measures, resulting in three estimates, a central estimate, as well as a lower and an higher bound estimate. Subsequently an estimation is being done for each of the twelve measure groups that will actually be depicted in the graph. We here assume that all the measures of one measure group are represented by the measure of this group with the lowest costs (=marginal costs*abatement potential).

Then per ship type a marginal abatement cost curve is set-up. Here it is taken into account that the abatement potential of a measure and thus also the marginal costs of a measure deteriorates when another measure has been applied before. Finally, the different curves are summed up horizontally, leading to the final aggregated marginal abatement cost curve.

3.7   Underlying Data

For the derivation of the marginal abatement cost curve three kind of data are required: data on the fleet and data on the abatement measures are needed and assumptions on the market conditions in 2030, i.e. on the fuel price and the interest rate, have to be made.

The structure of the fleet, in terms of the number of the different ship types and the fuel/CO_2 consumption over time, is derived from the latest IMO GHG study (Buhaug et al., 2009). Here data for 2007, 2020 and 2050 are given which we interpolated for fourteen ship types. Fishing vessels, vessels for offshore purposes, service vessels and yachts are not included in this MACC curve. Per ship type different size categories are being distinguished, leading ultimately to 53 ship categories.

It has to be pointed out here that the data is with respect to the global fleet. Since no comparable data is available for the fleet associated with Europe, we assumed that the structure of the global fleet is similar to the European one. For this reason the maximum abatement potential is given in relative terms only.

For the cost and reduction potential data of the abatement measures we relied on three different sources. First, DNV and MARINTEK provided us with data, second data was derived from the literature, and third, data from producers has been used.

In the analysis three different bunker fuel prices are used. US$ 700/metric tonne is the central estimate with US$ 350/tonne and US$ 1,050/tonne being the values used in the sensitivity analysis. The central estimate is based on the crude oil price prediction of the POLES model. According to the 2008 run of the model the crude oil price can be expected to be roughly US$ 90/bbl in 2030. To arrive at the corresponding bunker fuel price, different aspects have been considered. First, we used the relation that the price in Dollars of 1 metric tonne of heavy fuel oil is approximately five times the price in dollars of a barrel of crude (WTI)[5]. Second, we assumed that ships will have completed the transition to distillate fuels by 2030. Third, we assumed that, following IMO (2007), low sulphur fuel (marine distillate) costs 50% more than heavy fuel oil[6]. Taking these considerations together, the bunker fuel price prediction in dollar per metric tonne is roughly taken to be 7.5 times higher than the crude oil price prediction in dollar per barrel.

Calculating the marginal costs of the emission abatement measures, the non-recurring costs of the measures are annualized as describe above. To this end three alternative interest rates have been distinguished in the analysis: 4, 9, and 14%. The Dutch ministry VROM has published guidelines for the calculation of costs and benefits of environmental measures (VROM, 1998). Here it is being recommended to determine the private interest rate by adding annually differentiated mark-ups to the average return of the latest 10-year State bonds. The average return on 10-year State bonds in the United States and Europe fluctuated during the past five years between 3 and 5% (DNB, 2009). In order to illustrate the social perspective, we therefore decided to take an interest rate of 4% as the lowest value. For the private perspective we decided to use two alternative mark-ups, a five and ten percentage point markup.

3.8   Conclusions

We derived a marginal CO_2 abatement cost curve for the Maritime Transport Sector for 2030. For a bunker fuel price of US$ 700/tonne and an interest rate of 9% we come to the conclusion that the abatement measures we considered could maximally, when all the measures were taken, reduce total 2030 emissions by 27-47%. 23-45% of the total 2030 emission could be abated with measures that have negative marginal abatement costs, with 33% being the central estimate.

The 2030 net emission level is determined by the level of the baseline emissions (gross emissions) and the extent to which emission abatement measures will be applied. The latter depends on the marginal costs of the abatement measures, on the extent to which inefficiencies in the shipping market will remain important up to 2030, on the level of the bunker fuel price and the interest rate, and on the environmental regulation in place.

The abatement potential of the measures as mentioned above are related to a certain emission level of the Maritime Transport Sector in 2030, the so-called baseline emissions. The baseline emissions that are used in this analysis constitute a frozen-technology baseline. This is a hypothetical baseline,

---

[5]   This relation is derived from EIA data and holds well for most multiyear periods, except for the early nineties.

[6]   We used the lower range because the experts in our group thought that economies of scale of marine distillate production would lower the current spread in prices.

assuming that between the base year 2007 and 2030 there is no fuel-efficiency improvement within ship type and size categories[7].

Currently there are inefficiencies in the shipping market, as discussed in section 4.2, that prevent abatement measures with negative marginal costs to be applied. To which extent inefficiencies are corrected for in 2030 is difficult to predict, but section 4.2 argues that their importance will likely diminish, though not to zero. Note however that not all the measures as illustrated in Figure 2 that have negative marginal costs are currently not applied due to inefficiencies in the shipping market. Some of these measures are simply not commercially available yet.

What we can conclude is that for a bunker fuel price of US\$ 700/tonne and an interest rate for 9% and assuming that the European fleet is comparable to the global fleet in 2007 and develops comparable to it and if all the abatement measures are applied that have negative marginal costs, the 2030 net emissions of the European fleet will, due to the growth of the fleet be higher than the emissions in the base year 2007. Reducing total emissions of the shipping sector would thus call for regulation of CO_2 emissions.

---

[7]   Note that the emission projection that is presented in section 2.7 does not constitute a frozen-technology baseline.

4 Problem definition

4.1 Significant and rising CO_2 emissions from maritime transport

Shipping emits significant amounts of CO_2 (see chapter 2), which is a well-known greenhouse gas, a fraction of which can remain in the atmosphere for very long time periods (millienia) and cause significant warming of climate. In addition, ships emit a number of other pollutants including SO_2, particles and NO_x. These pollutants - not covered by current climate policies - have complex by more short-lived warming and cooling effects on the atmosphere. However, it has been shown that CO_2 emissions are still a significant problem and commit future generations to irreversible warming. The non-CO_2 pollutants are dealt with in a number of ad hoc reports in support of this work (Eyring and Lee, 2009a/b; Lee and Eyring, 2009; Lee et al., 2009) and the predominance of CO_2 discussed in the scientific literature (Eyring et al., 2009; Fuglestvedt et al., 2009). Thus, the focus of this work is on the long-term problem of greenhouse gas emissions of CO_2 from the shipping sector.

4.1.1 Estimates of current and historical emissions

Carbon dioxide (CO_2) emissions from total maritime transport accounted for approximately 3.3% of global anthropogenic emissions in 2007 (Buhaug et al., 2009).

This report estimates CO_2 emissions on voyages arriving at EU ports to be 208 Mt of CO_2 in 2006 (4.1% of the total EU-27 emissions) and emissions on voyages arriving at and departing from EU ports to amount to 311 Mt (6.2% of total emissions). See chapter 2 for more details[8].

CO_2 emissions have increased considerably since the mid-1980s, as shown in Figure 24.

---

[8]   Total GHG emissions in 2007, excluding LULUCF, amounted to 5,045 Mt CO_2 in 2007 (European Environmental Agency).

Figure 24   Historical development of CO_2 emissions from maritime transport

Emissions of total fossil fuel CO_2 and shipping CO_2

[Chart showing total fossil fuel CO_2 (Mt yr^{-1}) on left axis from 0 to 35000, and shipping CO_2 (Mt yr^{-1}) on right axis from 0 to 1750, plotted over years from 1940 to 2005. Red line: Total CO_2; Blue line: Shipping CO_2.]
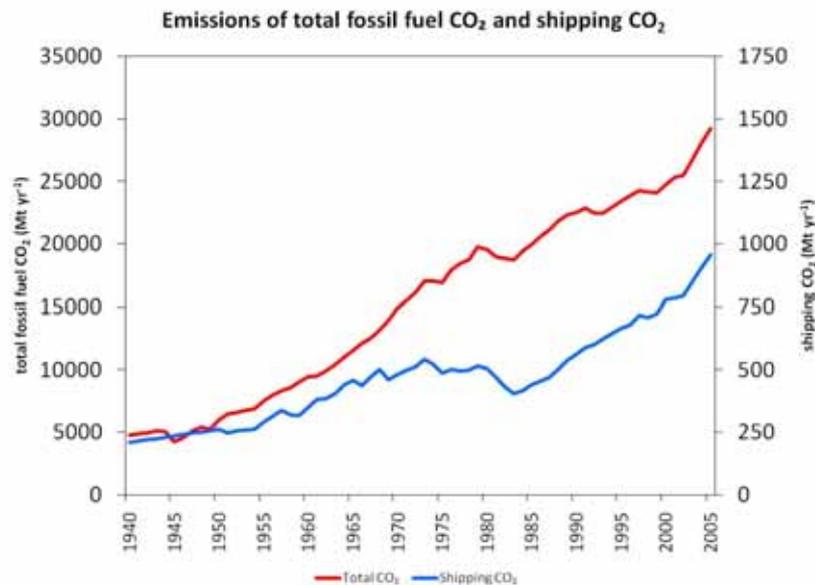
Source: Lee et al., 2009.

4.1.2   Scenarios for business-as-usual emission growth

It is beyond the scope of this project to develop future emissions scenarios for Europe. Instead, this report reviews existing projections and scenarios for both global and European shipping. Where possible, we assess the assumptions on trade and fleet efficiency assumptions separately. The reason to assess the assumptions separately is that trade growth gives an indication for emission growth in a frozen technology scenario. While such scenarios are unlikely to become reality they form the basis for our assessment of abatement costs and potentials in chapter 3 as we are trying to assess the potential for efficiency improvement over present day levels there. By assessing the rate of efficiency improvements, we are able to compare our bottom-up MACC with other estimates of efficiency increases.

This section first evaluates future scenarios of global shipping emissions and then turns to the smaller body of literature on emissions to and/or from the EU.

Future scenarios of global shipping emissions

This section analyses three future scenarios of global shipping emissions. They are from Buhaug et al. (2009), Eyring et al. (2005) and Behrens et al. (2007).

Buhaug et al. (2009) relates transport demand growth to Gross Domestic Product (GDP), demographic developments and developments in shipping such as the widening of the Panama Canal and the construction of new pipelines through an expert judgement approach. On average, transport work grows at a slower pace than GDP. They project transport demand for each of the IPCC SRES scenario families (which have different assumptions on GDP and population growth). The resulting transport demand is presented in Table 31.

Table 31   Transport demand increases in Buhaug et al. (2009) (2007=100)

Scenario	Average annual GDP growth 2000-2050	Projections of transport work in 2020	Average annual growth rate 2007-2020	Projections of transport work in 2050	Average annual growth rate 2020-2050	Average annual growth rate 2007-2050
A1B	3.9%	146	3.0%	402	3.4%	3.3%
A1FI	4.0%	146	3.0%	397	3.4%	3.3%
A1T	3.6%	146	3.0%	403	3.4%	3.3%
A2	2.4%	135	2.3%	302	2.7%	2.6%
B1	3.3%	133	2.2%	288	2.6%	2.5%
B2	2.7%	127	1.9%	247	2.2%	2.1%

Source: Buhaug et al. (2009).

As can be seen in Table 31, in the period up to 2020 transport work is projected to grow at an average annual rate of 1.9-3.0%. In the next period up to 2050, growth is projected to be higher.

Table 32 shows the projected emissions under different scenarios in the base case, i.e. using base assumptions on the rate of technical progress, slow steaming, uptake of low carbon fuels, et cetera. The base case estimate is that the efficiency per vessel improves by 12% in 2020 over 2007 values and by 39% in 2050. The average annual emissions growth rate is higher in the period 2020-2050 for all scenarios than in the period up to 2020. Efficiency, if defined as fuel use or CO_2 emissions per tonne-mile improve in the first period and remain constant or deteriorate somewhat in the second period. This measure of efficiency shows less improvement than the efficiency per vessel due to the fact that all scenarios assume an increase in the share of containerized cargo, which has higher emissions per tonne-mile than bulk cargo. It is not clear from Buhaug et al. (2009) why the fleet average emissions per tonne-mile grow in the period 2020-2050 in most scenarios.

Table 32   Projected total CO_2 emissions and implied efficiency improvements

Scenario	CO_2 emissions (Mt, 2007)	CO_2 emissions (Mt, 2020)	Average annual emissions growth rate 2007-2020	Implied efficiency improvement per tonne-mile 2007-2020	CO_2 emissions (Mt, 2050)	Average annual emissions growth rate 2020-2050	Implied efficiency improvement per tonne-mile 2007-2050
A1B		1,345	2.0%	12%	3,595	2.9%	15%
A1FI		1,293	1.6%	15%	3,644	2.9%	12%
A1T		1,294	1.7%	15%	3,634	2.9%	14%
A2	1,046	1,188	1.0%	16%	2,878	2.4%	9%
B1		1,167	0.8%	16%	2,735	2.3%	9%
B2		1,114	0.5%	16%	2,449	2.0%	5%

Source: Buhaug et al. (2009).

The results from Buhaug et al. (2009) clearly show that emissions are projected to increase in spite of significant improvements in vessel efficiency. There are many factors that account for this, and two are of prime importance: growing transport demand and a shift towards containerized freight.

The two other emissions scenarios are not based on transport work (mass of cargo times distance) but rather on total seaborne trade (mass of cargo). These approaches also allow to evaluate the efficiency improvements and the emission growth scenarios.

Eyring et al. (2005) developed scenarios for future ship traffic demands as well as specific technology scenarios. The ship traffic scenarios were determined by the assumed future growth of GDP which follows the IPCC SRES scenarios, whereas the technology scenarios are determined by the technological reduction factors for each of the pollutants and the fraction to what extent alternative energies and fuels will replace diesel engines in a future fleet. The study uses GDP and its correlation to the total seaborne trade, the number of ships, and the total installed engine power to estimate fuel consumption. Total seaborne trade is related to GDP using an extrapolated correlation. The number of vessels is related to total seaborne trade using historical correlation, and in the same way the engine power per ship is projected. No further improvements in fuel efficiency are assumed for 2020, but for 2050, an additional efficiency improvement of 5% is assumed and, in one set of scenarios it is assumed that 25% of the fuel consumed by a diesel-only fleet can be saved by applying future alternative propulsion plants in 2050, whereas the other scenario are business-as-usual scenario for a diesel-only fleet even in 2050.

The growth in CO_2 emissions and average annual growth rates in Eyring et al. (2005) are shown in Table 33. Emission growth rates range from 1.7 to 2.0% annually until 2020 and decline in the three following decades.

Table 33   Increase in maritime CO_2 emission rate from Eyring et al. (2005)

	2020		2050	
	CO_2 emissions (2001=100)	Average annual growth rate 2001-2020	CO_2 emissions (2001=100)	Average annual growth rate 2020-2050
2.3% GDP growth scenario	137	1.7%	136	-0.0%
2.8% GDP growth scenario	140	1.8%	152	0.3%
3.1% GDP growth scenario	142	1.9%	162	0.4%
3.6% GDP growth scenario	146	2.0%	185	0.8%

Source: Technology scenario 1, 2 and 3 from Eyring et al. (2005). Technology scenario 4 shows significantly higher emissions in 2050 but not in 2020.

Eide et al. (2007) models future fuel consumption and emissions for shipping in the years 2025, 2050 and 2100, using four IPCC SRES scenarios. Here, we focus on the first two years for which emissions have been projected. Eide et al. (2007) assume a number of measures to reduce CO_2 emissions, which are summarized in Table 34.

Table 34   Implemented measures to reduce maritime specific CO_2 emissions in Eide et al. (2007)

Measure	Implementation in 2025	Implementation in 2050
Biofuels	1-5%	5-10%
Gas powered engines	5%	5-10%
Fuel cells	1-2%	2-7%
Wind power	1-2%	3-7%
Fuel efficiency improvement	5%	10%

Source: Eide et al. (2007).

Assuming that gas-powered engines and fuel cells emit 25% less CO_2 per unit of power, it can be calculated from Table 34 that the efficiency improvements in 2025 range from 11-16% over the base year 2000. In 2050, efficiency improvements range from 21-34% over the base year.

Projected CO_2 emissions and average annual growth rates from Eide et al. (2007) are summarized in Table 35. Emissions are projected to increase at an average annual rate of 1.3 to 2.5% in the period 2000–2025, and at a higher rate of 1.6-2.7% in the next 25 years.

Table 35   Increase in maritime CO_2 emission rate from Eide et al. (2007)

	2025		2050	
	CO_2 emissions (2001=100)	Average annual growth rate 2000-2025	CO_2 emissions (2001=100)	Average annual growth rate 2025-2050
A1B	188	2.5%	363	2.7%
A2	140	1.3%	209	1.6%
B1	170	2.1%	267	1.8%
B2	162	2.0%	238	1.6%

Source: Eide et al. (2007).

Figure 25 compares the emissions scenarios of the three studies reviewed. It does so by calibrating the Eyring et al. (2005) and Behrens et al. (2007) future scenarios to the 2007 value from Buhaug et al. (2009) by adding a constant offset. It is clear that the Buhaug et al. (2009) future scenarios are the highest and the Eyring et al. (2005) are the lowest.

Figure 25   Comparison of emission scenarios from Buhaug et al. (2009), Eide et al. (2007) and
Eyring et al. (2005)
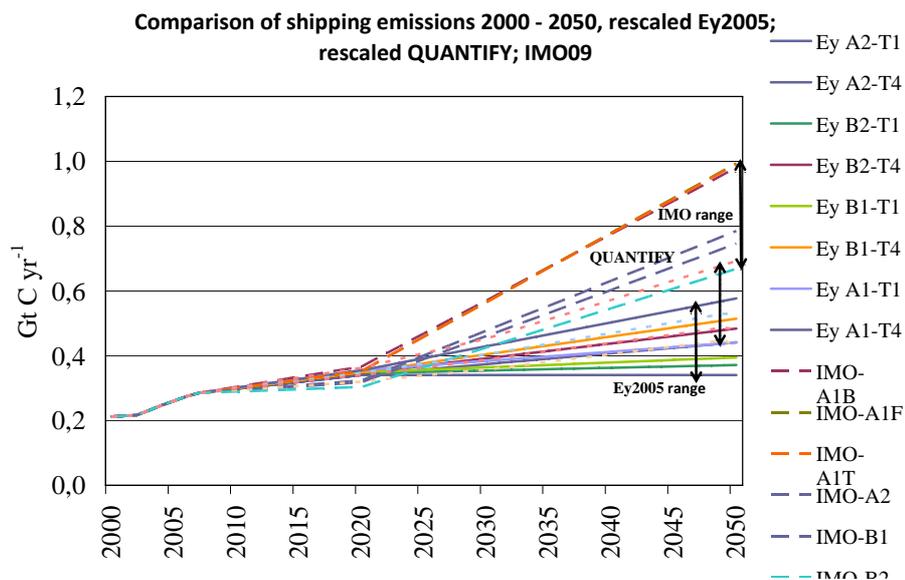
Source: Lee et al. (2009).

Future scenarios of European shipping emissions

There are two future scenarios of European shipping emissions: Chiffi et al. (2007) and POLES. Each will be analysed below.

The EX-TREMIS reference system projects emission growth rates for ships sailing to and from EU ports, based on ship miles. In the reference system, half of the distance of a voyage is allocated to the country where the ship departs from, and half to the country where she arrives. The reference system does not project transport work (tonne-miles), hence it is not possible to derive a frozen technology scenario.

For the period 2006-2020, the reference system assumes that growth rates of ship miles per country are the same as the actual growth rates of transport volume in the period 1997-2005 (Chiffi et al., 2007). For the decade starting in 2021, an approximately 1 percentage point lower growth rate has been assumed. The resulting growth in ship miles is shown in Table 36. The same table shows the increase in CO_2 emissions. The average annual growth rates in ship miles and emissions are almost equal. In other words, EX-TREMIS assumes that the emissions per ship mile will remain constant for the fleet visiting EU ports. Since the average size of ships increases in the EX-TREMIS reference system (although we have not been able to establish by how much), the emissions per tonne-mile would decrease by an certain amount. Hence, also in this case, despite efficiency improvements that we haven't been able to quantify in terms of emissions per tonne-mile, emissions are projected to increase.

Table 36   EX-TREMIS ship miles and emissions projections

	2005	2020	Average annual growth rate 2005-2020	2030	Average annual growth rate 2020-2030	Average annual growth rate 2005-2030
Ship miles (1,000 ship miles)	290,408	415,169	2.4%	484,183	1.5%	2.1%
CO_2 emissions (Mt CO_2)	76	108	2.4%	127	1.6%	2.1%

Source: Chiffi et al., 2007.

POLES projects both transport work and emissions on ships arriving in EU ports. The projection is presented in Table 37. The variability in average annual growth rates of both transport work and emissions is curious and we have not been able to find an explanation for it. In the period up to 2020, POLES projects an increase in transport efficiency of 12% over 2005 values. In the same period, emissions increase by 49%. After 2020, transport efficiency is projected to deteriorate for an unknown reason. Consequently, emissions rates increase more than transport work.

Table 37   POLES future scenario of transport work and maritime CO_2 emissions

	2005	2010	2015	2020	2025	2030
Transport work (10^{12} tonne-miles)	6.5	8.1	9.1	10.9	12.5	14.3
Average annual growth rate in period		4.6%	2.4%	3.7%	2.8%	2.7%
CO_2 emissions (Mt)	132	166	185	197	232	284
Average annual growth rate in period		4.6%	2.2%	1.3%	3.4%	4.1%
Transport efficiency (g CO_2/tonne-mile)	20.4	20.5	20.2	18.0	18.6	19.8
Implied transport efficiency increase relative to 2005		- 0.3%	0.8%	12.0%	9.1%	2.8%

Source: POLES.

In summary, although the figures differ, both future scenarios of European maritime transport work and emissions indicate that efficiency improvements will coincide with increases in annual emissions. This is due to the fact that efficiency increases are lower than growth rates of transport work.

4.1.3   Can efficiency gains outpace demand growth?

All the future scenarios of maritime transport emissions (with one possible exception in Eyring et al. (2005)) assume that in the next decades, emissions will rise despite sometimes significant increases in the fleet average efficiency and transport efficiency. This report estimates in chapter 3 that by 2030, 23-45% of the frozen-technology emissions forecast can cost-effectively be abated, with 33% being the central estimate.

If all these cost-effective measures would be implemented (an assumption that is further discussed in section 4.2.1), the transport efficiency in 2030 could improve by 23-45% of the 2007 base year value, under the assumption of a fuel price of US$ 700 per tonne of fuel. This is a higher efficiency improvement than most other estimates presented in this section, but note that this figure builds on the Buhaug et al. (2009) estimate of transport work and fleet

growth, which is the highest set of future scenarios reviewed here. A higher fleet growth translates into a higher efficiency improvement, because more modern and fuel-efficient ships come into the fleet. Still, the question arises whether efficiency gains can outpace demand growth. In other words, can demand growth be offset by efficiency gains in order to reduce emissions?

In order to answer this question, we note that improvements in efficiency of 23, 33 and 45% in seventeen years translate into average annual improvements of 1.5, 2.3 and 3.5% respectively. We can compare this with the future scenarios of the increase in transport work in Buhaug et al. (2009) and POLES. The lower and central estimate are less than all but one of the projected growth rates of transport work presented above. So only of the most optimistic estimates of costs and abatement potentials would be true or when the most pessimistic estimate of increase in transport demand would become a reality, would it be possible for efficiency gains to outpace demand growth, and emissions to decline.

The average annual increases in fleet efficiency assumed in this report are higher than the annual emission growth rates reported in Eyring et al. (2005). If these results are based on low or no efficiency improvements, it could be that if the Eyring et al. (2005) scenarios become a reality, emissions could decline if all cost-effective abatement measures would be implemented.

The average annual increases in fleet efficiency assumed in this report are also higher than the annual emission growth rates reported in Eide et al. (2005). However, these future scenarios assume an efficiency increase of about one third of the estimated cost-effective potential here. Taking this improvement into account, it is unlikely that the remaining cost-effective abatement options would be enough to offset emissions growth in these scenarios.

4.1.4 Conclusion

All future CO_2 scenarios reviewed here indicate that despite sometimes significant increases in fleet average efficiency and transport efficiency, emissions are predicted to increase because transport demand growth outpaces efficiency improvements. As said at the beginning of this section, it is beyond the scope of this project to develop emissions scenarios for Europe. It appears that in most scenarios reviewed here, implementing cost-effective abatement measures would not result in decreasing emissions.

4.2 Drivers of growth of maritime GHG emissions

The drivers of the increase in emissions are manifold. The following analytical framework captures the most important. It is presented in Figure 26 and described in more detail below.

Figure 26   Schematic overview of factors contributing to maritime CO_2 emissions
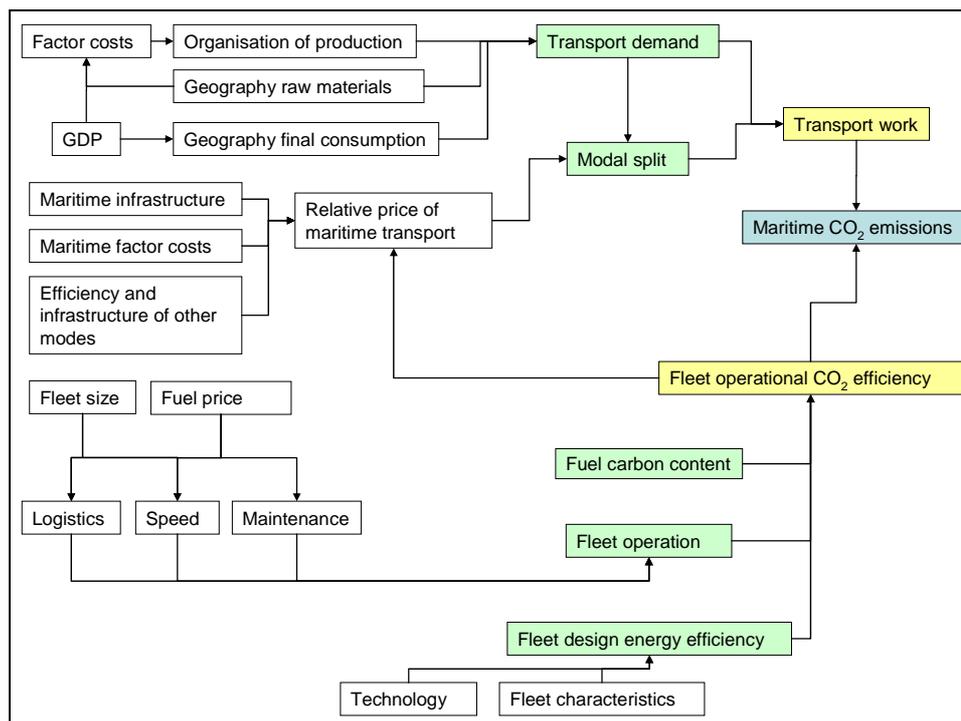
Source: CE Delft.

The volume of maritime CO_2 emissions depends by definition on fleet operational CO_2 efficiency (in terms of CO_2 emissions per tonne-mile) and the transport work (in tonne-miles).

Transport work of the maritime sector depends on two main factors: (overall) transport demand, and the modal split. In turn, transport demand is determined by the geography of raw materials, the geography of final consumption and the geographical organisation of production. Between each location, goods have to be transported. Production tends to be concentrated in areas with low factor costs. Both factor costs and geography of final consumption are dependent on GDP per capita in different parts of the world.

Modal split depends primarily on availability of alternative transport modes (not pictured) and relative price of maritime transport. Alternative transport modes are usually abundant in coastal shipping, but in ocean shipping, the only alternative mode is often air transport, which has very different qualities and costs than shipping and is therefore only marginally an alternative to shipping. Currently, the costs of CO_2 emissions are external to the price of maritime transport but to an extent internal to the price of other modes of transport. Moreover, these costs will be internalised in the price of air transport after the inclusion of aviation in the EU ETS. The relative price of maritime transport depends on the supply of ships (not pictured), fleet operational CO_2 efficiency, the maritime infrastructure, the factor costs of maritime transport and the prices of competing modes.

Turning to the operational CO_2 efficiency in the lower half of Figure 26, this depends on the carbon content of the fuel used, the operation of the fleet and on the fleet design energy efficiency. The fleet operation, or rather the operational aspects that have the largest impact on the CO_2 efficiency, are

logistics, maintenance, and speed. All three aspects are determined by the fuel price and the fleet size, and by the overall transport demand (a link not pictured here).

The fleet design energy efficiency depends on the type of ships in the fleet (e.g. type of engine, size, and hull form of a ship) and is obviously related to technical innovation triggered by advancements in research and development.

One should bear in mind that this is only a general scheme, not capturing all possible factors and interrelations. Alternative models are conceivable and may be equally valid. However we think that this framework allows us to identify a comprehensive list of policies to reduce maritime GHG emissions.

4.2.1 Drivers of operational fleet efficiency

Most analyses of marginal costs of emission reductions in maritime transport show that a significant cost-effective potential exists to improve the operational fleet efficiency. This would imply that barriers exist for the implementation of measures to improve the fuel efficiency of the fleet.

For the current fleet, we estimate that the total emissions can currently be reduced by 2-20% in a cost-effective way, with a central value of 10%. Measures that turn out to be among the most cost-effective are propeller maintenance, hull coating and maintenance, wind energy and retrofit hull measures such as transverse thruster openings (Buhaug et al., 2009). DNV (2009) estimates a cost-effective emission reduction potential of up to 15% in 2008. These values correspond with anecdotal evidence on gains that can be achieved by better fuel management (see e.g. DNV, 2006 and private communications of ship owners who have started trials with a ship energy efficiency management plan).

This section analyses possible reasons why ship owners and operators would not implement cost-effective measures to reduce emissions.

An often raised question in environmental economics is why cost-effective measures aren't implemented (see also Jaffe and Stavins, 1994; Jaffe et al., 2001). Answers can be sought in various directions. First, there may be market *barriers*, such as low priority for energy issues and high demanded risk premiums; second there may be market *failures* (OECD/IEA, 2007), such as split incentives and transaction costs. Third, cost-effective measures may be an artifact of the way cost-effectiveness is calculated, e.g. real costs components may be overlooked or underestimated (see e.g. CE, 2009). Too high oil prices may have been assumed, for example, or the internal discount rate in the MACC does not reflect the market rates for investors.

Chicago school neoclassical economists would assume that the existence of cost effective measures, which are not implemented, *always* indicates calculation artifacts, i.e. that the costs of market barriers and failures ought to be included in the calculation of cost effectiveness (see e.g. Nickell, 1978). In their view the market barriers and market failures do not exist as they define optimality in terms of revealed preferences. In this view firms are profit maximizing agents and if they decide not to invest in energy saving technologies, they do so because the benefits do not outweigh the costs. This view is debated, however. Others argue that the particular division of property rights that will influence the outcomes. If not firms, but governments would be responsible for investment schemes, interest rates would drop as governments can lend money at more favourable conditions on the capital

markets. Negative costs for energy saving measures than still reflect a suboptimal outcome, implying that social welfare could be enhanced if these measures were taken into account. The divergence between the social optimal outcome and the private outcome are called market failures (or market barriers).

We follow here this latter approach and identify the following market failures and market barriers.

1 Low priority

In general, firms must have regard to many other considerations - product quality, marketing, competitors' actions, other production inputs, occupational health and safety, to name a few - not just the benefits and costs of greater energy efficiency. If improving energy efficiency comes at the cost of forgoing other more cost-effective opportunities (because of capital or labour constraints or because the projects are mutually exclusive alternatives), it would be rational for the firm to give energy efficiency a low priority (Productivity Commission, 2005). This is particularly likely to happen in sectors where energy costs are only a small fraction of total production costs (OECD/IEA, 2007).

Shipping is a sector where fuel costs are a significant share of total costs, even when fuel prices were much lower than they are today. Still, in shipping, there is anecdotal evidence that during the 1980s and 1990s, many shipping companies have been giving a low priority to fuel-efficiency improvements, especially when fuel prices were low or stable in real terms and the general situation in the sector was not good. The available evidence seems to suggest that fuel-efficiency improvements of the fleet have been large in the 1940s and 1950s but have become much smaller in the 1980s and 1990s. Figure 27 suggests that the overall best efficiency of the fleet has improved for most ship categories until the 1980s but has remained more or less constant since then. Note, however, that the overall best efficiency is a rather crude measure as it which combines scale, speed and technology effects. In some cases, a decreasing efficiency may be due to the fact that the largest ship categories were not built anymore.

Figure 27   Indicative development in maximum ship design transport efficiency
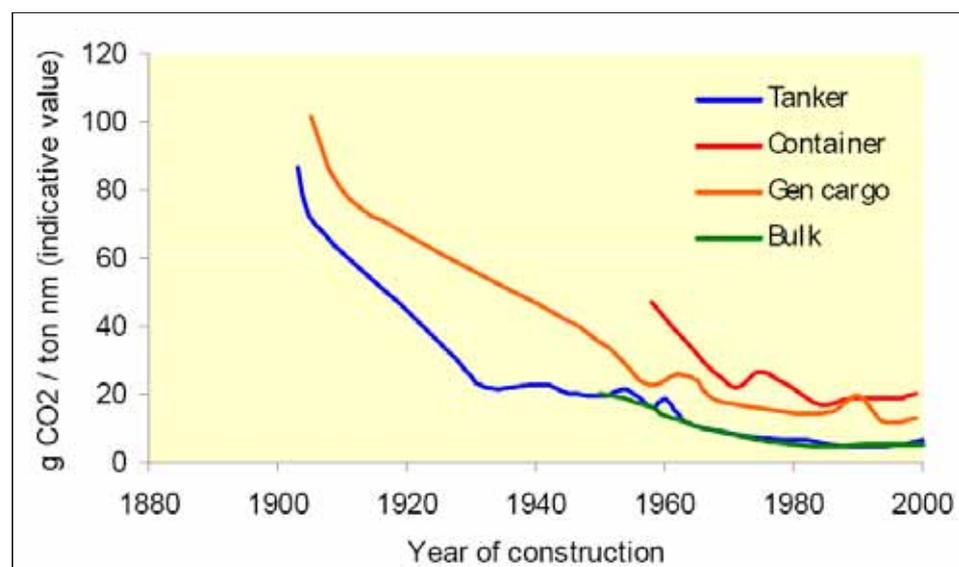
Source: Buhaug et al. (2009).

Over the last years, as fuel prices have risen dramatically, there have been several reports on shipping companies starting to look into their fuel efficiency and being surprised to find out the savings they could get from just optimizing operations[9].

This is in line with the theory of induced innovation as proposed by John Hicks (1932), which states that 'a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind - directed to economizing the use of a factor which has become relatively expensive'. In other words, in a time when labour costs are rising innovation is geared towards increasing labour efficiency while in a time when fuel costs are rising it is directed at increasing fuel efficiency. As Figure 28 shows, actual crude oil prices (which correlate well with bunker fuel prices) have risen dramatically over the last decade. Since about 2004, forecasts of crude oil prices have also started to increase. Hence, it can be expected that the shipping sector has been paying more attention to fuel efficiency.

Figure 28   Fuel prices and fuel price forecasts have increased dramatically
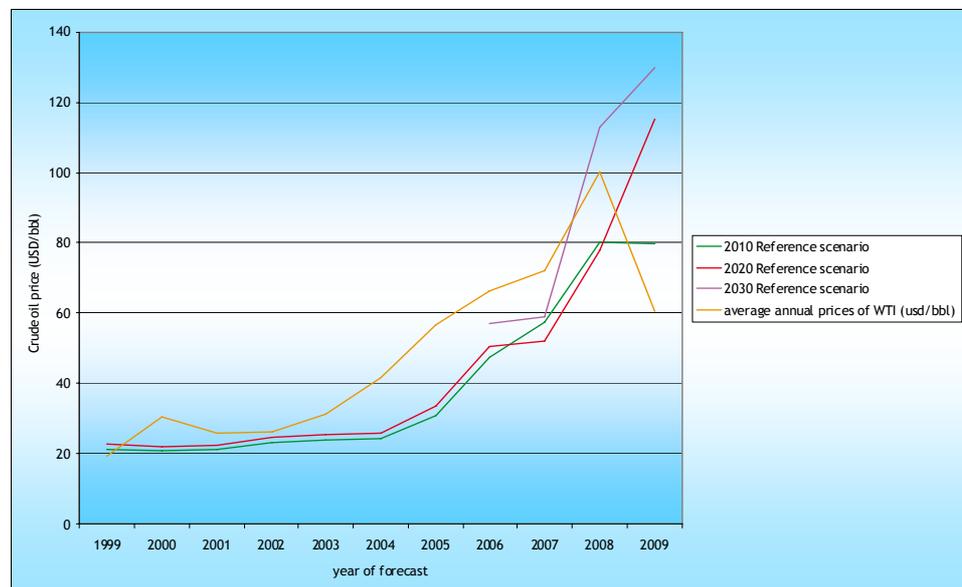
Source: EIA.

Indeed, there is evidence, albeit at this point anecdotal, that as fuel prices have risen and also forecasts of fuel prices have increased, ship owners and operators have increasingly paid attention to fuel efficiency. Many shipping companies have reported that they were implementing measures to reduce fuel use and emissions over the past years. To name a few examples, several container lines have implemented slow steaming schedules in their liner service, driven by a combination of high fuel prices and low freight rates (Notteboom et al., 2009; Sustainable Shipping 2009a; Sustainable Shipping 2009b). Moreover, many shipping companies have recently installed fuel saving technologies such as waste heat recovery systems and kites (Wärtsilä, 2006, Shiptechnology.com, s.a). And manufacturers of fuel saving equipment report a growing interest in their products (Sustainable Shipping, 2008). Press reports

---

[9]   DNV has reported that they can reduce fuel costs by 10% for many shipping companies by implementing adequate management standards and training of crew. DNV Press Statement 6 June 2006, http://www.dnv.com/press/Reducedemissionsandimprovedbottomline.asp.

have indicated that ship owners are demanding more fuel efficient ships from yards as they defer new buildings delivery dates (Porter et al., 2009).

While all this evidence is anecdotal, it suggests that shipping companies are paying increasing attention to both technical and operational measures to reduce fuel use and emissions, driven by increasing fuel prices.

2 Depreciation period or risk premium

Firms face additional risks of adopting new technologies that are not captured by the social discount rate because their assets are less diversified than those of society as a whole (Sutherland, 1991; Rivers and Jaccard, 2005). DeCanio (1993) showed that firms typically establish internal hurdle rates for energy efficiency investments that are higher than the cost of capital to the firm (OECD/IEA, 2007). Furthermore, there is a great deal of uncertainty around the potential outcomes of adopting new technologies. Further information about these prospects is typically asymmetric, in that developers of technologies have better information about these prospects than other investors who may wish to invest through adoption. Early investors may be sceptical about the prospects of a technology and demand a premium on return in order to cover the risks of the investment (MMA, 2008). Apart from this uncertainty regarding the *reliability* of new technologies, there is uncertainty regarding economic trends (e.g. fuel prices) and governmental policy, and uncertainty regarding sector and company trends (Sorrell et al., 2000). All of these might result in risk premiums that are not socially optimal.

A risk premium on investments is often taken into account by demanding that projects have a high internal rate of return. As is shown in chapter 3, Figure 21, the marginal abatement cost curve for shipping changes little when interest rates are increased. Hence, we conclude that the risk premium for operational measures, retrofits and maritime equipment in new built ships cannot explain to a large extent the existence of cost-effective options to reduce emissions.

The situation may be different when new buildings are considered. Ships are the most important asset of a shipping company. If depreciation is faster than expected, the solvency of the company may be threatened. So in some cases a ship owner commissioning a new ship would have to compare the risk of having a ship with an innovative design that may depreciate faster than expected with the risk of having a ship with a conventional design but higher operational costs. In such an assessment, the most fuel efficient ship may not always come out best.

3 Split incentives

Split incentives arise when the person purchasing an energy-consuming product is different from the person who benefits from it and the incentives facing the purchaser differ from those of users. Managers may choose not to adopt a potentially cost-effective energy efficiency measure because they perceive it to be risky and the personal consequences of failure are more costly than the pay-off from success, or because the performance is assessed on a shorter time frame that the energy efficiency measure will take to pay off (Productivity Commission, 2005).

The shipping industry has many ways of dealing with fuel costs. In most contracts, the fuel costs are passed on to the consumer:
- In time charter and bareboat charter contracts, charterers pay for the fuel, while the ship owner is in the position to make technical improvements to the ship (Stopford, 2009). Moreover, under a time charter agreement, the ship owner continues to manage and crew the ship, so in that case operational measures to improve the fuel efficiency are not under the control of the party who pays for the fuel.
- In liner shipping, ship operators levy bunker fuel surcharges called Bunker Adjustment Factors (BAF) that reflects the bunker fuel price increases over a certain level (Cariou and Wolff, 2006). Prior to the abolishment of liner conferences, these were set by a conference. Currently, they are set by shipping lines.
- In tramp contracts, the term bunker surcharge is not commonly used, but that is mainly due to the fact that the freight rates are set for one roundtrip or one leg. The freight rate will usually reflect the bunker price among other factors.
- Cruise lines and RoPax ferries sometimes also levy fuel surcharges.

Hence, in a major share of the market, bunker costs are passed on. We estimate that this may be the case for 70-90% of the bunker fuel consumed. This is hardly surprising for if costs couldn't be passed on, shipping would be unprofitable and there would be no shipping.

The fact that bunker costs are passed on is not proof of a split incentive. A split incentive only occurs when the fuel costs are paid by a party that has no control over them, while the party that can limit fuel use does not reap the benefits of doing so. Hence the question is, can the ship owner, who can invest in technical measures to improve efficiency, or the ship operator, who can take operational measures, reap the benefits of lower fuel costs?

In time charter and bareboat charter contracts, when agreeing on a charter, the ship owner usually guarantees a speed and fuel consumption of the vessel, both in good weather conditions (see e.g. BIMCO, 2009; Stopford, 2009). So if charter markets would be efficient, ships consuming more fuel would have lower time charter rates.

When considering the efficiency of the charter market, it is important to note that fuel consumption is only one of many factors that impact a ship's charter rate and certainly not the most important one (see box below). Still, if two identical ships are available with only a difference in fuel efficiency, the most efficient ship could negotiate a higher charter rate. Conversely, the least fuel efficient ship would have to compensate this with other factors in order to get chartered.

However, even when markets appear to be efficient, there could be institutional reasons why incentives are not always well aligned with responsibilities. There are indications that this is the case in the charter market. Charter parties often contain clauses that the Master should prosecute voyages with reasonable, due or utmost despatch. This means that the vessel should proceed as quickly as possible towards its destination. As long as there are no overriding reasons of safety, slow steaming could constitute a breach of charter party and therefore the ship owner could be liable (BIMCO, 2008). Such clauses prevent optimising speed in order to save fuel and emissions.

There may also be other reasons why charter parties cause ship operators to proceed at a high speed. These have to do with rules on port access. In a congested port, the earlier a ship arrives, the earlier is gets access to the port, the sooner it can take on a new assignment. By changing port access rules and charter party clauses, incentives can be changed resulting in lower emissions (Røsœg, 2008). It appears that BIMCO, one of the suppliers of standard charter parties, is reviewing their charter parties as to include the possibility of slow steaming and alligning incentives (BIMCO, 2009).

In conclusion, while charter markets appear to be working efficiently, there seem to be institutions that ensure that in some charter markets, incentives are not always well alligned. This could lead to split incentives. The size of this problem is hard to assess, as it depends on the type of charter party and on factors such as whether or not a ship is destined for a congested port or not. It merits further study.

How a charter agreement is settled

When a ship is going to be fixed for new employment, irrespective of whether this is a single voyage fixture, a time charter trip (the charterer hires the ship for one specific voyage instead of fixing the cargo on a voyage basis), a short time charter period (2-4 months, 3-5 months, or similar), or a true period time charter (typically 12 months, or more), both the charterer and the ship owner will look to 'last done'. I.e., the latest fixture that is similar to the potential fixture in question. In addition, as fixtures are normally concluded some time in advance of the commencement of the voyage in question, both parties make an allowance for expectations for market trends (going up, or going down). We would consider any time charter less than five months duration to be a spot market employment. The period time charter market is less volatile and in most cases on average lower than the average spot earnings. In the following, the term 'charter rate' is used and covers both time charter hire and freight. Time charter contracts are mostly used:

1 In industrial projects where the charterer would like to have control over the transportation costs by hiring in a ship on a long term basis. This is to secure transportation and also to budget some of the future transportation cost i.e. estimate future project earnings.

2 If an operator/owner, etc. believes the future spot market will be better (over time) than the current time charter market, he would charter in a vessel to try and profit by the difference between the spot market and the time charter market.

In addition to the 'last done' approach, there are several factors that contribute to the rate, or freight level agreed. Some of them are listed below:
- Spot market.
- FFA's (Forward Freight Agreement).
- Speed/Consumption.
- Cargo capacity.
- Cubic.
- Deadweight.
- Yard of construction, Design (e.g., draught, beam, loa).
- Cargo exclusions.
- Trading exclusions.
- Certification.
- Flag.
- Operator.
- Age.

These factors play a more or less important role when the charter rate/freight is negotiated. One has to remember that everything is open for negotiation. Considering charter rate and what level it should be, you normally look at 'last done' contract, the FFA's and the spot market development and what you believe the future of the spot market will be. Then you would have a good idea of the levels. The next step is to find out owners who are willing to

---

put their vessels on charter contracts and sort out the candidates (ships). Then you have to consider the different features of the ships, the speed/consumption, cubic capacity, dwt capacity, design, certificates and flag. You want the vessel to be able to carry as much cargo as possible to as many ports as possible. Also what certificates the vessels has and what flag it carries is important, as certificates and flag might restrict a vessel to call certain ports and terminals. It is also important to look at who is going to be your counterpart for the contract, are there bad experience with the owner/operator, rumours, or maybe you have great experience with some of them earlier and you can therefore rely more on them delivering their services as agreed. Problems can always occur, but how they are solved could potentially save you a lot of time, energy and money. Speed/consumption for a vessel is of course also considered, but if a vessels burns 2 tonne extra bunkers per day, this will equal to around US$ 1,000 per day and taking the other factors into consideration this could possibly not matter at all for a company wanting to hire a vessels on time charter.

Age is normally not an important factor, as it does not matter if the vessel is new or 12-15 years old as long as the vessel satisfies classification and flag state rules. However if the vessels is very old 20-30 years the age might be more relevant.

To exemplify a few of the above listed items:
- Cubic capacity and deadweight capacity is of vital importance and a function of the commodities you transport. In case you will carry light grains you will pay a premium for a ship with good cubic capacity as you can carry more cargo. Likewise, if you carry iron ore you do not care about the cubic capacity, but the deadweight capacity is of vital importance. This impacts the charter rate level.

- Some commodities are very unattractive. For example salt (sodium chloride), sulphur, and DRI (Direct Reduced Iron). The two former commodities are unattractive because in contact with water they become corrosive. After washing down the cargo holds (which is almost always necessary before receiving a new cargo) you will always have residues and water in the bilges and the wear and tear (corrosion) in these parts of the ship could become very costly. DRI is prone to self combust and cause great damage to the ship if so happens.

  If a ship owner/operator allows the charterer to carry these cargoes it is worth a lot to the charterer.

- Some parts of the world are undesirable to call. Some parts are undesirable due to political reasons; some due to biological hazards; and some due to climatic reasons.

  It is usually not desirable to call Israel as one risks that the ship could be barred from calling Arabian countries thereafter resulting in reduced trading flexibility of the ship. Calling Iraqi ports today is not desired due to the turmoil in this country.

  It is not desirable to call Russian Pacific ports due to the 'Gypsy Moth' – doing so could bar the ship calling ports in the USA or Canada thereafter.

  During parts of the year certain areas fall outside IWL ('Institute Warranty Limits'). This is an insurance term, and standard Hull and Machinery Insurance is not valid if the ship trades outside these limits. However, ship owners could agree to break IWL. If so, this is yet another advantage for the charterer.

- Past experience. Industrial charterer tends to do 'repeat business'. This means that if an owner, with whom the charter has done business with for years, they will usually do their utmost to complete a fixture with this owner. As mentioned above, this could be based on knowing that they will have a smooth operation; the owner will demonstrate flexibility; and, finally, there is a great degree of trust between the parties.

If we go back to the question of fuel consumption, how much does this matter? Two different owners own similar ships but one ship consumes five tonnes more bunkers per day, the obvious difference in costs is about 2,500 US$/Day. Now, if the owners of the poorest fuel consumer is willing to provide great flexibility in cargo exclusions this could result in the charterer being enabled to do a better combination of trades resulting in earnings that could increase many times more than the increased costs. In simple terms, dry cargo trades are typically 'one-legged' in the sense that each round voyage contains one laden leg and one ballast leg. Our research shows that the ballast share of the entire bulk carrier fleet is about 38% - but with variations between 23 and 50% depending on size. If one could reduce from 50 ballast to 23% ballast share this obviously means greatly increased earnings.

In the other case, if cargo flexibility does not have any significance, the vessel with the lowest fuel consumption will be preferred provided everything else is equal.

In conclusion, fuel consumption is only one of many factors that impact a ship's charter rate and certainly not the most important one. Still, if two identical ships are available with only a difference in fuel efficiency, the most efficient ship could theoretically negotiate a higher charter rate. Conversely, the least fuel efficient ship would have to compensate this with other factors in order to get chartered. Hence, we can conclude that the market is sufficiently transparent and that there seems to be no need for a policy intervention.

Source: Fearnley Consultants.

4   Transaction costs

Firms do not have perfect information about all different technologies available in the market, and gathering and synthesizing that information is a costly endeavour (Sutherland, 1991). Transactions costs include the costs of obtaining and interpreting information as well as any costs associated with implementing energy efficiency opportunities including the costs of negotiating, implementing and enforcing contracts. Implementing energy efficiency solutions also include such 'hidden' transactions costs as time taken to arrange and supervise work, disruptions while work is occurring and so on. Such costs are easily ignored in analyses of the benefits from energy efficiency improvements and can lead to an exaggeration of the expected net benefits from implementing energy efficiency opportunities (MMA, 2005). The costs of obtaining information are not just direct financial costs - they may include the opportunity costs of devoting time and effort that could be spent elsewhere. For firms it might mean less attention is given to other business activities and obligations. (Productivity Commission, 2005). Transaction costs can also include the costs of negotiating, drawing up, monitoring and enforcing contracts.

Transaction costs and other unobserved cost items may render apparently cost-effective measures costly. Especially smaller ship owners and operators may experience high transaction costs as they cannot spread the costs of e.g. gathering information over a large number of ships.

5   Fuel price

Uncertainty over future fuel prices may add an additional market failure by installing higher risk premiums. For investors, fuel prices can be related to other risks of operations. In that case they would add a risk premium to diversify this risk in their portfolio. Fuel prices have fluctuated strongly over the last years. While for many years the fuel price has been estimated at an average of 20 US$ per barrel, prices peaked above 140 US$ in 2008, dropped to 30 again, and returned to about 70 US$ per barrel at the time of this writing. It goes without saying that the assumed fuel price has a decisive influence of the determination of cost-effectiveness of fuel saving measures. In other

words, if a measure is deemed cost effective at an expected fuel price of 100 US$ per barrel, it may not be so at a price of 50 US$, as is shown in chapter 3.

Ships have an economic life of 25 years or more. Hence, design requirements probably take fuel price forecasts into account rather than actual fuel prices at the time of the shipbuilding. Likewise, decisions to retrofit fuel-efficiency improvement technology will also be based on forecasted fuel prices. In the past years, forecasted oil prices from reputable organizations such as EIA and IEA have increased considerably (see Figure 28). Due to the long lead time from commissioning a ship to its delivery from the yard, ships that are currently being delivered may have been designed with crude oil prices of US$ 20–30 in mind, rather than the current 80 US$ and the forecasted 110-130 US$ for 2020. If these forecasts turn into reality, ships built during the last decades and based on these projections will turn out to have suboptimal fuel efficiencies.

6   Time lag

Some measures to reduce emissions require retrofits that can only be installed by temporarily suspending production. These measures are very costly to implement except at times when production is halted for other reasons, such as major maintenance of installations. There may therefore be a lag between the time when a measure becomes available and its actual implementation.

Retrofits to existing ships such as the installation of wind power, stern flaps, waste heat recovery systems et cetera can only be done cost-effectively when a ship undergoes a major overhaul. This causes a time-lag of several years in the implementation of cost-effective measures.

Conclusions

Negative costs can be indicative of a market outcome that is not socially optimal. Economic and environmental policies can be directed to internalize these costs through an alternative institutional setting. In addition can negative costs occur because of mistakes in calculation due to uncertain variables such as fuel prices or internal rates of return.

It appears that the shipping sector has given increasing priority to fuel-efficiency and will likely continue to do so if fuel prices stay at their current levels or increase further. The risk premium for operational and technical measures is not of major importance, but there may be a considerable risk premium in new ship designs. And although considerable uncertainties remain in fuel price forecasts, it is likely that ship owners will currently use higher forecasts in evaluating measures than a few years ago.

For the coming years, the most important factors that could contribute to a continuation of the apparently cost-effective measures to improve the fuel efficiency may be split incentives, transaction costs and time lag.

In conclusion, some factors that have contributed to the current existence of cost-effective options to reduce emissions will become less important over the next years. This would even be the case in the absence of policies, as long as fuel prices stay at a relatively high level or keep on increasing. Other factors will most probably remain important. It is not possible to assess quantitatively what impact this would have on the existence of cost-effective options, but we believe that it is unlikely that the abatement potential of cost-effective abatement options will increase relative to emissions. On the contrary, it is likely that this share will decrease, though not to zero.

4.3   Non-CO$_2$ emissions of maritime transport

Maritime transport is also responsible for a number of non-CO$_2$ emissions, some of which have multiple effects, e.g. on climate, air quality, regional pollution and acidification/eutrophication as listed in Table 38 below.

Table 38   Non-CO$_2$ Emissions (combustion-related and leakage/indirect) from maritime transport and indication of interaction with different environmental effects

Emission	Interactions with					
	Air quality/regional photochemical oxidants	Acidification	Eutrophication	Climate	Global source[1] (Mtonnes)	Other sources[2] (Mtonnes)
NO$_x$	✓	✓	✓	✓	7.6 (as N)	33.4 (as N)
SO$_2$	✓	✓		✓	7.5 (as S)	~ 70 (as S)
BC	✓			✓	0.06	3-5
CH$_4$				✓	0.1	582
HCs	✓			✓	0.8	140 (as C)
CO	✓			✓	2.5	~ 300-400
HCFC-22[3]				✓	0.003	0.231
HFC[3]				✓	0.0004	0.124
R717 (NH$_3$)[3]		✓	✓		0.000007	45.5 (as N)
CFCs[3]				✓	0.000015	0.174
N$_2$O				✓	0.03	~ 6.7 (as N)

Notes:

(1) From total shipping, 2007, from Buhaug et al. (2009), BC estimate from Lee and Eyring (2009), refrigerants from UNEP (2007) cited by Buhaug et al. (2009).

(2) Anthropogenic emissions from a variety of literature sources, but most referring to 2000/2002 emission rates, largely from IPCC Fourth Assessment Report (Denman et al., 2007) of fossil fuels (excepting CH$_4$ and N$_2$O, which have more diverse sources) and IPCC special report (Campbell et al., 2005).

(3) Indirect emission from leakage; other sources are combustion (HCs may also be lost on tank venting).

The non-CO$_2$ emissions listed in Table 38 indicate that total maritime transport makes significant contributions to the NO$_x$ and SO$_2$ budgets. The importance of shipping NO$_x$ and SO$_2$ emissions on air quality, acidification, eutrophication, regional photochemical oxidant production and climate are dealt with in more detail by supporting documentation (see ad hoc papers). Whilst the BC emissions are a relatively small present component of total fossil fuel emissions, the ad-hoc paper point out that BC affects climate in a number of ways, and future development in the Arctic may make particularly significant impacts through deposition on snow.

Policies that reduce fuel usage and therefore CO$_2$, generally will reduce other non-CO$_2$ combustion emissions where they have simple linear or non-linear relationships. Emissions of NO$_x$ have a more complex non-linear relationship with fuel usage and in principle, as CO$_2$ emissions are reduced, NO$_x$ emissions can increase without further efforts on combustion and combustor design. However, NO$_x$ emissions from shipping are subject to IMO regulations and are limited by this means.

4.4 Discussion

Section 4.1.1 showed that CO_2 emissions from maritime transport are significant, both on a global scale and for the EU. Section 4.1.2 concluded that in all scenarios of future maritime emissions, emissions are forecasted to rise despite gains in efficiency. Even if efficiency gains would be higher than expected, but more along the lines presented in this report, it is likely that emissions will continue to increase.

Section 4.2 identifies drivers of maritime transport emissions. One important driver is the fleet operational efficiency. It appears that there is a scope to cost-effectively reduce emissions, but not all cost-effective measures seem currently to be implemented. Reasons are the market barriers and market failures identified in section 4.2.1. Of these reasons, three are argued to remain relevant in the coming decades: split incentives, transaction costs and time lag.

Even though the removal of these market failures and barriers would not result in a reduction of emissions below current levels or in a trend of decreasing emissions, the continuing existence of cost-effective abatement options diminishes the overall cost-effectiveness of policies aimed at reducing emissions.

4.5 Conclusion

The main problem is significant and rising maritime GHG emissions of CO_2.

While it is beyond the scope of this report to develop emission scenarios for Europe, we consider it very likely that emissions that emissions will continue to increase, even when all cost-effective abatement measures are implemented. In addition, there are a number of market barriers and market failures that cause apparently cost-effective measures not to be implemented.

Even in the likely case that the implementation of these cost-effective measures would not result in a decrease in emissions, implementing them would reduce the cost of reducing emissions.

Hence, the secondary problem is the apparent market barriers and imperfections that exist in the uptake of fuel-efficiency improving measures. Addressing this problem would improve the cost-effectiveness of any policy aimed at limiting or reducing maritime GHG emissions.

4.6 Policy objectives

The policy objectives are linked to the problems identified in section 4.3.

The first policy objective is to limit or reduce maritime GHG emissions.

The secondary policy objective is to remove barriers and market failures that prevent measures to improve fuel efficiency from being implemented, so that the first objective can be met in the most cost-effective way.

5 Policy instrument selection

5.1 Introduction

A large number of different policy instruments can be conceived to affect maritime GHG emissions. This chapter identifies a large number of policies based on an analytical framework of GHG emissions. It proposes a high-level design for each and evaluates the options broadly. The purpose of this broad evaluation is to select a limited number of policy instruments for further design and impact assessment. The selected policy instruments are designed in detail in chapters 6 through 10, their impacts are assessed in chapter 12 and chapter 13.

This chapter selects five options for policies that have the potential to reduce GHG emissions in maritime shipping for further design and analysis. It does so in four steps:
1. It develops an analytical framework for the emergence of maritime CO_2 emissions (section 5.2).
2. It assesses which factors leading to maritime CO_2 emissions can be altered by policy instruments so that the emissions decrease (section 5.3).
3. It evaluates these instruments in a multi criteria analysis (section 5.4).
4. It selects the instruments on the basis of the multi criteria analysis (section 5.5).

5.2 Framework for the emergence of maritime CO_2 emissions

This section presents a stylised overview of factors that determine the magnitude of shipping emissions. This analytical framework will be used in subsequent sections to identify policies to reduce emissions. Figure 29 is a graphical presentation. Each factor and its direct or indirect relation to maritime emissions will be described in more detail below.

Figure 29   Stylised representation of factors determining maritime emissions
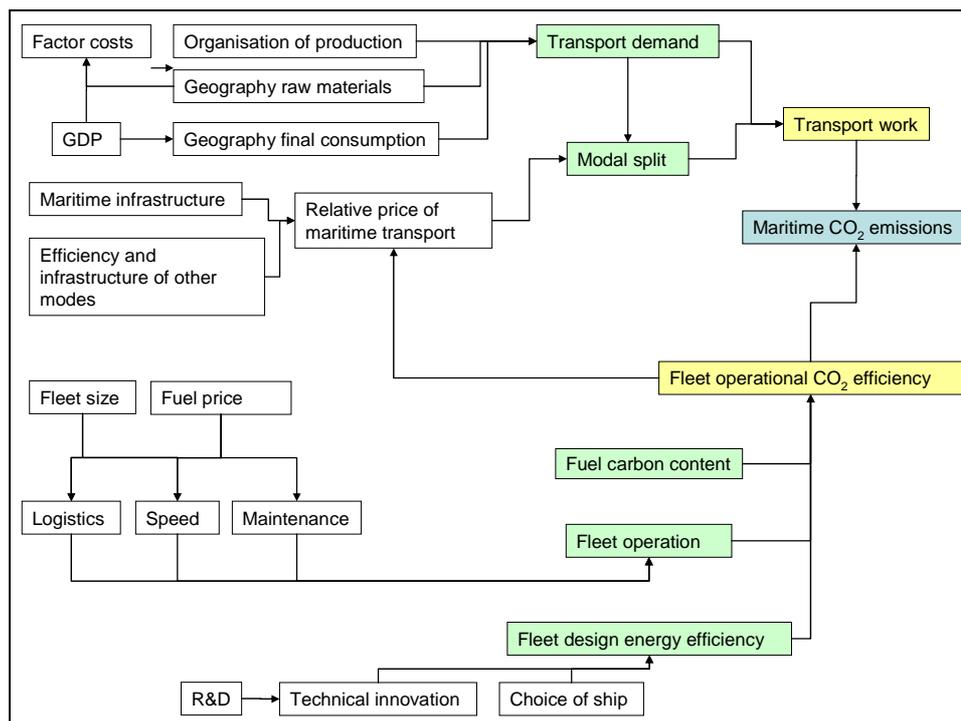
Source: This paper.

The volume of maritime CO_2 emissions depends by definition on fleet operational CO_2 efficiency (in terms of CO_2 emissions per tonne-mile) and the transport work (in tonne-miles).

Transport work of the maritime sector depends on two main factors: (overall) transport demand, and the modal split. In turn, transport demand is determined by the geography of raw materials, the geography of final consumption and the geographical organisation of production. Between each location, goods have to be transported. Production tends to be concentrated in areas with low factor costs. Both factor costs and geography of final consumption are dependent on GDP per capita in different parts of the world.

Modal split depends primarily on availability of alternative transport modes (not pictured) and relative price of maritime transport. Alternative transport modes are usually abundant in coastal shipping, but in ocean shipping, the only alternative mode is often air transport, which has very different qualities and costs than shipping and is therefore only marginally an alternative to shipping. Currently, the costs of CO_2 emissions are external to the price of maritime transport but to an extent internal to the price of other modes of transport. Moreover, these costs will be internalised in the price of air transport after the inclusion of aviation in the EU ETS. The relative price of maritime transport depends on the supply of ships (not pictured), fleet operational CO_2 efficiency, the maritime infrastructure, the factor costs of maritime transport and the prices of competing modes.

Turning to the operational CO_2 efficiency in the lower half of Figure 26, this depends on the carbon content of the fuel used, the operation of the fleet and on the fleet design energy efficiency. The fleet operation, or rather the operational aspects that have the largest impact on the CO_2 efficiency, are logistics, maintenance, and speed. All three aspects are determined by the fuel price and the fleet size, and by the overall transport demand (a link not pictured here).

The fleet design energy efficiency depends on the type of ships in the fleet (e.g. type of engine, size, and hull form of a ship) and is obviously related to technical innovation triggered by advancements in research and development.

One should bear in mind that this is only a general scheme, not capturing all possible factors and interrelations. Alternative models are conceivable and may be equally valid. However we think that this framework allows us to identify a comprehensive list of policies to reduce maritime GHG emissions.

5.3   Identification of policies to reduce maritime CO_2 emissions

In principle, policies can be aimed at each of the factors that determine maritime CO_2 emissions as identified in section 5.2. In practice, some policies would obstruct free maritime movement or trade, e.g. policies that would directly influence the amount of transport work. These policies have not been considered.

This section identifies conceivable options to influence factors that contribute to maritime CO_2 emissions. The aim is to draft a comprehensive list of options. Not all these options may be effective or feasible and therefore a broad evaluation will be made in section 5.4.

The first set of policies are policies that are *directly aimed at reducing maritime CO_2 emissions*. Figure 30 presents these in the black prism, viz. emissions trading, an emissions tax and a fuel sales tax. In theory, taxes and charges have broadly the same effects, the difference being that a tax provides certainty on the price but not on the environmental effect, whereas emissions trading provides certainty on the environmental effect, but not on the price.

Figure 30   Policies aimed directly at maritime CO_2 emissions
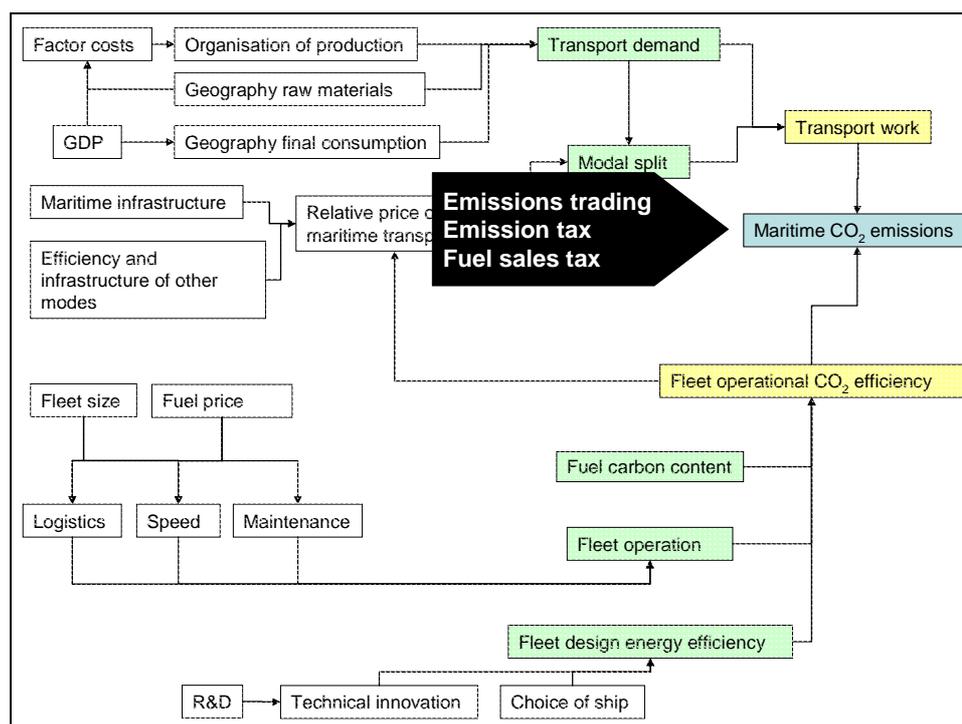
Source: This paper.

An emissions cap-and-trade system in maritime transport could either be closed (i.e. include only maritime emissions) or open (i.e. include more sectors than maritime transport). An open system can be integrated in an existing system, e.g. the EU ETS, or a self-standing system that is linked to other systems, e.g. by mutual recognition of emissions allowances. So there are three policy instruments within this category:

1   Inclusion of maritime transport emissions in the EU ETS.
2   A separate maritime emissions trading scheme, linked to the EU ETS.
3   A closed maritime emissions trading scheme.

All these instruments can have the main design parameters identified in CE et al. (2006) and Kågeson (2007). These are:
– CO_2 emissions on routes to EU ports or on intra-EU routes would be included in the scheme; or alternatively emissions in some time period prior to calling at an EU port would be included.
–   The ship would be legally responsible for surrendering allowances.
–   Enforcement would be organised in ports.
–   Initial allocation would be done by auctioning allowances.
–   The cap needs yet to be established.

An emissions tax would require ships or ship operators to pay a tax on emissions. Since the environmental effectiveness could be very different depending on the way in which the revenues are spent, we distinguish between an emissions tax where the proceeds are spent on mitigating emissions either in the shipping sector or in other sectors; and a tax where the proceeds are included in the fiscal budget.

So there are two different policy options:
1   An emissions tax with revenues hypothecated for climate change
    mitigation.
2   An emissions tax without hypothecated revenues.

Both instruments would have the following design features:
−   Either CO_2 emissions between EU ports or on the route to EU ports could be
    taxed.
−   The level of the tax could be set at the social costs of CO_2 emissions to be
    economically efficient, or at the average level of allowance prices in the
    EU ETS if that would be considered more fair and practical.
−   Taxes would have to be paid in ports.

An alternative to an emission tax could be a tax on bunker fuels levied at the
point of sale. In this case, all sales of bunkers within EU jurisdiction would be
taxed. The rate of tax would be the same for all types of maritime bunker
fuels (a differentiated tax is proposed in option 1). Again, the tax revenues
could either be hypothecated for mitigation or not.
1   Bunker fuel sales tax with revenues hypothecated for climate change
    mitigation.
2   Bunker fuel sales tax without hypothecated revenues.

The second set of policies are aimed at improving the *operational fuel
efficiency* of the fleet and of the ships that constitute the fleet. As the
operational efficiency is not directly observable (in contrast to e.g. emissions
which can be calculated from fuel use), the policies are aimed at improving an
indicator that reflects operational CO_2 efficiency. The indicator (the grey
diamond) and the policies (the black prism) are presented in Figure 31.

Figure 31   Policies aimed at operational fuel efficiency
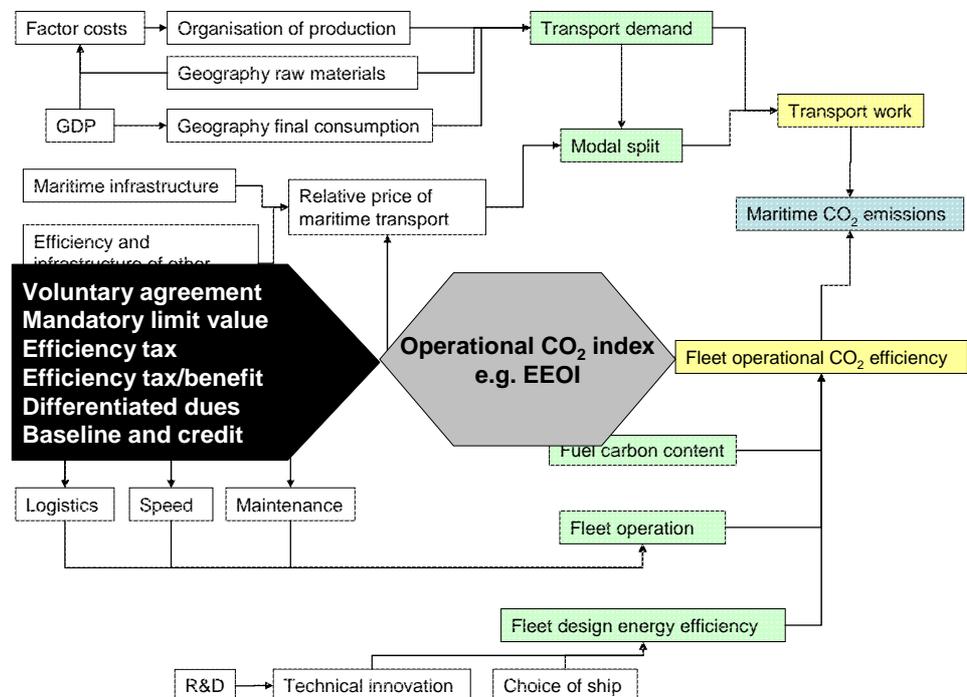
Source: This paper.

Before turning to the design of the policy instruments, the design of the operational CO_2 index will be described. Our definition of an operational CO_2 index is a metric that reflects the amount of CO_2 emitted per unit of transport work. The energy efficiency operational index (EEOI) as defined by the IMO MEPC (and formerly known as the IMO CO_2 index), is an example of such an index. It is defined as (MEPC.1/Circ.684):

$$ EEOI = \frac{\sum_i \sum_j FC_{i,j} \times C_{F,j}}{\sum_i m_{c\arg o,i} \times D_i} $$

Where:

- j is the fuel type.
- i is the voyage number.
- $FCi\ j$ is the mass of consumed fuel j at voyage i.
- CFj is the fuel mass to CO_2 mass conversion factor for fuel j.
- $m$cargo is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships.
- D is the distance in nautical miles corresponding to the cargo carried or work done.

Other operational CO_2 indices exist that differ in details, e.g. the period over which the index is calculated or the treatment of ballast voyages. At this point it is not yet clear how a standard could be defined that is able to distinguish efficient from inefficient sea transport. Key questions relate to (based on CE et al., 2006):

- **Baseline**: Transport efficiency potential depends on location of origin and destination, cargo volumes, ability to find return goods (trade triangles, etc.) type of goods and more.
- **Allocation**: Distribution of emissions in cases where multiple cargo types are carried (e.g container vessels, RoRo vessels, etc.).
- **Baseline drift**: Changes in transport demand and fleet size cause changes in relative cargo availability hence efficiency. To be effective, the baseline must be more or less continuously adjusted.
- **Regional impacts**: A side effect of this approach could be that transport cost increase in remote and sparsely populated areas due to the inherent lower efficiency.
- **Ownership and verification**: The CO_2 efficiency of a ship depends on its operation which may be controlled by a charterer that is not the ship owner. In this case, if a ship is sold or transferred, who owns the index.

At the first intersessional meeting of the IMO MEPC Working Group on Greenhouse Gas Emissions from Ships (July 2008), the EEOI has been discussed. Consensus was that the EEOI 'should not be mandatory, but recommendatory in nature, but this does not mean that it could not be made mandatory in the future' (MEPC, 2008)[10].

---

[10] MEPC, 2008: Report of the outcome of the first Intersessional Meeting of the Working Group on Greenhouse Gas Emissions from Ships, MEPC 58/4.

A recent analysis of efficiency indexing conducted as part of a European research project Flagship B.1.1[11]. concluded that efficiency definitions such as used in the IMO EEIO is suitable as a benchmarking tool to identify possible areas of improvement, while the precision cannot be expected to be sufficient enough in a policy context where judgement is passed on basis of the index result only.

A large number of policies is conceivable that are aimed at improving the operational fleet efficiency. Improvements in efficiency would mean that the emissions per unit of transport work would be reduced. This would also reduce emissions (there may be a rebound effect, however, as lower emissions per unit of transport work generally means lower costs, and hence to some extent higher demand for transport). We identify 6 policy instruments, which we broadly describe below:

1. A voluntary agreement to reduce the operational CO_2 index. Such an agreement would have to be set within an organisation capable to organise and enforce it. Such an institution could agree on the kind of specific measures to be taken by ship operators in order to reduce the average CO_2 emissions per tonne-mile sailed.
2. A mandatory operational CO_2 index limit value. It would require ships to meet or exceed a minimum operational efficiency standard in terms of CO_2 emitted per tonne-mile sailed. Ships that do not meet this requirement would be banned from EU ports.
3. A tax on the operational CO_2 index. The point of taxation could be either port authorities or port states. Less efficient ships would pay a higher tax than more efficient ships, thus creating an incentive to improve the efficiency of ships in EU ports. This instrument is similar to the CO_2 tax, with a difference that the tax would have to be calculated according to efficiency (for example CO_2 emissions per tonne-mile) and not on absolute CO_2 emissions.
4. A tax/benefit system based on the operational CO_2 index. The tax/benefit system would be similar to the tax on the operational CO_2 index, the difference being that with a tax/benefit system, the ships with an efficiency better than the benchmark level would get a benefit (a subsidy) while those whose efficiency is worse than the benchmark would have to pay the tax. Thus there will be no net revenue and the proceeds will be ploughed back into the sector.
5. Differentiation of harbour and fairway dues according to the operational CO_2 index. It is an instrument similar to the tax/benefit scheme described above. It would reward efficient ships and require inefficient ships to pay higher harbour and fairway dues. In this way the instrument creates an incentive to improve the operational efficiency of the fleet in EU ports. The difference with the tax/benefit scheme is that in this case, an existing charge is used to create the incentive. The differentiation could either be absolute (the same amount of money per unit of efficiency throughout Europe) or relative (the same percentage reduction per unit of efficiency throughout Europe).
6. A baseline and credit trading system based on the operational CO_2 index. Such a trading system requires the fleet in EU ports to achieve a certain average level of efficiency as set by the regulator. It does so by establishing a baseline which reflects the efficiency level to be met. It then allows actors flexibility by creating a market in which efficient ships

---

[11]   Flagship - European Framework for Safe, Efficient and Environmentally-friendly Ship Operations. D-B1.1 Influence of external factors on the energy efficiency of shipping (MARINTEK, 2008).

(ships whose efficiency is better than the baseline) can earn credits which they can sell to inefficient ships. Inefficient ships that cannot surrender credits too make up for their inefficiency would be penalised or barred from entering an EU port.

A third set of policies focuses on *technical efficiency*. With analogy to the operational CO_2 index, here we will look at options to improve design efficiency, which can be expressed with a design efficiency index. Figure 32 shows the policies indentified.

Figure 32   Policies aimed at technical efficiency
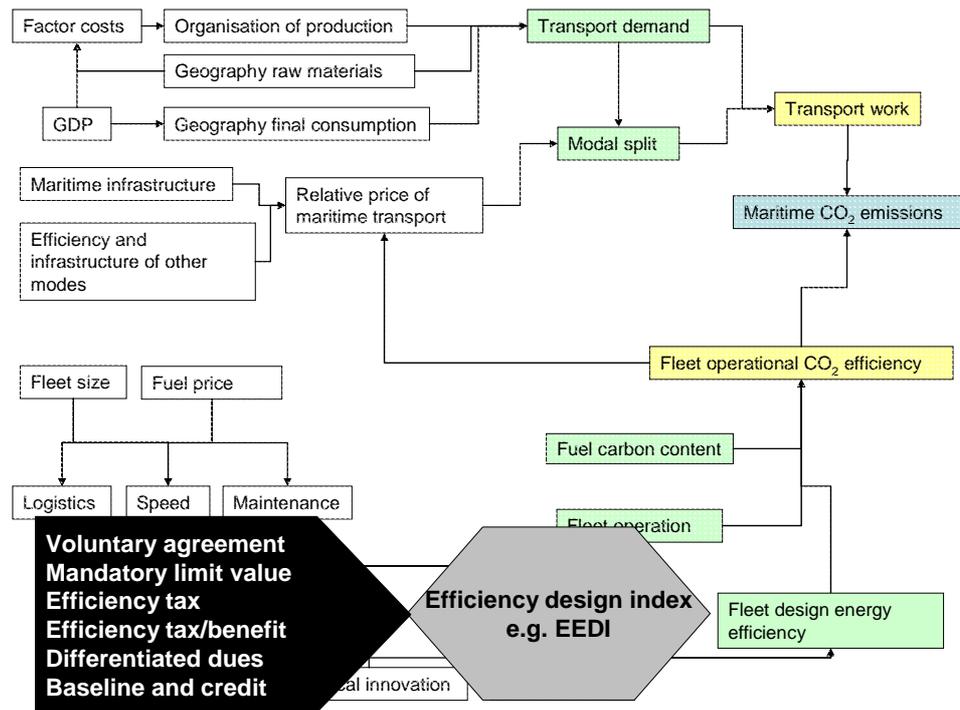
Before turning to the design of the policy instruments, the energy efficiency design index will be described. It is a metric that reflects the amount of CO_2 emitted per unit of transport work under standardised conditions. Unlike the operational efficiency indicator referred to above, it is a fixed value per ship that does not change with the load factor of a ship, the conditions under which she is operated, maintenance et cetera. The energy efficiency design index (EEDI) as is currently being discussed in by the IMO MEPC is an example of such an index. The EEDI is currently defined as (MEPC.1/Circ.681):

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}*\right) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

Where:
− *CF* is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content. The subscripts *MEi* and *AEi* refer to the main and auxiliary engine(s) respectively.

- *Vref* is the ship speed, measured in nautical miles per hour (knot), on deep water in the maximum design load condition.
- *Capacity* is deadweight for dry cargo carriers, tankers, gas tankers, containerships, RoRo cargo and general cargo ships, gross tonnage for passenger ships and RoRo passenger ships, and 65% of deadweight for container ships.
- *Deadweight* means the difference in tonnes between the displacement of a ship in water of relative density of 1,025 kg/m^3 at the deepest operational draught and the lightweight of the ship.
- *P* is the power of the main and auxiliary engines, measured in kW. The subscripts *ME* and *AE* refer to the main and auxiliary engine(s), respectively.
- *SFC* is the certified specific fuel consumption, measured in g/kWh, of the engines.
- *fj* is a correction factor to account for ship specific design elements.
- *fw* is a non-dimensional coefficient indicating the decrease of speed in
- representative sea conditions of wave height, wave frequency and wind speed.
- *feff(i)* is the availability factor of each innovative energy efficiency technology.

From the few available evaluations of the EEDI, it is clear that the EEDI could be a good reflection of the design efficiency of large tankers, bulkers, general cargo and container ships. Smaller ships are often designed for special trades and for them a generalized index may not be a good reflection of the design efficiency (CMTI, 2009)[12]. Other ship types such as ferries, cruise ships, offshore support vessels, tugs and dredgers are not primarily designed to transport cargo.

Furthermore, it appears that the EEDI is inversely correlated to the size of a ship (CMTI, 2009). Consequently, for small ships a small difference in size corresponds to a large difference in the index value. Therefore, it is difficult if not impossible to establish a baseline for ships smaller than 15,000 or 20,000 dwt.

In this category, we identify 6 policy instruments. Like the instruments addressing the operational efficiency, these instruments all share the strengths and weaknesses of the indicator. For all these instruments, ships would be required to report their design efficiency in terms of CO_2 emitted per tonne-mile sailed under standardised conditions. For all other items, their design is similar to the design of the policy instruments addressing operational efficiency, the only difference being the indicator of efficiency. Therefore, we will not repeat the main design choices here. The instruments are:
1   A voluntary agreement to reduce the design CO_2 index.
2   A mandatory design CO_2 index limit value.
3   A tax on the design CO_2 index.
4   A tax/benefit system based on the design CO_2 index.
5   Differentiation of harbour and fairway dues according to the design CO_2 index.
6   Baseline and credit trading scheme.
A fourth set of policy options that we propose to take into consideration are policies related to *fuel quality* expressed with fuel carbon content.
The possible policy options are shown in Figure 33.

---

[12]   CMTI, 2009, The IMO Energy Efficiency Design Index: A Netherlands Trend Study, Zoetermeer.

Figure 33   Policies aimed at fuel quality
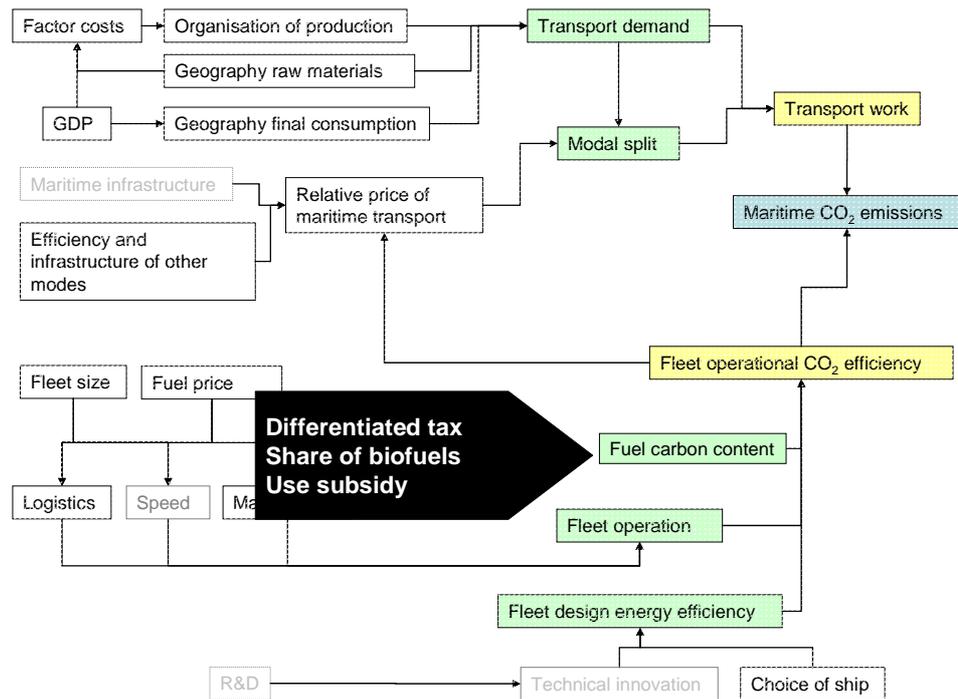
Source: This paper.

In this category, three instruments are proposed:
1 A tax on fuel for ships differentiated according to carbon content. This instrument would be very similar to the fuel sales tax (see above under 1 and 2). The difference would be that the rates of a tax proposed in this category would be differentiated depending on carbon content of the fuel. This would effectively become a tax on CO_2 emissions.
2 Obligatory share of biofuels for maritime shipping. This instrument would require all ships in EU ports to demonstrate that they have bunkered fuels containing a minimum share of biofuels either for the voyage to an EU port or in a certain time period prior to entering an EU port.
3 A subsidy for the use of fuels with low life cycle CO_2 emissions. In this case, ships entering EU ports would receive a subsidy if they demonstrate that they have used a fuel with lower life cycle CO_2 emissions than a certain value.

The final set of policies identified here is indicated in Figure 34. These policies are quite diverse, as they are aimed at maritime infrastructure, vessel speed, and technical innovation. Each policy identified in the figure will be briefly described below.

Figure 34   Policies aimed at maritime infrastructure, vessel speed and technical innovation
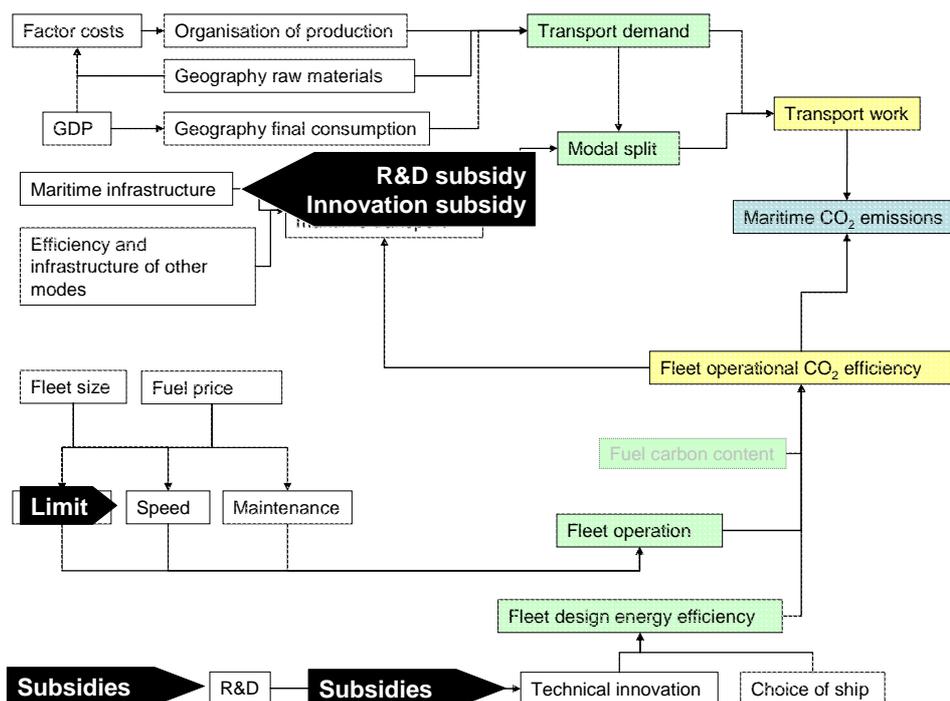
Source: This paper.

This category includes the following instruments:
1   Subsidies for R&D aimed at the improvement of maritime infrastructure. The aim of this policy instrument would be to improve the supply of technologies that reduce existing inefficiencies in the transport system. Provided that these technologies are implemented, emissions could be reduced.
2   Innovation subsidy for maritime infrastructure. The aim of this policy instrument would be to reduce existing inefficiencies in the transport system and thereby reduce emissions by stimulating the adoption of new technologies.
3   Obligatory speed limit for ships. Since the fuel use of ships is roughly proportional to the third power of the speed, a speed reduction of 10% would roughly decrease fuel use and emissions by 20%, also depending on auxiliary fuel use. A mandatory speed limit of ships would thus be a way to reduce emissions.
4   Subsidies for R&D aimed at improving the efficiency of ships. The subsidies could support research aiming for improving technical or operational efficiency of ships. As a result of the subsidies, the supply of new technologies would increase and their price would decrease. Other things equal, this would increase the adoption of new technologies by ship owners and operators which, in turn, could lower emissions.
5   Innovation subsidies for ship owners. These subsidies would be aimed at incentivising the adoption of new technologies that reduce emissions by lowering the costs of adoption.

5.4   Broad evaluation of policies identified

Section 5.3 has identified a long list of policy options. This section evaluates them with the aim of identifying the four most promising policy options for further design and impact assessment. In the evaluation, four criteria are applied:

a   Environmental effectiveness – what potential does the policy hold for reducing CO_2 emissions?

b   Cost effectiveness – what would the societal costs of reducing emissions be per unit of emission?

c   Legal obstacles – are there legal obstacles to the unilateral implementation of the policy by the EU?

d   Feasibility of implementation – are there any practical factors that would be an obstacle in the implementation of these policies?

With regard to EU unilateral action in general, the legal analysis contained in annex B shows that although unilateral action could be challenged, potential counterarguments exist and could be deployed if necessary:

–   Under the UNFCCC and the Kyoto Protocol challenges could be made, e.g. that unilateral action contravenes the principle of common but differentiated responsibilities (CBDR) or that it undermines the IMO mandate. However, there are persuasive counterarguments that could be used in this regard:

  •   The CBDR principle is not incompatible with the principle of equal application applied by the IMO.
  •   Applying CBDR to shipping emissions would be inconsistent with the IMO's mandate.
  •   EU unilateral action does not contradict principles agreed by the IMO on the regulation of greenhouse gas emissions.
  •   The Kyoto Protocol anticipates and encourages unilateral measures to address greenhouse gas emissions.

–   Unilateral EU action may also potentially be found to be an unlawful restriction on trade under the General Agreement on Tariffs and Trade (GATT) and/or (depending on the policy option) the General Agreement on Trade and Services (GATS). Again, however, there are counterarguments that could be used in this regard. They can be summarised as follows:

  •   EU measures are justified under Article XX of GATT (e.g. as measures relating to the conservation of exhaustible natural resources).
  •   EU measures are justified under Article XIV of GATS (as measures necessary to protect human, animal or plant life and health).

In addition to the overarching potential challenges outlined above, issues and obstacles may arise under the international shipping, EU (including issues of competence), tax law as well as the WTO Subsidies and Countervailing Measures (SCM) Agreement. However, these options are summarised in connection with individual options below.

1   Include maritime emissions in the EU ETS

  a   The environmental effect would be determined by the scope of the system, the cap and the possibilities for avoidance. The scope of the system could be as large as all voyages to EU ports or emissions in a certain time period prior to visiting an EU port. Caps could be set at various levels. There would be possibilities for avoidance, and avoidance would be more likely with higher emission prices. In sum, the environmental effectiveness would be large as long as avoidance can be minimised.

 b An emissions trading system would enable a large variety of options to reduce emissions to comply with the system. These include efficiency improvements of ship design and operations, buying allowances from other sectors and/or non-EU countries through the JI and CDM mechanisms, and reducing demand. Because of the large variety of options available, an open emissions trading system or the inclusion of maritime emissions in the EU ETS provides many opportunities for emissions reductions at low cost reductions. Naturally, the cost effectiveness will be affected by the administrative costs and avoidance. As long as these can be kept at an acceptable level, the cost-effectiveness of the inclusion of maritime transport in the EU ETS is good.

 c So long as any EU ETS scheme is not applied to ships passing through EU waters and is only applied to those vessels which call at an EU port, the application of such a scheme may not necessarily constitute a breach of the EU's duties and obligations under UNCLOS and other relevant international shipping legislation.

 d There are issues that have to be solved before maritime transport can be included in the EU ETS. These include monitoring, reporting and verification requirements for ships and the regulatory administration of the system. Although these issues need further study, at this point none of these issues seem insurmountable.

2 A separate cap-and-trade system linked with the EU ETS

The difference between this option and the previous one would be the laws governing maritime emissions. As these do not impact the environmental effectiveness nor the cost-effectiveness, and since the legal feasibility of an inclusion would be the same as the feasibility of a linked emissions trading system, these criteria are assessed to be the same for this option and the previous one.

 a The environmental effect would be the same as in option 1.

 b The cost effectiveness would be the same as in option 1.

 c The legal feasibility would be the same as in option 1.

 d Although the feasibility of implementing the policy at the EU level would be the same, the feasibility of expanding the system to other states could be different. Under this option, states wanting to include their shipping could do so without simultaneously having to bring their land-based large emitters and their aviation sector under the EU ETS.

3 Closed cap-and-trade system for maritime transport

 a Although in principle, the scope and target could be set to reflect open emissions trading systems, in practice the possible threat of very high prices in case the cap is set too low would induce policy makers to set a higher cap.

 b Emissions trading systems are generally considered to be more cost effective if they include more emissions and more sectors (Tietenberg, 2006). The larger the scope of the system, the larger the potential number of measures to reduce emissions, and the larger the chance that there are low cost measures in the system. Moreover, shipping being a highly cyclical sector, a closed system would most likely have a larger price volatility than an open system. Volatile prices have the effect to postpone investment decisions and may decrease the cost effectiveness (Farzin et al., 1998). Again, administrative costs are an issue. Therefore, the cost-effectiveness of a closed system is worse than the cost-effectiveness of an open system.

 c The legal feasibility would be the same as in option 1.

    d   A closed cap-and-trade system would have the same feasibility of implementation as option 2.

4   Emissions tax with hypothecated revenues
    a   In principle, an economy wide emissions tax is as environmentally effective as an economy wide emissions trading system. However, an emissions tax applied to one sector in the presence of an emissions trading system in other sectors could have a different environmental effect. The emissions reduction in the shipping sector would be the same. However, if the marginal abatement cost curve in shipping is higher, meaning that emission reductions in shipping are more expensive than in other sectors, imposing a tax on shipping and emissions trading for other sectors would result in lower overall emissions reductions (and lower prices in the emissions trading scheme). Conversely, if emission reductions in shipping are cheaper, a tax would result in higher emissions reductions overall. However, if the proceeds of the tax are spent on reducing emissions in other sectors, the environmental effectiveness of a dual system would be improved.
    b   The cost-effectiveness of an emissions tax would be similar to an open emissions trading system if the tax rate is the same as the equilibrium allowance price. It could even be somewhat better as the tax rate would be more predictable which could make investment decisions easier. If the tax rate is lower, however, the cost-effectiveness to the shipping industry would be better, but the social cost-effectiveness would be worse as some of the potentially cost-effective measures would not be taken (CE, 2009). If the tax rate is higher, both the social cost-effectiveness and the cost-effectiveness to the sector would be worse.
    c   The introduction of an emissions tax may be legally challenging. The challenges mainly stem from international law. In order for the shipping activities of an entity to be taxable, it would need to be decided whether the operation of a ship within the territorial waters of a state is sufficient to bring the shipping entity within the territorial scope of that state for tax purposes. Moreover, the imposition of a tax on international shipping activities would also require consideration of double tax treaties. In addition, there are some double tax treaties that apply only to shipping and air transport, some of which exempt all income derived from the business of shipping from all taxes on income or profits. The territoriality and double tax treaty issues become more significant if the tax also applies to emissions on route to (as opposed to just between) EU ports.
    d   Since a tax would require the same data to be monitored and would be enforced at the same place, its feasibility of implementation would be similar to an emissions trading scheme. However, since in the EU, tax is a Member State competence, implementing an emissions tax would require Member State unanimity. This lowers the feasibility of this option. Moreover, there is the possibility of a legal challenge to hypothecated revenues as it may breach the principle of subsidiarity and may not be constitutional in certain Member States.

5   Emissions tax without hypothecated revenues
    a   Following the argument under a above, the environmental effect of this option would be less than an emissions trading system if emissions reductions in the shipping sector are more expensive than in the ETS sectors and higher if the emission reductions are less expensive.

b   Cost-effectiveness would be about the same as option 4 – there may be some differences but these are likely to be mitigated by other design choices.

c   The legal feasibility would be similar to option 4.

d   The feasibility of implementation would be the same as for option 4.

6   An EU maritime fuel sales tax with hypothecated revenues

a   An EU maritime fuel sales tax would most probably suffer from avoidance caused by ship choosing to bunker outside the EU tax area (Michaelis, 1997; LAO, 2001). This legal avoidance could lead to increased transport of fuel and increased ship movement hence have a net negative effect on emissions. As a result, the environmental effectiveness of this option would be low.

b   The cost-effectiveness of a fuel tax could be similar to an emissions trading system provided that the cost of CO_2 emissions resulting from the tax rate is the same as the allowance price in the emissions trading system.

c   The legal feasibility would be similar to option 4, except that the territoriality issues discussed in option 4 may not be as problematic.

d   This option would be feasible to implement. However, since in the EU, tax is a Member State competence, implementing an emissions tax would require Member State unanimity. This lowers the feasibility of this option. Moreover, there is the possibility of a legal challenge to hypothecated revenues as it may breach the principle of subsidiarity and may not be constitutional in certain Member States.

7   An EU maritime fuel sales tax without hypothecated revenues

a   Environmental effectiveness would be even lower than in option 6 because directing the revenues in the form of subsidies either back to the sector or to other sectors where they can be used to lower CO_2 emissions could result in higher overall effectiveness.

b   Cost effectiveness would be slightly better in this option than in option 6 with the revenues directed back to the maritime sector because subsidies weaken the potential of reducing demand for maritime shipping as one of the options to reduce CO_2 emissions, and in this option there would be no such subsidies.

c   The legal feasibility would be similar to option 4, except that the territoriality issues discussed in option 4 may not be as problematic and the potential challenge to hypothecated revenues as a breach of the principle of subsidiarity or a particular Member State's constitution would not apply.

d   The feasibility of implementation would be similar to option 4.

8   A voluntary agreement to reduce the operational CO_2 index

a   The environmental effectiveness of a voluntary agreement would be limited by the existence of ships or operators who would not enter into this agreement. As a result, the targets of the agreement would be limited by competitiveness consideration; an ambitious target would reduce the competitive position of the parties entering into an agreement. This solution can therefore not be considered robust in terms of achieving significant reductions.

b   Cost effectiveness would depend on kind of measures agreed among the members of an institution committing to an efficiency standard. Probably, as the impact on competitiveness would need to be limited, the cost effectiveness of a voluntary commitment would have to be good, however the net amount of reductions received unsatisfactory.

c   There would be no serious legal obstacles to a voluntary agreement.

    d   The practical feasibility would be good.

9   A mandatory operational CO_2 index limit value
    a   A requirement to meet or exceed a minimum efficiency standard expressed with a CO_2 index limit value would have to be applicable to all ships in the EU. Since a large share of the world fleet visits EU ports, the policy could affect a large number of vessels. If the operational efficiency standard would be based on annual data, it would also affect efficiency of these ships when they are not sailing towards the EU. As such, the environmental effectiveness could be large. However, this analysis presumes that a baseline can be set, which would be challenging. It would probably be practical to cover only certain types of ships and cargos, thus limiting the effectiveness. Another side effect could be that ships could decide or be prevented from trade in Europe, resulting in reduced overall logistical efficiency.
    b   The cost-effectiveness of an operational efficiency standard would depend on the ability to set and adapt the correct standard efficiencies at all times. This would be very challenging, hence there is a clear risk that the cost effectiveness would be non-optimal. Performance standards are generally less cost-effective than economic instruments such as taxes or tradable permits because standards do not allow flexibility and set the same requirement for all actors regardless of possible differences in marginal abatement costs. Efficiency standard, however, is in this respect better than a technology-based standard.
    c   There is a likelihood that legal challenges may result. This option would interfere with 'generally accepted international rules and standards' including construction, design, equipment and manning (CDEM) standards on the basis that vessels would be obliged to comply with the new standards by making physical changes to existing machinery and equipment.
- There is an ongoing legal debate as to whether it is open to a port state to impose regulations on ships calling at its ports voluntarily that are more stringent than those agreed by way, for instance, of international convention. Foreign ships have been visiting port states for many centuries and a high measure of custom and understanding based on comity has developed. On top of this lies general international law and the system of international conventions including the United Nations Convention on the Law of the Sea, (UNCLOS) and conventions agreed at the International Maritime Organisation, the marine agency of the UN. Additionally, agreements originating from the World Trade Organisation (WTO) such as the General Agreement on Tariffs and Trade (GATT) or General Agreement on Tariffs and Services (GATS) further complicates the issue.
- Such international law and custom has achieved a remarkable consistency in application of internationally agreed standards relating to international shipping, in particular, to the safety of life at sea, and the prevention of marine pollution.
- More recently and following the major oil pollution incidents of the *Exxon Valdez, Erika* and *Prestige*, there has been an increasing willingness on the part of national and regional administrations to apply more stringent standards than those found in the international conventions where they are deemed to be lacking or insufficiently stringent. Numerous legal reasons have been stated to justify the legality of such measures: the sovereignty of states exercising their authority over ports and internal waters as they would over their land; the fact that international conventions refer

to minimum standards whereas more exacting standards are deemed to be appropriate; or where there is an absence of international regulation which should be remedied for the protection of the port and coastal states.

- The European Union has taken such measures in relation to oil pollution, for instance, in the accelerated phase out of single hull tankers and requirement that all tankers visiting EU ports be double hulled - in advance of the MARPOL regulations and in enhanced stability regulations for RoRo passenger ships. Such measures were justified by the extraordinary harm that might be done should such measures not be put in place.
- That said the legality of such measures continues to be debated and decisions have been made both in favour of and against the proposition that port states can impose higher standards than those generally accepted. Whatever the strict legal position, it is now the case that such laws and regulations are put in place where the need for state or regional rules is identified.
- The imposition of a mandatory efficiency limit may require significant changes to the construction, machinery, equipment of vessels visiting EU ports and as such fall outside the generally accepted international rules and standards presently applicable to international commercial shipping. This would cause ship owners or operators additional expense, the scale of which depends on the measures imposed. If this is onerous, a legal challenge may be mounted.
- A further consideration in relation to such measures would be the nature of a mandatory efficiency limit and the enforcement of such rules. A vessel not meeting the standards required may not be capable of economic modification to achieve the required standards and therefore detention of the offending vessel and permission to sail to a repair yard would not be a useful sanction to impose. Instead, the banning of vessels not meeting the standards would be required for those ships that could not be modified. In our view, such action would be disproportionate given the potentially wide effect that meaningful regulations in this regard would have, bearing in mind that the life of a commercial vessel is 25 years and the vast majority were not built with the prospect of being subject to climate policy in mind.
- It is considered that such a measure would lead to legal challenge on the basis of a departure from generally accepted international standards and a disproportionate response to the issue at hand when compared with the alternatives considered further in this study.

d   As long as a baseline can be set, the feasibility of implementation would be good as the data to calculate the index are available on ships and in shipping companies.

10 Efficiency tax based on the operational CO_2 index
a   The environmental effectiveness of efficiency taxes would be more or less the same as for closed emissions trading, provided that a good baseline and indicator for the tax can be developed. As it is likely that the baseline can only be set for larger ships, the environmental effectiveness would be lower than the ETS options.
b   Cost-effectiveness of operational efficiency taxes would be comparable to CO_2 taxes and emissions trading as all options to reduce emissions are rewarded by the system.

    c   The legal feasibility would be the same as in option 1. In addition, it should be noted that as tax is a Member State competence, implementing such a tax would require Member State unanimity. This lowers the feasibility of this option. As access to EU ports will still be permitted, albeit that a tax will be charged and calculated according to the ship's efficiency, the implementation of such a tax system will not require vessels either directly or indirectly to comply with enhanced CDEM standards. Consequently a tax on the operational CO_2 index would not interfere with internationally accepted CDEM standards and therefore would not be capable of challenge on that ground.

    d   The data issues would be the same as for option 9. Since this option involves a tax, the same considerations as under option 4 apply.

11   A tax/benefit system based on the operational CO_2 index

    a   The environmental effectiveness of a tax/benefit system would be lower than the tax (option 10) because of the subsidy element (benefit in case of performing better than a standard).

    b   Cost-effectiveness of this option would be the same as for option 10, since the marginal incentive to improve efficiency would be the same.

    c   The legal feasibility would be the same as in option 10.

    d   The feasibility of implementation would be the same as in option 10.

12   Differentiation of harbour and fairway dues on the basis of operational efficiency

    a   The incentive of differentiated harbour and fairway dues would be limited, as opposed to the incentive provided by a tax or a tax/benefit system. We assume that a *differentiation* of dues will not result in negative dues, so the largest incentive that a differentiation can provide is the level of the due. Since for most ships the share of harbour and fairway dues in total costs is limited[13, 14], the maximum incentive of a differentiation would also be limited. In addition, dues are often negotiated bilaterally and other than efficiency-related factors influence their level. Therefore, the environmental effectiveness is likely to be lower than option 11.

    b   Cost-effectiveness of this option would be the worse than option 10, since the marginal incentive to improve efficiency would be limited by the level of harbour and fairway dues.

    c   The legal feasibility would be the same as in option 10, although please this would require the EU to adopt a directive harmonising harbour and fairway dues. There is EU precedent for ports voluntarily imposing higher standards (e.g. Swedish ports scheme to reduce NO_x and SO_2 emissions).

    d   The data issues would be the same as for option 9. This option would require the EU to adopt a directive harmonising harbour and fairway dues.

13   A baseline and credit system based on the operational CO_2 index

    a   The environmental effectiveness of a baseline and credit system would be lower than in a closed cap-and-trade system because in this option the regulator sets a relative and not an absolute target. However, adjustment of the performance standard used as a benchmark can be

---

[13]   T. Nottenbom – Time factor in liner shipping services, Maritime Economics & Logistics, 2006, 8, (19-39).

[14]   Rawson & Tupper, Basic Ship Theory, Butterworth Heinemann 2001 ISBN 0 7506 5397 3.

made over time (e.g. if emission reduction seems to be too low and not satisfactory, the standard can be made more strict). If the regulator chooses to buy emission reduction credits from ship operators (creating a subsidy programme), the price offered can also be used as an incentive to increase or decrease the level of emissions reduction. In essence, the effectiveness of a baseline-and-credit system would be similar to a tax/benefit system as in option 11.

b   Cost-effectiveness of such a system would be slightly lower than in closed cap-and-trade system as the option of reducing emissions by reducing transport work would not be promoted here.

c   The legal feasibility would be the same as in option 10.

d   The feasibility of implementation would be the same as in option 10.

14   A voluntary agreement to improve technical ship efficiency

a   The environmental effectiveness of this option would be low, for the same reasons as in option 8. in fact, it would be even lower than option 8 as operators would have fewer measures they can take to improve their efficiency.

b   Again, for the same reasons as under option 8, the costs-effectiveness of this option would be good.

c   The legal feasibility would be the same as option 8.

d   The feasibility of implementation would be the same as option 8.

15   A mandatory design CO_2 index limit value

a   A requirement to meet or exceed a minimum design standard would have to be applicable to all ships in the EU. Since a large share of the world fleet visits EU ports, the policy could affect a large number of vessels. As such, the environmental effectiveness could be large. However, establishing a fair baseline design index is challenging. It would probably be practical to cover only certain types of ships and cargos, thus limiting the effectiveness. In addition, the environmental effectiveness would be low if applied only to new ships. Retrospective application is possible, although consideration should be given to avoid avoidance where inefficient ships trade outside EU only. Another side effect could be that ships could decide to change routes or be prevented from trade in Europe, resulting in reduced overall logistical efficiency. Compared to option 9, the environmental effectiveness of this option would be lower as fewer measures could be taken to improve the index.

b   Cost-effectiveness of technical design standards is generally lower than cost-effectiveness of operational standards because of allowing little flexibility in achieving the desired effect. On the other hand, the administrative burden of this option may be less than for some other options like including in ETS. On balance, for a well designed policy, the administrative costs would be lower than the technical costs and the cost-effectiveness would be worse than option 9.

c   There is a strong likelihood that the legal challenges would be very difficult to overcome. This option would interfere with construction, design, equipment and manning (CDEM) standards on the basis that vessels would be obliged to comply with the new standards by making physical changes to existing machinery and equipment and to alter the operational trading pattern of individual vessels in order to comply. This is not permitted under UNCLOS Articles 21 and 211 which require that laws and regulations shall not apply to CDEM of foreign ships unless they are giving effect to generally accepted international rules or standards. Such measures would also potentially conflict with other IMO Conventions, such as the International Convention for the

Prevention of Pollution from Ships or the International Convention for the Safety of Life at Sea.

d   The feasibility of implementation would be good, since the index could probably be calculated for all large new build ships and most large existing ships.

16 A tax based on technical efficiency
   a   Compared to the tax based on operational efficiency (see option 10), this option would be less environmentally effective as it only incentivises technical measures to reduce emissions but not operational measures.
   b   Compared to the option 10, this option would be less cost-effective, as cheap operational options to reduce emissions would not be rewarded under this system.
   c   The legal feasibility would be the same as in option 10.
   d   The data requirements would be the same as for option 15. The feasibility of implementation would be lower than option 15, however, due to the fact that Member State unanimity would be required to implement a tax on the design CO_2 index.

17 A tax-benefit system based on technical efficiency
   a   Compared to the tax-benefit system based on operational efficiency (see option 11), this option would be less environmentally effective as it only incentivises technical measures to reduce emissions but not operational measures. The rebound effect resulting from a subsidy (benefit) element makes this option slightly less effective than option 16.
   b   Compared to the option 11, this option would be less cost-effective as cheap operational options to reduce emissions would not be rewarded under this system. It would be as cost-effective as option 16 since the marginal incentive to improve the design efficiency would be the same.
   c   The legal feasibility would be the same as in option 10.
   d   The feasibility of implementation would be the same as option 16.

18 Differentiated harbour or fairway dues according to technical efficiency
   a   Compared to the differentiated harbour and fairway dues based on an operational efficiency indicator (as discussed under 12), this option would be less effective environmentally for the same reasons discussed above under 17. It would also be less environmentally effective than option 17 because the maximum incentive provided by this differentiation is limited by the level of the harbour and fairway dues.
   b   Again, for the same reasons as discussed under 17 above, this option would be less cost-effective than the harbour and fairway dues differentiated according to an operational index. Cost-effectiveness of this option would be the worse than option 17, since the marginal incentive to improve efficiency would be limited by the level of harbour and fairway dues.
   c   The legal feasibility would be the same as in option 10, although a new EU Directive would be needed.
   d   The feasibility of implementation would be the same as option 16.

19 Baseline and credit system of emissions trading based on technical design index
   a   Environmental effectiveness of a baseline and credit system based on technical efficiency would be lower than the same mechanism based on operational efficiency (option 13) because less options of reduction

would be included in such a scheme. The environmental effectiveness would be similar to the tax/benefit scheme under option 17.

    b   Cost-effectiveness would also be lower as compared to the same system with an operational index, for the same reasons as described in option 16. In addition, administrative costs could be higher because design of credits taking into account technical index would probably me more complicated as in case of operational index.

    c   The legal feasibility would be the same as in option 10.

    d   The feasibility of implementation would be the same as option 16.

20   A tax on fuel for ships differentiated according to carbon content;

    a   Because of a very high risk of avoidance for the same reasons as in option 6, the environmental effectiveness of this option is expected to be low.

    b   Using low-carbon fuels appears to be a costly measure to reduce emissions of ships (Buhaug et al., 2009). Hence, the cost-effectiveness of this measure would be low.

    c   The legal feasibility would be similar to option 6, except that the potential challenge to hypothecated revenues as a breach of the principle of subsidiarity or a particular Member State's constitution would not apply.

    d   The feasibility of implementation would be similar to option 4: data availability is good but taxes require unanimity in the EU.

21   An obligatory percentage of biofuels or other fuels with low life cycle CO_2 emissions

    a   Environmental effectiveness of setting an obligatory percentage of biofuels would be low. The reason is that gains in CO_2 emissions over the life cycle of biofuels are limited. Since biofuels are more expensive than fuels currently used in shipping, an obligation to use biofuels would incentivise ship operators to increase the fuel efficiency, thereby increasing the environmental effect. In sum, the environmental effect of this policy would be larger than a subsidy on the use of fuels with low life cycle CO_2 emissions

    b   The cost-effectiveness would be slightly better than the biofuel subsidy, as this option would to a larger degree incentivise efficiency increasing measures due to higher fuel costs.

    c   Requiring ship operators to purchase and use biofuels outside the EU may be subject to challenge on extra-territorial grounds in that such regulations would inevitably require ships to burn biofuels outside EU waters. However any such scheme could only be applied to EU bunker suppliers without distorting trading patterns.

    d   The feasibility of implementation could be limited if the biofuels were required to meet sustainability criteria which have been recently introduced in, for example, the forthcoming Directive introducing a mechanism to monitor and reduce greenhouse gas emissions from fuels (road transport and inland waterway vessels), COD/2007/0019.

22   A subsidy on the use of fuels with low life cycle CO_2 emissions for ships calling at EU ports

    a   The environmental effectiveness of a subsidy on environmentally-friendly fuel would be low as compared to other options. First of all, such a subsidy would create incentive only for increasing fuel-related efficiency and not for other options. Secondly, ship owners themselves will not get any incentive to be active in looking for efficiency improvements. Lastly, in the long run, a subsidy may result in additional growth of the maritime sector and increase CO_2 emissions.

b   The cost-effectiveness of a subsidy would not be good even if reduction in emissions can be achieved, they will result only from fuel-related gain in efficiency, and other options will be excluded. Only if there are no cheaper options of achieving higher efficiency in terms of CO_2 reduction, such an instrument could be cost-effective.

c   A subsidy may contravene the WTO Subsidies and Countervailing Measures (SCM) Agreement, depending on the nature and scope of the subsidy.

d   In principle, the EU would have internal competence to operate a subsidy scheme for fuels with low life cycle CO_2 emissions across the EU. However, the operation of the subsidy scheme would have to comply with EU rules on state aid (Article 87 ECT) and be notified as required.

23 Increased R&D funding for maritime infrastructure improvements

a   R&D funding will increase the supply of technologies or reduce their costs. Its environmental effect will depend on the adoption of these technologies.

b   It is impossible to assess the cost-effectiveness of such a wide range of measures in general.

c   There do not appear to be issues with respect to EU competence.

d   The feasibility of implementation seems to be good as the funding could be provided through established EU mechanisms.

24 Subsidies for innovation in maritime infrastructure

a   Improvement in maritime infrastructure include elements such as traffic management, port facilities, dredging and more. The benefits that may be achieved include more efficient operation, less time in port, ability to serve a port with a larger ship, etc. The effect of such measures on maritime and total emissions is difficult to quantify. For the ability of a port to accept larger ships may be beneficial since larger ships are typically more energy effective. However, if this larger ship now replaces a smaller ships stopping in more ports, the net result could be increased road transport. Improved infrastructure could also result in increased seaborne transport which may be good in the case of regional short sea shipping but not generally so in case of intercontinental trade. Therefore, the environmental benefit is difficult to assess generally. However the potential environmental effectiveness as compared to some other options able to capture and provide efficiency incentives to a large share of the world fleet (such as cap-and-trade or emissions tax) is rather low.

b   It is impossible to assess the cost-effectiveness of such a wide range of measures in general.

c   There do not appear to be issues with respect to EU competence.

d   The feasibility of implementation seems to be good as the funding could be provided through established EU mechanisms.

25 Mandatory speed limit

a   Speed reduction is an effective measure to reduce emissions of CO_2 and is generally also effective in reducing other emissions. However, since most of the emissions are on the high seas, and since the EU could not regulate speed beyond its territorial waters, EEZ or continental shelf (and even there its powers may be limited – see under c below) the environmental effect would only apply to emissions in EU waters. If the speed limit applies only to a part of the complete voyage, the effect could be that of increased speed outside the regulated area which

increases total emissions as compared to constant speed. In sum, the environmental effectiveness would be low.

b   The cost-effectiveness of a mandatory speed limit would be low. There could be two possible responses from ship operators. They could either speed up outside EU control, or accept the lower average speed and respond by buying more ships. The first option would be costly as a ship could not sail its optimal speed. The second would be even more costly as new ships are expensive. Moreover, if the speed limit is introduced rapidly, the supply of ships cannot keep up with increased demand and freight rates will increase significantly.

c   There is a strong likelihood that the legal challenges would be very difficult to overcome. It is only possible to set a speed limit within the territorial seas of EU Member States or arguably within the EEZs or continental shelf. However such a measure arguably amounts to interfering with freedom of navigation and the right of innocent passage and in any event it is difficult to see how any speed limit could successfully be enforced, particularly on vessels not calling at EU ports as this would require arrest on the high seas. In addition, it is not possible to say at this stage whether the EU would have competence to set speed limits due to subsidiarity issues.

d   The feasibility of implementation would probably be good, as the coverage of the Automatic Identification System (AIS) covers up to 50 nautical miles and thus extends to most EU territorial waters. AIS data could in principle be processed to yield ship speeds.

26   Increased R&D funding for ships

a   The environmental effect of R&D funding would be realised in the longer term. The immediate effect will be almost zero, but when innovations start to emerge from R&D and when these innovations are adopted in the fleet, emission reductions would occur. It is very hard, if not impossible, to quantify the likely reductions. Likewise, it is very hard to determine the environmental effect. In general, effectiveness of subsidies is limited by the existence of free riders. Subsidies are environmentally effective if the supply of knowledge is the limiting factor in reducing emissions. The existence of cost-effective abatement options suggests that the supply of knowledge is not the only limiting factor. To maximise environmental efficiency, the funds for R&D would have to be directed specifically to projects with the main goal of increasing fuel efficiency. However, if ship owners and operators do not have an incentive to adopt the innovations resulting from R&D, the effectiveness of such funding would be very low. Therefore, R&D is likely to be important in a policy package, but it cannot be expected to bring about emission reductions if it is the only policy instrument.

b   Given the uncertainties in establishing the environmental effectiveness, it is hard, if not impossible, to estimate the cost effectiveness of increasing R&D subsidies.

c   Subsidies may contravene the WTO SCM Agreement, depending on the nature and scope of the subsidy.

d   The feasibility of implementation seems to be good as the funding could be provided through established EU mechanisms.

27   Innovation subsidies for ship owners

a   Innovation subsidies could be quite effective if the amount of co-financing innovations in ships is set in proportion to increasing operational efficiency and if the funds available for creating such a subsidy programme are sufficiently large to achieve the desired effect

in CO_2 reduction. In the long run, subsidies may result in additional growth of the maritime sector and increase absolute CO_2 emissions. Innovation subsidies could be designed as an additional instrument in a package of measures.

b   It is impossible to assess the cost-effectiveness of such a wide range of measures in general.

c   Subsidies may contravene the WTO SCM Agreement, depending on the nature and scope of the subsidy.

d   The feasibility of implementation seems to be good as the funding could be provided through established EU mechanisms.

5.5   Selection of policies for further design and evaluation

This section presents a summary of the evaluation of section 5.4. In this analysis, environmental effectiveness is given more weight than cost effectiveness. The reason for this is that the primary policy objective is to reduce emissions. Amongst the environmentally effective policies, the most cost-effective would be preferable. Legal and practical barriers have not been scored quantitatively but rather used as exclusion criteria. The reason is that policies which are likely to encounter legal challenges in that would be very difficult to overcome would not be effective, as would policies that would be very hard to implement.

The summary evaluation of policy options shows that in terms of environmental effectiveness and cost effectiveness, the emissions trading options, the emission tax, the mandatory operational CO_2 index limit value and a tax on the operational CO_2 index score best. However, mandatory standard limit values (be it operational or design standards) have a strong likelihood that the legal challenges in relation to the particular option would be very difficult to overcome. Taxes have the drawback that they require unanimity among Member States.

Since the choice between operational efficiency index and a design index merits more analysis, we propose to merge options 9 and 15 into a mandatory efficiency limit. The client would like to have the legal feasibility and the design of this option examined in more detail, and for this reason, this merged option is selected. Likewise, we merge options 6 and 6 into a baseline and credit system based on an operational efficiency indicator or a design index, and merge these two with 12 and 18 because differentiated harbour dues can in some cases provide incentives similar to a baseline and credit system. A fifth policy, voluntary action and innovation support, is added as a reference.

The options that score best and do not have strong legal obstacles are:
1   Emissions trading, either inclusion of shipping in the EU ETS or emissions trading for shipping under a separate directive but linked to the EU ETS.
2   An emissions tax with hypothecated revenues.
3   A mandatory operational or design efficiency standard.
4   A baseline and credit system or differentiated harbour dues based on an operational efficiency indicator or a design index.
5   Voluntary action and innovation support.

As the other options either have a low effectiveness or have legal barriers, we propose not to design them in further detail.

		Score 1 (worst) to 5 (best)		Score	No quantitative score	
		Environmental effectiveness	Cost effectiveness		Legal feasibility	Feasibility of implementation
	Weight	0.67	0.33			
1	Inclusion in EU ETS	5	5	5.0		
2	A separate cap-and-trade system linked with the EU ETS	5	5	5.0		
3	Closed cap-and-trade system	5	3	4.3		
4	Emissions tax with hypothecated revenues	4	5	4.3	May conflict with international tax law; may require changing tax treaties.	Needs MS unanimity; hypothecation may breach subsidiarity principle
5	Emission tax without hypothecated revenues	2	5	3.0	May conflict with international tax law; may require changing tax treaties.	Needs MS unanimity
6	Fuel sales tax with hypothecated revenues	1	5	2.3	May conflict with international tax law; may require changing tax treaties.	Needs MS unanimity; hypothecation may breach subsidiarity principle
7	Fuel sales tax without hypothecated revenues	1	5	2.3	May conflict with international tax law; may require changing tax treaties.	Needs MS unanimity
8	A voluntary agreement to reduce the operational ship efficiency	1	5	2.3		Hard to define baseline
9	Mandatory operational efficiency standard	4	4	4.0	Interference with CDEM standards.	Hard to define baseline
10	Operational efficiency taxes	4	4	4.0		Hard to define baseline; needs MS unanimity
11	A tax-benefit system based on operational efficiency	4	4	4.0		Hard to define baseline; needs MS unanimity
12	Harbour or fairway dues differentiated based on operational efficiency	2	3	2.3		Hard to define baseline
13	A baseline and credit trading based on operational efficiency	4	4	4.0		Hard to define baseline
14	A voluntary agreement to improve technical ship efficiency	1	4	2.0		Hard to define baseline
15	Mandatory technical design standard	3	3	3.0	Interference with CDEM standards.	Hard to define baseline
16	A tax based on technical efficiency	3	3	3.0		Hard to define baseline; needs MS unanimity
17	A tax-benefit system based on technical efficiency	3	3	3.0		Hard to define baseline; needs MS unanimity

		Score 1 (worst) to 5 (best)		Score	No quantitative score	
		Environmental effectiveness	Cost effectiveness		Legal feasibility Feasibility of implementation	
	Weight	0.67	0.33			
18	Harbour or fairway dues differentiated based on technical efficiency	1	2	1.3		Hard to define baseline
19	Baseline and credit trading based on technical design index	3	3	3.0		Hard to define baseline
20	A tax on fuel for ships differentiated according to carbon content	1	5	2.3	May conflict with international tax law; may require changing tax treaties.	Needs MS unanimity
21	An obligatory percentage of biofuels	2	2	2.0		
22	A subsidy on the use of fuels with low cycle CO_2 emissions	1	1	1.0		
23	Increased R&D funding for maritime infrastructure improvements	N/A	N/A	N/A	A subsidy may contravene the WTO Subsidies and Countervailing Measures (SCM) Agreement, depending on the nature and scope of the subsidy.	
24	Subsidies for innovation in maritime infrastructure	1	N/A	N/A	A subsidy may contravene the WTO Subsidies and Countervailing Measures (SCM) Agreement, depending on the nature and scope of the subsidy.	

		Score 1 (worst) to 5 (best)		Score	No quantitative score
		Environmental effectiveness	Cost effectiveness		Legal feasibility Feasibility of implementation
	Weight	0.67	0.33		
25	Mandatory speed limit	1	2	1.3	There is a strong likelihood that the legal challenges would be very difficult to overcome. It is only possible to set a speed limit within the territorial seas of EU Member States or arguably within the EEZs or continental shelf. However such a measure arguably amounts to interfering with freedom of navigation and the right of innocent passage and in any event it is difficult to see how any speed limit could successfully be enforced, particularly on vessels not calling at EU ports as this would require arrest on the high seas.
26	Increased R&D funding for ships	N/A	N/A	N/A	A subsidy may contravene the WTO Subsidies and Countervailing Measures (SCM) Agreement, depending on the nature and scope of the subsidy.
27	Innovation subsidies for ship owners	1	N/A	N/A	A subsidy may contravene the WTO Subsidies and Countervailing Measures (SCM) Agreement, depending on the nature and scope of the subsidy.

5.6 Conclusion

This paper selects four options for policies that have the potential to reduce GHG emissions in maritime shipping for further design and analysis. A fifth is added as a reference. These policy instruments are:

1 Emissions trading, either inclusion of shipping in the EU ETS or emissions trading for shipping under a separate directive but linked to the EU ETS.
2 An emissions tax with hypothecated revenues.
3 A mandatory limit on the operational efficiency indicator or the design index.
4 A baseline and credit system or differentiated harbour dues based on an operational efficiency indicator or a design index.
5 Voluntary action and innovation support.

In the next phase of the project, each of these instruments will be designed and their impacts will be assessed.

6 Design of an emissions trading scheme for maritime transport

6.1 Introduction

The design of an emissions trading scheme for shipping comprises the following design elements:
1   Responsible entity.
2   Geographical scope.
3   The climate unit.
4   Cap.
5   Initial allocation of allowances.
6   Use of revenues (if any).
7   Monitoring emissions.
8   Administration of reporting emissions and surrendering allowances.
9   Compliance and enforcement.
10 Expandability to third countries.
11 Ship size scope.
12 Ship type scope.

Each of these will be discussed in detail in this chapter.

6.2 Responsible entity

6.2.1 Options
A large number of responsible entities is in theory conceivable, e.g.:
–   The ship.
–   The registered owner.
–   The ship operator, e.g. the DOC holder.
–   The ship manager.
–   The charterer.
–   The consignee.
–   The fuel supplier.

6.2.2 Assessment of the options
The choice of the responsible entity cannot be assessed in isolation with other design choices. Especially the choice on the point of enforcement, the administration of surrendering allowances and the initial allocation are interconnected. For the choice of the responsible entity, especially the point of enforcement is relevant. As section 6.12 concludes, enforcement can best be organised in ports. Failure to surrender sufficient allowances will result in that ship being denied the right to call voluntarily at EU ports and such denial would be exercised by port based state control in accordance with Article 25.2 UNCLOS (the term port based state control is used here and throughout this report to identify all state agencies with enforcement powers that operate in ports, they comprise Port State Control as governed by Directive 2009/16/EC, but possibly also other agencies).

In such a system it makes sense to make the owner of the ship, the vessels' operator (e.g. the bareboat charterer or the disponent owner, or the DOC holder), or the charterer liable. They are the three entities involved in making use of seagoing vessels, and they are also to an extent in a position to make decisions that influence the amount of CO_2 emitted.

However, the ownership of a vessel may change, and during the course of a single year several operators, charters and consignees could potentially make use of a vessel and such could equally be the case even where ownership of the vessel has not changed. Such changes will complicate monitoring and enforcement.

The option of making the fuel supplier the responsible entity would imply that fuel bunkered in the scope of a scheme would be more expensive than fuel bunkered outside the scope of a scheme. Experience with a fuel tax introduced at the port of Long Beach in California suggests that many ships can easily bunker elsewhere, even in other parts of the world (Michaelis, 1997; LAO, 2001). Moreover, many ship owners and operators have indicated to us that they currently choose to bunker most where fuel is cheapest, and this can be anywhere on the route that they sail. Hence it is likely that making the fuel supplier the responsible entity would lead to many ships bunkering outside the EU and this would significantly limit the environmental effectiveness of such a system.

Norway taxes emissions of nitrogen oxides. In the shipping sector, ship owners are required to register for the tax. Foreign owners of taxable vessels with no place or business or domicile in Norway are not required to register in Norway. Undertakings of this nature may pay tax through a representative on their taxable traffic. Upon arrival in Norway the master or pilot of a foreign vessel must notify the customs authorities of the identity of the representative who will pay the tax. The owner of the ship and the representative are jointly and severally liable for the tax.

Sweden enforces mandatory fairway dues on all ships calling at Swedish ports. In an effort to facilitate and simplify the submission of data, the Swedish Maritime Administration, SMA, in 2005 introduced electronic reporting of the declaration for fairway dues. According to the ordinance, 'those who sign' declarations for fairway dues assume payment liability for these dues. The ordinance does not say whether signing the declaration and paying the due is a duty of the owner, the charter or the ships master. According to the SMA, some customers use agents for submitting declarations for fairway dues on their behalf. This is allowed provided that an agreement has been signed with the company to which invoices are to be sent.

In the case of the Swedish fairway dues, the ordinance does not specifically place the liability with any legal entity. It is understood to be the ship that needs to comply with the regulation. If it is deemed necessary to make a defined legal entity liable it would be natural to require the owner to register the ship and open a CO_2 account in its name. Also, from a legal point of view it may be better to place all responsibilities with the owner, who can then choose to delegate to the operator, the charterer or an agent to report and submit allowances that match the fuel consumed.

What may also argue in favour of making the owner legally responsible is that in a case where the shipping sector would be allocated some of the CO_2 allowances free of charge, the owner, or by agreement his agent, would be the only entity to which these allowances could be transferred.

This report therefore advices to make the ship the accounting entity and the ship owner the legally responsible entity. Making the ship the accounting entity has a number of advantages:

− The ship can be identified on the basis of its IMO number. In international shipping, every ship needs to have an IMO number, which is a permanent number that can be used for registration purposes (IMO resolution A.600(15); SOLAS Chapter XI).
− Anybody who has an interest in the continued operation of a ship on voyages to EU ports can surrender allowances on behalf of the ship, whether this is the owner, the charterer or the consignee.
− In case of non-compliance, the ship can be denied the right to call voluntarily at EU ports.

Making the ship the accounting entity puts a number of obligations on the ship.
− All participating ships that call at EU or EEA ports have to register with the relevant authority in charge of the scheme, identifying them by their IMO number.
− All participating ships that call at EU or EEA ports have to monitor emissions and submit verified emission reports to the relevant authority in charge of the scheme. In order to limit the administrative burden for ship owners, operators or charterers that are responsible for more than one ships, reports could be submitted on the emissions of more than one ship.
− All participating ships that call at EU or EEA ports have to surrender allowances to cover their emissions. Again, in order to reduce the administrative burden, it would be allowed to surrender allowances for more than one ship.

6.2.3 Conclusion

The responsible entity for surrendering allowances in an emissions trading scheme for maritime transport should be the ship owner. The accounting entity should be the ship. Hence, a ship owner is required to report emissions and surrender allowances for each ship he owns, and enforcement can target both the ship owner and the ship.

6.3 Geographical scope

6.3.1 Options

There are four options for defining the geographical scope:
1 Territorial sea option 15. In this option, the policy would be applied only to the GHG emissions that were released within the limits of the territorial sea. Within this option, all the ships loading or unloading their cargo within the territorial waters of the EU (thus either in the EU ports or via ship-to-ship transfer) would be obliged to submit allowances for all emissions of GHG released within the territorial zone of the EU (of any country being the EU Member). The ships that are only passing through the territorial zone, without making a port call or unloading the cargo would be excluded on the basis of the law on innocent passage. Data needed to calculate the required number of allowances would include emissions (fuel use) in the territorial waters of EU Member States (alternatively, emissions can be approximated by using data on tonne-miles travelled within the EU territorial zone, average fuel use per tonne-mile for a given ship and type of fuel used).

---

[15] Alternatively, contiguous zone or continental shelf option could be considered, which would allow to extend the geographical scope of the policy, subject to legal feasibility.

2   Only intra-EU shipping. In this option, the policy would apply only to the ships which travel from one EU port to another EU port.

3   All distance to the EU, all cargo option 16. This option would aim at covering all GHG emissions related to the whole distance to any EU port travelled by ships which make port calls at the EU ports or unload their cargo within the EU territorial waters zone. We assume that the EU port would be the point of calculation of GHG emissions for each ship. However, a question arises: where the measurement of emissions should start? This leads us to considering the following sub-options.
    a   Including emissions only from the last port call to the EU port.
    b   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU.
    c   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and from the last port call for ships with multiple bills of lading. For non-cargo ships, such as passenger ships, the port of last embarkation may be considered and for other ships, such as offshore support vessels, distance from last operation and transit to EU waters and then the time on station (as such vessels may loiter for long periods of time).

4   All distance to the EU, EU-bound cargo only option. This option would be similar to the option 3, with the difference that only the cargo with destination to the EU would be covered with the policy. Thus, allowances would have to be calculated for every unit of cargo (container or barrel of oil, etc.) which would be dispatched at any port worldwide with the destination of any EU Member State. The number of the required allowances would be calculated based on the data on transport work in tonne-miles travelled by all the EU destined cargo, fuel type and index of fuel used per tonne-mile specific for the ship.

6.3.2   Assessment of the options
The assessment of the options will focus on the following elements:
−   Environmental effectiveness. The environmental effectiveness of a policy is determined, among other factors, by the amount of emissions under the scheme. The larger this amount, the larger the environmental effect can be, other things being equal. Hence, we use the amount of emissions within the geographical scope as a measure for it's environmental effectiveness.
−   Possibilities for avoidance. Annex H analyses the potential for avoidance of a certain geographical scope based on the assumption that a scheme will be avoided if the benefits of doing so outweigh the costs. We use the findings of this annex to evaluate the possibilities for avoidance.
−   Legal feasibility. This aspect relates to the risk of a successful legal action against the scheme.
−   Administrative complexity. This feature is related mostly to the need of collecting and reporting data on CO_2 emissions.

---

[16]   'All cargo' as opposed to 'EU cargo' i.e. the cargo with destination to any EU country.

Environmental effectiveness

The basis for the assessment of the environmental effectiveness is the results of the model calculations of emissions presented in chapter 2.

1   Territorial sea option. Territorial waters extend only up to 12 nautical miles i.e. about 20 km from the coast line so for most voyages this distance would account for a small percentage of the distance travelled. Hence, the environmental effectiveness of this option as compared to most other options is very limited as ships emit most outside territorial waters. We cannot estimate exactly how large the emissions are. Table 21 in section 2.6 of this report shows that according to Entec (2005), CO_2 emissions in territorial waters of the EMEP region amounted to approximately 38 Mt. However the territorial waters are only a fraction of the EMEP region and this estimate was not considered to be reliable for reasons explained in section 2.6. If we assume that ships sailing on intra-EU voyages emit 25% of the CO_2 generated on these voyages in territorial waters and ships sailing intercontinental voyages do so for 5% of their emissions, the emissions can be estimated at 16% of emissions on routes to EU ports (33 Mt CO_2) and 12% of emissions on routes to and from EU ports (38 Mt CO_2).

2   Only intra-EU shipping. As shown in chapter 2, emissions on intra-EU voyages accounted for 112 Mt CO_2 in 2006, being 36% of emissions on voyages to and from EU ports and for 54 % of emissions on voyages to EU ports.

3   All distance to the EU, all cargo option.
    a   Including emissions only from the last port call to the EU port. The scope of emissions covered by the policy can be estimated to be at the level of approximately 208 Mt CO_2 per year, based on the modelling described in chapter 2.
    b   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. The emissions in this scope are hard to assess, as they depend on the length of the period. If this period is short, e.g. days or weeks, the scope will be in the order of 208 Mt or less. If the scope is longer, e.g. one year, most likely many emissions on voyages between two non-EU ports will be included in the scope, so the amount of emissions would be considerably higher.
    c   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. The scope of emissions covered by the policy can be estimated to be at the level of approximately 208 Mt CO_2 per year, based on the modelling described in chapter 2.

4   All distance to the EU, EU-bound cargo only option. The scope of emissions covered by the policy can be estimated to be below 208 Mt per year (the estimated general scope for the option 3), however the percentage of cargo not destined to the EU for ships arriving at the EU ports would not expected to be high thus the scope would not be expected to be much different from the scope of option 3.

Possibilities for avoidance

Annex H analyses the potential for avoidance of a certain geographical scope based on the assumption that a scheme will be avoided if the benefits of doing so outweigh the costs. Analysing the costs and benefits for a number of ship types and routes, it concludes that:

— If a voyage is defined so that no transshipment of cargo is necessary, the potential for avoidance is quite high, as the costs savings related to lower CO_2 fees are not counterbalanced with substantial costs related to such an additional port call.

— In options where a voyage is defined so that transshipment is necessary to start a new voyage, the potential for avoidance from an economic point of view would be very limited. However, based on the analyzed examples, some risk of avoidance can be observed in a situation of low freight rates and high CO_2 costs.

For some cargoes, a voyage can be defined so that avoidance can be reduced. For most bulk cargoes, there is a single port of loading and a single port of discharge, and the bill of lading identifies both (see box on bill of lading). For break bulk and containerized cargo, there is often not a single port of loading and there may be numerous bills of lading associated with the ship movement, many of which would have different ports. So for these voyages, a definition cannot be based on the port of lading and the port of discharge.

A definition of voyage that requires transshipment for starting a new voyage is the route from the port of loading to the port of discharge for ships with a single bill of lading and from the last port call for ships with multiple bills of lading or ships in ballast. For non-cargo ships, such as passenger ships, the port of last embarkation may be considered and for other ships, such as offshore support vessels, distance from last operation and transit to EU waters and then the time on station (as such vessels may loiter for long periods of time).

We can apply these findings to the options under consideration in the following way:

1 Territorial sea option. The possibilities for avoidance in this option would be small, as ships sailing to EU ports would have to pass through territorial waters.

2 Only intra-EU shipping. Avoidance can take several forms, depending on the definition of a 'port call'. If port calls without transhipment would mark the beginning of a new voyage, it would result in avoidance in areas where non-EU ports are not too far away from the intra-EU route. Routes in the Mediterranean, from the Mediterranean to other ports vice versa, in and to the Baltic are susceptible for avoidance. If, on the other hand, port calls are defined so that transshipment is necessary for bulk cargoes, avoidance would be possible in the same regions, but just for containerized and break bulk cargoes. We assume that avoidance would not be attractive for passenger ferries because of the associated additional time of the voyage (see, however, section 13.3 on cruise ships). Assuming that avoidance occurs for container ships, general cargo ships, and RoRo ships, and assuming that they could reduce their emissions under an intra-EU scheme to zero for half of their voyages, we estimate that the maximal potential for avoidance would be 22 Mt of emissions (19% of intra-EU emissions).

3   All distance to the EU, all cargo option.
     a   Including emissions only from the last port call to the EU port. This is likely to cause avoidance by inducing ship operators to make additional port calls in non-EU country. If we assume that all ships sailing from non-EU ports could reduce their emissions under the scope by 75% by making an additional call at a non-EU port near the EU and half of the ships sailing on intra-EU routes could reduce their emissions by 50%, the scope for avoidance can be estimated at 73 Mt in 2006 (35% of emissions on voyages to EU ports).
     b   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. This scope can be avoided by transhipping cargo, both in bulk and in break bulk. Even for break bulk cargoes, this option would require them to offload all of their cargo and loading it on another ship that is dedicated to transport within the EU. This would be costly and hence we conclude that avoidance of this option is probably small.
     c   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. This is likely to cause avoidance by inducing operators with break bulk cargoes to make additional port calls in non-EU country. If we assume that all container ships, general cargo ships, and RoRo ships sailing from non-EU ports could reduce their emissions under the scope by 75% by making an additional call at a non-EU port near the EU and half of these ship types on intra-EU voyages could reduce their emissions by 50%, the scope for avoidance can be estimated at 32 Mt in 2006 (16% of emissions on voyages to EU ports).

4   All distance to the EU, EU-bound cargo only option. This scheme can only be avoided by offloading cargo in a non-EU port and transporting it overland to the EU. As Table 39 suggests, the major European ports, with the possible exception of Algeciras, are far away from non-EU ports. Therefore we conclude that avoidance will be very small under this scheme.

Table 39   Major EU ports, 2007

Total cargo volume 1,000 tonnes		Container traffic TEUs	
Rotterdam	401,181	Rotterdam	10,790,604
Antwerp	182,897	Hamburg	9,917,180
Hamburg	140,923	Antwerp	8,175,951
Marseilles	96,282	Bremen/ Bremerhaven	4,892,056
Amsterdam Ports	87,840	Gioia Tauro	3,445,337
Le Havre	78,885	Algeciras-La Linea	3,414,345
Bremen/ Bremerhaven	69,095	Felixstowe	3,341,787
Grimsby and Immingham	66,279	Valencia	3,042,665
Genoa	57,189	Le Havre	2,638,000
Dunkirk	57,091	Barcelona	2,610,099

Source: American Association of Port Authorities.

> **Bills of lading**
>
> When a ship is loaded with cargo, the master of the ship, or the charterer of the ship (or their agents) is required to sign a bill of lading. The bill is often prepared by the shipper of the goods. Such document acts as evidence of receipt of the cargo, as a transferable document of title to the cargo and evidence of the contract of carriage between the holder of the bill and the ship owner or charterer (the carrier).
>
> The bill is a private commercial document - it does not serve a regulatory function although it is often required by customs authorities to calculate import dues and so on. In commercial law, it is often vital, for contractual reasons, that the bill of lading reflects accurately the amount of cargo on board and the date and place the cargo was shipped. For instance, with respect to an oil cargo, the date of shipment will determine the price to be paid by the buyer to the seller. A bill issued for a single container of furniture to be shipped by liner container service will reflect the date and place of loading but such information is unlikely to be so important.
>
> In a usual transaction the bill will be prepared by the shipper (usually the seller of goods) issued by the master or charterer and physically transferred (directly by the shipper or more usually through a banking chain) to the buyer of the cargo in return for payment. Possession of the bill allows the receiver to demand delivery of the goods at the discharge port. If international letters of credit are involved, then the bill will pass between banks in the country of export and the country of import. If the cargo is traded whilst en route, such as an oil cargo, then the bill will pass down a chain from buyer to buyer (or more usually, their banks). This often takes longer than the voyage so the cargo arrives at the discharge port before the bill. In such case, the ship owner usually will discharge the cargo to the receiver in the absence of a bill but in return for a letter of indemnity from the receiver holding the ship owner harmless in case the person receiving the cargo turns out not to be the person to whom the cargo should have been delivered.
>
> Whilst the bill of lading is good, reliable evidence of the date and place of shipment of the goods, and therefore a reliable indicator of the voyage undertaken, the delay in the bill arriving at the load port after the ship has discharged and sailed might make practical problems for their use in the scheme. That said, customs authorities always obtain copies of the bill for import duty purposes and would be able to provide this evidence to any emissions authority who would, in turn, be able to check the details of the voyage against those provided by the ship's master, agent, or emissions allowance accounting agent.
>
> It would be wrong to say that there is no instance of bills of lading being forged but such instances are, as far as the writer is aware, rare. The bill is an important document due to the three functions it performs and therefore more than one party would have to be involved in the fraud. This risk may decrease as the industry moves away from paper bills to electronic bills over the next few years.

Legal feasibility

This section assesses the legal enforceability of a scheme and the risk of a successful legal action against the scheme.

In general, with regard to enforcement, a route based scheme would appear to be a more attractive option. In particular it will be relatively easy for the port based state authority to assess the level of emissions from a ship during its journey from its load port to the discharge port in the EU according to the records held onboard the ship and the ability to assess emissions and the carbon efficiency of the vessel during the voyage. Formal notices can be provided to the ship regarding the emissions. Accounts for each ship can be held and maintained in the EU so that balancing payments can be made in relation to the ship at the end of the accounting period.

1   Territorial sea option. Inclusion of emissions of CO_2 within territorial waters for ships loading/unloading cargo in the EU ports does not seem to be challenging from a legal point of view. However the ships in innocent passage would need to be excluded from the scheme.

2   Only intra-EU shipping. From a legal point of view, the EU has no right to impose extraterritorial rules where it has no sovereignty or jurisdiction and a legal challenge is likely may be made. In response, the EU could argue that it was not attempting to exercise jurisdiction over waters outside its territorial sea. The scheme would simply apply as a condition of entry into EU ports. Both UNCLOS and GATT allow regional measures to be put into place to preserve and protect the environment. However the introduction of any such scheme is likely to be challenged by non-EU states on jurisdiction grounds and there are no provisions in UNCLOS or any other IMO conventions which could fully protect the EU from such challenges to the extraterritorial effect of the regulations.

3   All distance to the EU, all cargo option.
    a   Including emissions only from the last port call to the EU port. The legal feasibility of this option is the same as for option 2.
    b   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. Depending on the length of the period, there may be more extraterritorial emissions under the scope of the scheme which could aggravate the issue raised under option 2. A further issue, which will have trade and economic consequences, is that charterers or operators will not want to take on a vessel for a single journey to an EU port if upon entry to that port it is going to become liable for that ships' emissions for the specific allocated period of time prior to entry. These might have been incurred by previous operators and charterers; in such circumstances it is highly unlikely that the previous operator/charterer would agree to be liable for the allowances required to be made and as such a time based scheme would likely result in a distortion of competition. It would also be very unpopular as the lack of transparency would mean that passing such costs onto cargo and sub charters would be problematic. Further, in terms of the integrity of an EU ETS, it would appear that the operation of such a scheme should at least be based on a link between emissions in the EU and the ship's entry into EU waters. In circumstances where operators could be held liable not only for emissions incurred outside EU waters but further as in respect of journeys which were in no way connected with or destined for the EU, it is highly unlikely that the operation of such a scheme would be met with a warm reception by the international industry.
    c   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. The legal feasibility of this option is the same as for option 2.

4   All distance to the EU, EU-bound cargo only option. The legal feasibility of this option is the same as for option 2.

Administrative complexity

This section assesses the need to monitor and report data on CO_2 emissions. As a measure of administrative complexity directly associated with the choice of the geographical scope.

1 Territorial sea option. This option would require ships to monitor their fuel use from the point of entry of territorial waters to the point of exit. For ships that rely on tank soundings (see section 6.10), this may require additional tank soundings which, if taken at rough seas, would not always be very accurate. Moreover, it could be challenging to verify whether these measurements were indeed made at the right location. Note that a ship sailing at 12 knots passes through the territorial waters in one hour, so taking the measurement 5 or 10 minutes too early or too late could have a large impact on the emissions.

2 Only intra-EU shipping. This option would require ships to monitor their fuel use and emissions on every voyage between two EU ports. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions.

3 All distance to the EU, all cargo option.
   a Including emissions only from the last port call to the EU port. This option would require ships to monitor their fuel use and emissions on every voyage to an EU port. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions.
   b Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. This option would require ships to monitor their fuel use and emissions on a period prior to calling at an EU port. If this period is sufficiently long so that the ship operator may not yet know whether he will sail to an EU port in this period, he may have to monitor fuel use on a daily basis. This is actually the current practice for most ships who send noon reports including data on fuel use to the ship owner and/or operator. Whether the quality of these noon reports is sufficient for an ETS remains to be established.
   c Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. This option would require ships to monitor their fuel use and emissions on every voyage to an EU port. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions. In addition, ships would have to monitor whether or not a new bill of lading was issued at a port.
   d All distance to the EU, EU-bound cargo only option. This option would require ships to monitor their fuel use and emissions on every voyage to an EU port. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions. Moreover, they would have to monitor the share of cargo destined for the EU. This option would be administratively complex for ships carrying break bulk cargo or containers, where there may be multiple bills of lading. Ship owners would have to allocate emissions on every leg of every voyage to the various items of cargo on board.

Discussion

The assessments in this section are summarised in Table 40.

Table 40   Assessment of geographical scope options for emissions trading

		1: territorial waters	2: intra-EU	3a: last port of call to EU port	3b: period before entry in EU port	3c: port of laden to EU port	4: EU-bound cargo only
Environmental effect	Emissions under the scope (2006)	33-38 Mt CO_2	112 Mt CO_2	208 Mt CO_2	More or less than 208 Mt, depending on length of period	208 Mt CO_2	Less than 208 Mt CO_2
	Possibilities for avoidance	Small	22 Mt CO_2	73 Mt CO_2	Small	32 Mt CO_2	Small
Legal feasibility		Best	Second best	Second best	Third best	Second best	Second best
Administrative complexity		Less complex than 4, more complex than 2, 3a, and 3c	Less complex than 4, more complex than 3b	Less complex than 4, more complex than 3b	Least complex	Less complex than 4, more complex than 2 and 3a	Most complex

Option 3c has the largest amount of emissions under its scope, even when accounting for avoidance. Note, however, that the estimate of emissions that could be subject to avoidance depends on assumptions that have been hard to substantiate. Option 3c has a slightly higher administrative complexity than option 3a. The choice between option 3a and options 3c is one between environmental effectiveness and administrative complexity.

6.3.3   Conclusion

Among the identified options, option 3c, distance from the port of loading for ships with a single bill of lading and distance from the last port call for sips with multiple bills of lading or non-cargo ships, is the most recommended because:

- It has a large environmental effectiveness.
- It offers relatively little scope for avoidance.
- It does not have a large chance of successful legal action.

6.4   Ship size scope

Small ships tend to be small emitters. If administrative costs are relatively independent of ship size, the administrative burden for small ships would be large compared to their emissions. Hence, a size threshold could increase the overall cost-effectiveness of an emissions trading scheme by reducing the total administrative burden while not affecting the amount of emissions under the scope to the same degree.

A possible negative effect of a size threshold could be that it would distort the competitive market, by increasing the operating costs for ships above the threshold wile not affecting the costs for ships below the threshold. This could also impact the environmental effectiveness of the scheme by encouraging avoidance through using ships below the threshold.

This section assesses the ship size scope. It looks at the structure of the administrative costs.
This design choice depends on the emission calculations that yet have to be finalized.

6.4.1 Options

A ship size threshold that coincides with a threshold that is already used in the regulation of maritime transport does not create new market distortions. It may exacerbate current distortions, but the sector has learned to deal with those distortions.

In maritime regulation, two universal thresholds are used. IMO conventions such as MARPOL and the International Convention on the Control of Harmful Anti-fouling Systems on Ships have thresholds of 400 GT; SOLAS uses a threshold of 500 GT.

In addition, some conventions have a stepwise increase in liability based on size, but these conventions generally apply to specific ship types. The International Convention on Civil Liability for Oil Pollution Damage applies to all seagoing vessels actually carrying oil in bulk as cargo, but only ships carrying more than 2,000 tons of oil are required to maintain insurance in respect of oil pollution damage. Moreover, it specifies different compensation limits for ships of less than 5,000 GT, ships larger than 5,000 GT but smaller than 140,000 GT, and ships over 140,000 GT. The Convention on Limitation of Liability for Maritime Claims (LLMC) limits the liability for claims for loss of life or personal injury for ships up to 2,000 GT; between 2,000 and 30,000 GT; between 30,000 and 70,000 GT; and over 70,000 GT.

Chapter 2 shows that ships up to 5,000 GT account for 21.1% of emissions. We consider this to be a significant share. Increasing this share would undermine the environmental effectiveness of the scheme. Hence, we consider the following size thresholds:
1   No threshold.
2   400 GT.
3   500 GT.
4   5,000 GT.

6.4.2 Assessment of the options

Section 6.12 concludes that the administrative costs of an ETS are mainly in verification and reporting of emissions. Monitoring emissions carries little additional costs, as fuel use is monitored regularly on ships (see section 6.10). The costs of verification per ship owner are probably correlated with the number of ships the owner has, and there would probably be economies of scale as the verifier can use the same company information systems for each ship. This means that the choice for a threshold should be based on the emissions per ship owner.

Unfortunately, this assessment is limited by the availability of data. We do not have data on emissions and/or number of ships per ship owner (see chapter 2). Moreover, we are not allowed to publish data on the number of unique ships or their port calls from the Lloyds MIU database. Instead, we

report on the emissions per ship in relation to its size. Table 41 shows the emissions of vessels in different size classes and the number of calls of vessels of these size classes in major EU ports.

Table 41   Emissions of different size classes

	Port calls in major EU ports (2006)		Emissions on routes to Europe (2006)	
	Number	Share of total	Amount	Share of total
< 400	166,190 [a]	1.2% [a]	7.5	2.7%
400-500	54,262 [a]	0.4% [a]	1.3	0.5%
500-5,000	168,6470	12.4%	49.7	18.0%
> 5,000	11745565	86.0%	218.2	78.9%

Source: EUROSTAT; SEAKLIM.

(a)   Assuming that 25% of vessels in the class 100-500 GT are 400-500 GT large.

Table 41 shows that for the four size classes considered, the number of calls at major EU ports correlates well with the amount of emissions of these size classes. In fact, smaller ships emit more than their number of port calls in the EU. Hence, it is not possible to exclude a large number of ships from the scheme with only a limited impact on the emissions under the scope. Note, however, that this is a tentative conclusion and a more thorough analysis, including an analysis of the number of ships and their sizes per ship owner, would be warranted.

Because it does not seem possible to reduce the number of ships in the scheme without reducing the amount of emissions under the scheme even more, we advice to have a low size threshold for ships. A threshold of 400 GT seems best, as ships over this threshold have to comply with MARPOL regulations and thus can be expected to have adequate management systems on which monitoring and verification could be based.

6.4.3   Conclusion

Although more research may be needed, our conclusion is that the threshold should be set low, e.g. at 400 GT in line with the MARPOL threshold. Such a threshold would not create additional market distortions and there seems to be little benefit in raising the threshold.

6.5   Ship type scope

6.5.1   Options

A number of ship types have different operating characteristics than cargo vessels. For example, cruise ships, dredging vessels, offshore support vessels, tugs and fishing vessels do not transport cargo between ports. This section will assess whether the different mode of operations of these vessels constitutes a reason to exclude them from the scheme.

A second, related question, is whether inland ships can and/or should be incorporated in the scheme.

6.5.2 Assessment of the options

This section assesses if any ship types need to be excluded from the scheme and if so, which ones. On the basis of the preceding sections, ships need to satisfy a number of criteria in order to able to participate:

− They have to be identifiable, either by their IMO number or otherwise.
− They have to operate in the geographical scope of the scheme, i.e. they have to call at EU ports.

Non-cargo ships

The International Convention for the Safety of Life at Sea (SOLAS) provides that all passenger ships of 100 gross tonnage and above and all cargo ships of 300 gross tonnage and above shall be provided with an identification number conforming to the IMO ship identification number scheme, as adopted by resolution A.600(15) in 1987.

Although the requirement seems to be limited to passenger and cargo ships, an overview of the ships with an IMO number shows that many non-cargo and non-passenger ships also have an IMO number.

Table 42   Number of ships with an IMO number, 2007

Ship type	Ship size	Number of vessels with an IMO number
Ferry	Pax Only, 25kn+	984
Ferry	Pax Only, <25kn	2108
Ferry	RoPax, 25kn+	177
Ferry	RoPax, <25kn	3144
Cruise	100,000+ GT	24
Cruise	60-99,999 GT	69
Cruise	10-59,999 GT	130
Cruise	2-9,999 GT	74
Cruise	-1,999 GT	202
Yacht	Yacht	1051
Offshore	Crew/Supply Vessel	607
Offshore	Platform Supply Ship	1733
Offshore	Offshore Tug/Supply Ship	550
Offshore	Anchor Handling Tug Supply	1190
Offshore	Support/safety	487
Offshore	Pipe (various)	246
Offshore	FPSO, drill	273
Service	Research	895
Service	Tug	12330
Service	Dredging	1206
Service	SAR & Patrol	992
Service	Workboats	1067
Service	Other	813
Miscellaneous	Fishing	12849
Miscellaneous	Trawlers	9709
Miscellaneous	Other fishing	1291
Miscellaneous	Other	667

Source: Buhaug et al., 2009.

So in practice, all self-propelled seagoing ships over 100 or 300 GT have an IMO number.

Inland ships

Inland navigation in Europe is concentrated on the Rhine and Scheldt estuary and the Danube (Eurostat, 2007). In total, inland navigation provided 138 billion tonne kilometres in 2006, which is 5.6% of total transport work within the EU (Eurostat, 2008). In the Rhine and Scheldt estuary, about 10,000 self-propelled inland vessels were registered in 2008 (CCNR, 2008).

Emissions of inland ships are not reported regularly for the EU-27. For the Netherlands and Germany, estimations have been carried out of the actual emissions of inland water vessels on the national territory. For the Netherlands 1.79 Mt CO_2 emissions are reported for 2006 (PBL et al., 2009). Thereby emissions from commercial inland navigation, from passenger ships and ferries, as well as from recreational craft are taken into account (Klein et al., 2007). For Germany 2.19 Mt CO_2 are reported for 2004 (ITP and BVU, 2007). Here only the transport of goods is being considered. Taken the emission data of Netherlands and Germany together this results in about 4 Mt of CO_2.

Another way to estimate of the CO_2 emissions is to make use of the total transport work of the vessels and to apply an average emission factor. In the estimation of the German emissions an average emission factor of about 35 g CO_2/tkm is being used. IFEU (2005) reports an average of 30-49g/tkm for Europe. Applying this latter emission factor range to the 138 billion tkm reported this results into about 4-7 Mt of CO_2 related to the transport of goods on EU-27 inland water ways.

As inland vessels are registered in EU countries and regularly call at EU ports, it would be feasible to include them in an emissions trading scheme.

Note that if the initial allocation of allowances (see section 6.8) would be done on the basis of an output benchmark, or of the revenues would be recycled on the basis of output, it would be much harder if not impossible to incorporate these vessel types in the scheme as their output cannot be measured in tonne-miles.

6.5.3 Conclusion

All ship types can be included. The scheme can include inland shipping, if this is considered to be desirable.

6.6 The climate unit

CO_2 is the only greenhouse gas emitted by maritime transport that is emitted in large quantities and for which a Global Warming Potential has been established.

Emissions of methane for 2007 are estimated at 240 kilotonne for the world fleet, or 6 Mt CO_2 eq.(Buhaug et al., 2009). Emissions on voyages to the EU, assuming that they are proportional to fuel use, would total 1 Mt CO_2 eq. About 60% of these emissions are associated with the transport of crude oil and are hard to monitor (Buhaug et al., 2009). Therefore, it does not seem to be feasible to include methane emissions in the emissions trading scheme.

Emissions of HFCs for 2007 are estimated at 400 tonne for the world fleet, or less than 6 Mt CO_2 eq. (Buhaug et al., 2009). Again assuming that the share of these emissions on voyages to the EU is proportional to the share of fuel used on voyages to the EU, the emissions under the scope of the system equal less than 1 Mt CO_2 eq.

Some other gases emitted by shipping have indirect climate impacts. However, there is currently no scientific consensus on the GWP of these gases (CE et al., 2008). Consequently, they cannot be included in an emissions trading scheme.

6.7 Cap

6.7.1 Options

In the EU ETS, the cap has generally been based on estimated historical emissions and a politically agreed reduction path. This was implicit in the first and second phase, and explicit in the review which takes 2005 emissions as a baseline (2009/29/EC). The inclusion of aviation in the EU ETS also has a cap that is based on historical emissions, this time the average 2004-2006 emissions (2008/101/EC). For global GHG emissions, the European Council adopted a cap of 20% below 2005 emissions in 2020 (EU Council, 2009).

Another option could be to set the cap so that it would not impact the price in the EU ETS, as has been proposed by Norway in the case of a global emissions trading scheme for shipping (MEPC/4/24).

A third options would be to base the cap on a climate stabilisation scenario. This can be done by allocating a share of the available carbon budget compatible with a stabilisation scenario to shipping. The share could equal the current or the historical share of emissions of emissions in the total emissions. Such a cap has been quantified for global emissions in Lee et al., 2009.

A fourth option would be to set the cap as a political decision.

6.7.2 Assessment of the options

Historical emissions. The position of the EC on the Copenhagen agreement states that maritime emissions should be included in a global agreement and proposes a cap on emission rates for maritime emissions of 20% below 2005 levels by 2020.

The question is whether this cap can be quantified. Ship emissions on voyages to the EU are estimated at 208 Mt in 2006. This estimate has the same range of uncertainty as the estimate in Buhaug et al., 2009, i.e. ±20%. This range is considerably larger than the range for aviation emissions or the 2005 emissions of stationary installations. If the uncertainty range is considered to be unacceptable, more accurate data could be obtained by introducing a requirement to monitor and report fuel use on emissions to EU ports prior to implementing the emissions trading scheme. A disadvantage of this would be that for the shipping sector as a whole and, if allowances are freely allocated based on historical emissions, for individual ships this would in fact be an incentive to emit during the reporting period. Moreover, it would delay the implementation of an emissions trading scheme by at least two years: one year for data collection and one for setting the cap and distributing allowances.

Equal marginal abatement costs. In order to be able to calculate the marginal costs in an emissions trading scheme one needs to have a good forecast of emissions and a marginal abatement cost curve. In the case of shipping, the forecast would be based on current emissions and emission growth and have a larger range of uncertainty than the current emissions. Moreover, the marginal abatement cost curve for shipping has a considerable degree of uncertainty: at a price level of € 30 per tonne of CO_2, the range of uncertainty due to the uncertainty in the abatement potential and costs of the measures is ± 37%, without taking fuel price uncertainty into account. As these uncertainties are cumulative, the total uncertainty would be at least ± 60%. This report therefore does not consider this option to be feasible.

Moreover, setting the level on the basis of equal marginal abatement costs is not necessarily the most equitable option. If the cap would be set at this level, there would be no net trading between the shipping sector and other sectors in the EU ETS. It could be argued, however, that a fair burden is not achieved by the determination of the cap. If all emission allowances are auctioned to the maritime sector and the revenues of such an auction are not recycled to the sector, and if the price of the auction is equal to the price in the trading scheme, it makes no difference for the maritime sector whether it buys allowances at the auction or at the market. Hence, where the is set does not determine the financial impacts on the sector, but just the level of global emissions. Instead, the (financial) burden for the maritime sector is determined by the amount of emission allowances which are allocated at no cost to the maritime sector. Whether such an amount is fair depends upon the amount of emission allowances which are allocated for free to other sectors. However, in the EU ETS, different sectors are already treated differently, which makes a comparison problematic.

Climate stabilisation scenario. As stated above, Lee et al., 2009 have quantified a cumulative emissions cap based on a climate stabilisation scenario. If the share of shipping in the future climate budget would be set equal to the share in the emissions since pre-industrial times, the cumulative cap for shipping would be 40 GT CO_2 in the period 2006-2050 for a stabilisation at 450 ppm CO_2 scenario. If the share of shipping would be set equal to its current share in emissions, the cumulative cap would be 36 GT CO_2. Assuming constant growth rates, the global cap for 2030 would be 765-815 Mt CO_2, and assuming the EU's share is proportional to the global share, the EU cap would be 158-169 Mt CO_2 in 2030.

All these estimates are subject to the same uncertainties as the estimate of current emissions, i.e. ± 20%.

A political decision could take into account the estimates of current emissions and of the marginal abatement costs, the risks associated with setting the cap too high or too low, the ambition of climate policy and other politically relevant factors.

6.7.3 Conclusion

If the emissions trading scheme needs to be implemented soon, a political decision is the only feasible way to set the cap, as the degree of uncertainty in current emissions is quite high. The political decision could be informed by emission estimates presented in this reports, by equity considerations and by natural science arguments relating to climate stabilisation scenarios. If a delay of two year and a perverse incentive during one of these years is acceptable, the cap can be set on empirical emissions data collected prior to the implementation of the scheme.

6.8 Initial allocation of allowances

6.8.1 Options
In principle, there are three methods for the initial allocation of allowances:
- Auctioning.
- Free allocation on the basis of historic emissions.
- Free allocation on the basis of an output benchmark.

In practice, the number of options is larger as two or more of the above options may be combined.

6.8.2 Assessment of the options

Allocation by auction
The arguments in favour of auctioning the allowances fall into four categories; the use of auction revenues, avoiding windfall gains, positive effects on industry dynamics and administrative burden[17].

Auctioning the allowances would create substantial revenues that could be used for reducing the rates of distortionary taxes elsewhere in the economy. The use of the revenues is discussed in more detail in section 6.9.

A second reason for auctioning is to avoid the generation of windfall profits, which may occur when allowances are given away free of charge. Regardless of whether the initial allocation of allowances is carried out by auction or by grandfathering based on historic emissions, enforcing a cap on emissions acts to raise the marginal cost of production. A company that receives grandfather rights will, if production expands, need to purchase additional permits at market price. Firms will also have to contemplate the opportunity cost of keeping emission allowances, which could otherwise have been sold. The effect of this is to raise product prices in order to pass on to the customers the marginal cost of emission allowances.

In the EU ETS free allocation of allowances to the power industry has resulted in windfall profits, in particular in deregulated markets (Sijm et al., 2006)[18]. Whether windfall gains would also occur in the shipping sector depends on the extent to which ship owners and charterers would be capable of passing on the marginal cost to freight owners and passengers. Their ability to do so may change over time and vary among the various types of shipping, being greater in times of high demand, and smaller in situations of overcapacity.

Auctioning promotes an efficient long-term evolution of the industries that are subject to the trading scheme as it ensures that existing firms and new entries are given equal treatment. Regular auctioning will also tend to increase market liquidity and transparency, which in turn will help to dampen tendencies to high price volatility. Having to buy allowances on auction may also make management focus on the allowance market and stimulate change in response to the price.

---

[17] OECD (Stephen Smith), *Environmentally Related Taxes and Tradable Permit Systems in Practice*, Paris 11TH June 2008.

[18] Sijm, J; Neuhoff, K.; and Chen, Y. (2006), CO_2 cost pass-through and windfall profits in the power sector, Climate Policy, no. 6, 2006, pp.49-72.

In contrast to free allocation, auctioning does not require monitoring and reporting of emissions or output data prior to the allocation of allowances. Moreover, auctioning can be implemented quickly because Member States already will have experience with auctioning allowances to land-based emission sources and aviation.

A potentially negative effect of auctioning is that it places a financial burden on the regulated industries. This may cause problems in energy-intensive industries that are subject to global competition. The cost of fuel is already substantial in most types of shipping, but all ships calling at EU ports would be given the same treatment regardless of ownership and flag.

Free allocation based on historic emissions

Besides removing all or part of the financial burden from the industry (but, as shown above, not necessarily from its customers) what argues in favour of grandfathering is that imposing a new regulation on pre-existing facilities may be viewed as unfair. It could be argued that those who ordered the ships already in use had little reason to anticipate the introduction of an emissions trading scheme that would increase the cost of burning fossil fuels. Given the long life of sea vessels this may be true for new capacity ordered in the 1980s and early 1990s, while for any ship built during the last fifteen years the owner may have been aware that maritime transport would at some point in time start to contribute to climate change mitigation. Moreover, owners and operators of existing ships also have considerable potential to reduce emissions by operational measures and retrofitting.

In many parts of shipping, ships may be active in one part of the world during a certain period, and in another part of the world in the next period. So it is likely that a significant number of ships that would report emissions under the scheme in a certain year would not have emissions in the next. If allowances would then be grandfathered over a trading period, a ship that would be active in Europe in one year would receive free allowances over a number of years, while another ship that happened to trade outside Europe in the first year and would be active in Europe in the next years would not receive any allowances. This would distort the market. Such market distortion may be overcome by new entrant and closure rules, but these create inefficiencies (they would subsidise ships to remain in Europe) and would probably be very complicated in the case of shipping.

Free allocation based on a benchmark

An alternative way of compensating firms for the financial burden of purchasing allowances on auction is to allocate emission allowances based on each firm's output level. Compared to free allocation based on historic emissions, an output-based allocation has the advantage of rewarding early action, i.e. improvements in efficiency made prior to the introduction of a scheme. Moreover, it would reward efficient operators as they would receive more allowances relative to their emissions than inefficient operators (MMU and CE, 2007).

Free allocation based on a benchmark has two disadvantages. One is a general disadvantage, the other is specific to the shipping sector.

The general disadvantage of free allocation based on a benchmark is that it is very data-intensive. Output data needs to be monitored, verified and reported to the authorities. This is a considerable administrative burden.

The disadvantage specific to shipping is that it would be very hard to design a benchmark that would be a relevant measure of output for all ships. Currently, many bulk ships measure their output in tonne-miles, but the output of container ships is measured in TEU-miles. Car carriers, ferries, cruise ships, LNG and LPG tankers, dredgers, tugs, offshore support and fishing vessels may have still other output metrics. It would be a considerable challenge to design a metric for output that would be applicable to s large part of the fleet, let alone to all ships.

An alternative could be to use a measure of input rather than output, i.e. cargo-carrying capacity rather than actual transport performance. Each ship has a certified size, measured in GT or dwt, and it is conceivable to use a metric such as GT-miles or dwt-miles as a basis for the initial allocation.

A question that needs to be addressed in the case of free allocation on the basis of a benchmark is whether to take ship size into consideration. All else equal, large ships are more energy-efficient than smaller vessels, which may argue in favour of enforcing the same baseline regardless of size. However, making use of large vessels may in some circumstances mean having to accept a longer journey as ships above a certain size cannot use the Panama Canal. The use of large ships may also give rise longer trips by feeder boats.

It should be noted that free allocation on the basis of a benchmark does not differ from grandfathering where the risk of windfall gains and poor liquidity in the allowance market are concerned. Moreover, free allocation on the basis of a benchmark would share the main disadvantage of free allocation based on historical emissions, viz. that ships are highly mobile and free allocation could distort the market and keep new entrants out.

Limiting the financial impact on the shipping sector

Although auctioning all the allowances has many advantages, there may be a need to reduce the financial impact on the shipping sector during a phase-in period. As is clear from the analysis above, this could hardly be done with partial free allocation, as free allocation in the shipping sector causes market distortions due to the fact that ships are movable objects.

In principle, the financial impacts on the shipping sector could be reduced by auctioning all allowances and then recycling some of the revenues. However, this would imply a hypothecation of revenues, which may be opposed and even be unconstitutional in some Member States.

An alternative way of gradually introducing full responsibility in the shipping sector may be to rule that ships initially only have to surrender allowances equal to a certain portion of their emissions. Such an approach would have three disadvantages:
- The cap will in practice not apply fully until the liability reaches 100%.
- The approach de facto lowers the carbon price for the shipping sector and therefore reduces the incentive to take action.
- It could lead to higher overall GHG emissions: a tonne of CO_2 bought from other trading schemes would allow the emission of more than one tonne in the shipping sector, thus increasing overall emissions.

Yet another way of gradual introduction of liability would be to recycle allowances, a mild form of grandfathering. Ships could during a few years be awarded some allowances free of charge based on the reported individual emissions of the previous year. The free allocation would never represent more than a certain percentage of the emissions caused during the year

before. The first year of operation could be used as a trial when ships have to report emissions but do not have to surrender any allowances. As each ship would be granted free allowances during the forthcoming year based on its emission report, the trial would provide a strong incentive to deliver.

In order to diminish the usual disadvantages of grandfathering (described above), the emissions reported during year one would only be used for awarding allowances for the next year. For year three, the emissions of year two would be the basis for calculating the amount of free allowances and so on. When limiting the allocation of free allowances based on historic emissions to one year, the risk that a ship owner will make money from selling the allowances and moving the ship to some other part of the world would be small. However, other disadvantages from grandfathering remain. For instance, high polluting ships are rewarded (even though they only get back allowances matching part of the emissions caused). Therefore this model for compensating the industry should only be used during a transitory period during which the share that is allocated free of charge is gradually reduced to zero.

6.8.3 Conclusion

Auctioning allowances has major economic advantages:
− It promotes economic efficiency if the auction revenues are used to reduce distortionary taxes.
− It avoids the windfall gains associated with free allocation. And
− It has positive effects on industry dynamics as it treats new entrants, closing entities; growing and declining entities alike.

Yet, there are three possible reasons to allocate allowances for free:
1   Protect industries from losing market shares to competitors in non-participating countries.
2   Ensure equal treatment of industries covered by the EU ETS.
3   Temporarily allocate freely in order to give a sector time to adjust to new circumstances.

The first reason is not applicable to shipping when all vessels calling at participating ports, regardless of flag and port of departure, must surrender allowances equal to the fuel used. The second and third reason could, however, support the argument for free allocation of part of the allowances.

In that case, there are five possibilities:
1   Free allocation on the basis of historic emissions.
2   Free allocation on the basis of an ex-ante output benchmark.
3   Partial recycling of allowances.
4   Gradually increase the share of emissions for which allowances have to be surrendered.
5   Recycling auction revenue ex-post based on output.

The first three options may be problematic since vessels engaged in tramp shipping may have irregular emissions within the scope of a regional scheme. Nevertheless the variant based on 'recycling of allowances' could be contemplated as it would be a simple way of compensating ship owners and would provide them with a strong incentive to report emissions during the initial trial year. The fourth option is also easy to implement but has the disadvantage of not enforcing a definitive cap until the year when 100% liability is reached. The fifth option probably has a higher administrative cost, yet the incentives to reduce emissions are higher.

6.9 Use of revenues (if any)

6.9.1 Options

This section discusses three options for use of the revenue:

1   Use the revenue as tax income.
2   Recycle the revenue back to the participants of the scheme (ship owners).
3   Use the revenue to fund research on and development of emission reducing technologies.

6.9.2 Assessment of the options

There are legal and economic considerations regarding the use of revenues. As for the legal considerations, pursuant to the principle of subsidiarity the EU may only act (i.e. make laws) where action of individual countries would be insufficient. The principle of subsidiarity can be overridden where certain criteria are met. From a legal perspective, it is argued that hypothecation of EU ETS revenues breaches the principle of subsidiarity, a fundamental principle of EU law, enshrined in Article 5(2) EC Treaty. Any attempt to earmark revenues, by transferring competence away from Member States to the EU level, could breach this principle. The principle of subsidiarity has not been challenged before the EU Courts in relation to the current EU ETS scheme. However, the question has been, politically, highly controversial, most recently during the drafting of the Aviation Directive, due to the opposition of a number of Member States, including the UK, to any earmarking of revenues. It is very likely that any attempt to hypothecate revenues in relation to maritime emissions would meet the same opposition. We also understand that the hypothecation of revenues may be unconstitutional in certain Member States.

In the context of carbon dioxide emissions and climate change it may be possible to demonstrate that there is some need for collective action at the Community level; however, whilst this argument would support the imposition of an emissions trading scheme, it would not appear to extend to the hypothecation of revenues generated. Rather the destination of funds raised through emissions trading would appear to be a matter that could be satisfactorily regulated at the Member State level.

Nevertheless, it could be argued that international transport does not fall under the jurisdiction of Member States (or any other states for that matter). This is typically an issue where a common European decision is needed in the absence of a global solution. The revenue is money without an obvious owner which the appropriate EU bodies can decide to use for climate change mitigation and adaptation or to distribute among MS. The latter may show problematic as disagreement between major port States and land-locked countries over the principles is easily foreseen.

However, if emissions from domestic traffic are to be covered by the same scheme, the national treasuries may have a case concerning the revenues that are tied to this portion of overall traffic. If so, it should be possible to transfer this part (as lump-sums) to the coastal countries concerned.

As for the economic considerations, there are arguments both for and against hypothecation. These general arguments can be divided in four categories (Revenue 2006):

−   Based on efficiency. Governments have to allocate resources over a wide range of sectors. The actual allocation depends on where funds are spent best. The most efficient allocation would rank all projects and fund the highest ranking ones. Hypothecation, i.e. restricting allocation of funds

would create inefficiencies unless coincidentally all the projects in the sector that benefits from hypothecation would be amongst the projects that would be funded anyway. So in the absence of government failure, efficiency arguments are clearly against hypothecation.

- **Based on equity.** Equity issues might create arguments in favour of hypothecation, e.g. if high price changes brought about by including maritime transport in an emissions trading scheme would disproportionally affect lower income households or developing countries. The former is unlikely as the expected price increase of consumer products is unlikely to be more than a percent (see section 12.3.5). However, the second may be an issue. We will study the impact on developing countries in more detail in the impact assessment.

- **Based on acceptability.** The acceptability of an emissions trading scheme by the maritime shipping sector could be higher if proceeds would be ploughed back into the sector than if revenues were not hypothecated. From this perspective, revenue earmarking can lower administrative costs of policy implementation (e.g. lobbying and negotiation costs) although this could be offset with generally higher administrative costs of the scheme with hypothecation as compared to no hypothecation. This may be used as an argument for hypothecation.

- **Based on political and administrative considerations.** Hypothecation, depending on the criteria used for spending the revenue, could imply higher administrative costs related to creating a new institution and rules. This is an argument against hypothecation.

On the basis of these arguments, it is hard to see that there would be an economic benefit in using the revenue for anything else than fiscal purposes. This would open the way to reduce distortionary taxes in the economy.

However, In the field of climate change (and of environmental protection in general), economists have argued that there are two market failures that reduce the rate of innovation (Jaffe et al., 2005). The first is that pollution is often an externality. When shipping is included in an ETS, this would no longer be the case for CO_2. The second is that there are knowledge spillovers and other externalities that in general result in lower than optimal investments in R&D. The existence of these two market failures could be addressed by using some of the revenue of an auction to fund R&D into emission reducing technologies (see chapter 11).

In addition, if the EU were to auction the allowances allocated to maritime shipping, the proceeds would presumably have to be distributed among Member States based on some key. An alternative option would be to use the money for some common good, perhaps as a contribution to the mitigation of and adaption to global warming, in particular in the developing countries. It could be argued that without this way of financing such efforts they would have to be paid for by taxes raised in the individual Member States, and thus marginally add to the use of distortionary taxes.

6.9.3 Conclusion
In summary, hypothecation seems to be restricted legally. Nevertheless, in some cases there could be arguments for using part of the revenue for funding R&D and/or financing climate policy in developing countries. How large this part should be, is a question beyond the scope of this report.

6.10 Monitoring emissions

6.10.1 Options
A policy addressing CO_2 emissions from shipping would require the establishment of emissions from individual ships in a consistent and verifiable manner. Since CO_2 emissions are proportional to fuel consumption it is necessary to establish the fuel consumption from ships.

There are two basic approaches to tracking fuel consumption onboard ships:
1   Fuel inventory management.
2   Measuring and recording fuel consumption directly as it happens.

All ships have some knowledge and record of the amount of fuel carried at certain points in time, and many ships record fuel consumption on a daily basis, although not all ships have equipment needed for measuring fuel consumption directly.

6.10.2 Assessment of the options
The main data sources that are available to monitor fuel use are:
1   Total amount fuel purchased by (or on behalf of) the ship.
2   Total amount bunkered.
3   Measuring fuel tank levels (or tank pressure, etc.)
4   Measuring flow to engines/day tanks/settling tanks.

Each will be discussed in more detail below. After this review, this section will review current practice of fuel monitoring on board ships and design a monitoring scheme that can be used for the inclusion of vessels in an emissions trading scheme.

Total amount fuel purchased by (or on behalf of) the ship
Information necessary to establish the total amount of fuel purchased is normally contained within the budgets, accounts and records kept at a ship operator, however it needs not be readily available.

The amount purchased within a certain timeframe can differ from the amount of fuel used within the same time frame; hence fuel inventory information is also needed to establish periodic consumption. To establish the inventory it would be necessary to measure fuel tank levels (see below). In the event that geographic criteria are used to define emissions covered, this cannot be determined by accounts alone. With respect to verification/audit, it may be difficult to document that as ship has not received fuel purchased by a third party.

Total amount fuel bunkered
There are existing requirements (Regulation 18 of MARPOL Annex VI) that a bunker delivery note (BDN) containing information the quantity of fuel in metric tons loaded is to be kept onboard for a period of three years. BDN information may also be made available by the ship to the ship operator/ management office, however it can be relied on to be available onboard the ship.

A BDN states the total quantity of fuel bunkered (metric tonnes) and density at 15°C (kg/m^3), as well as sulphur content (% m/m).

The quantity of fuel bunkered stated on the BDN is measured using ASTM look-up tables to correct the volume to 15°C and a density measurement in conjunction with 'dipping' the sounding pipes to measure tank volume to

calculate the total mass of the bunker fuel delivered. BDNs have an accuracy level of 1 to 5%[19].

The amount bunkered within a certain timeframe can differ from the amount of fuel used within the same time frame, hence fuel inventory information is also needed to establish periodic consumption. In the event that geographic criteria are used to define emissions covered, this cannot be determined by bunkered amounts alone. With respect to verification/audit, it may be difficult to document that a bunker delivery note is presented for all bunkering operations undertaken and that the quantity of the bunker delivery note is correct (i.e. not forged, etc.).

Measuring fuel tank levels

Fuel tank levels are commonly measured onboard ships. In modern ships, tank soundings are normally taken using built-in automatic systems, such as pitot tubes (which measure pressure) or radar tank level indication systems, both of which transmit readings to the engine control room. These devices need to be regularly calibrated to ensure accuracy (calibration dates should be recorded), and this may currently not always be done as there are no regulations for this.

Additionally, tank soundings can be manually taken with a measuring tape and digital thermometer via sounding pipes (need to be kept free of sludges that may cause inaccuracies in measurements), although this method is less common as it takes a greater amount of time.

Sounding is a very common since it is a transparent way of measuring the fuel level that can be done also by third parties. When sounding is done to the benefit of third parties, the dipstick may be coated with a chemical that changes colour if contacted with (pure) water

Sounding tables are necessary to convert tank level to volume. Typically, this is available in an approved form through the ship stability documentation. Fuel density information is necessary to calculate the corresponding mass. This is available from the BDN, however blending onboard may cause slight complications. Fuel temperature will also affect volume.

A ship may have a large number of fuel tanks, with different quantities and grades of fuel. Accuracy of sounding is limited, and may be affected by trim, heeling, etc. Manual sounding may be very inaccurate at sea if the ship is moving.

Alternatively, fuel mass in the tank can be measured by way of measuring the pressure in the bottom of the tank. Fuel density and temperature information is not needed in this case.

Fuel tank level can be measured at specified times to establish an inventory. Changes in tank levels correspond to consumption provided that fuel is not transferred between tanks or supplied from shore, hence this must be controlled.

---

[19]   Bunkerspot, Vol. 6, No.1, Feb/March 2009.

Measuring fuel flow

Net fuel flow to the engine can be measured directly using various types fuel flow meters. Flow meters record the actual fuel used on any voyage; the data can be used to prove fuel consumption, however, the seal must be intact to ensure validity.

Fuel Consumption Monitoring Systems incorporating electronic fuel flow meters (with digital display) are the most accurate and reliable method of measuring fuel consumption in marine diesel engines. Flow meters are fitted to the main engine fuel supply and return lines and are used to constantly monitor fuel consumption. The values recorded by the flow meters are calculated in the fuel flow calculation unit and form the basis for all other functions in the system; fuel consumed over a given distance/period of time can be mapped to within an accuracy of +/- 0.2%.

Flow meters of turbine type are common in bigger ships while many smaller ships do not have fuel flow meters. In many cases, fuel flow to the settling tank or day tank is measured rather than net flow to the engine which requires two flow meters (supply and return flow). Turbine flow meters measure rotational speed of a turbine in the pipe which can be converted to volumetric flow. The accuracy depends inter alia on accurate information on fuel viscosity and density.

Fuel flow measurement will allow breakdown by time interval. Geographical breakdown can be done if combined with a positioning information system e.g. GPS.

Current practice

Different practices are used for monitoring fuel consumption onboard ships depending on needs and means. For accounting and budgeting, information on a ships' accumulated fuel consumption over extended periods (e.g. a year) can be obtained with reasonable accuracy, however a certain lack of consistency must be expected between values determined from measurements onboard and those from bunker delivery notes and what can be determined by bunker bills[20]. Differences may be attributed to lack of accuracy in onboard measurements, however the accuracy in determining the amount of fuel loaded may also vary between the various bunker barges and facilities around the world.

In case of contracts where the ship is chartered to a third party who pays the fuel bill, fuel consumption is commonly establishes as follows: At the start of the charter contract, the amount of fuel onboard the ship is established by sounding of tanks by an independent party or jointly by the ship crew and a representative of the charterer. When a chartered ship is bunkering, the amount of fuel received is determined by tank sounding and a declaration of how much fuel has been received is prepared by the ship for the charterer. Each day of voyage the ship reports speed and consumption to the charterer in a so-called noon report covering. The consumption at sea is established by flow meters. Usually, at the end of the voyage the tanks are sounded to establish true fuel consumption at sea. Fuel consumption reported during voyages in noon reports is the corrected to maintain consistency. At the end of

---

[20] Note that while a ship's fuel consumption can be established with a reasonable accuracy, ship owners are not obliged to report fuel consumption. Hence, there are no central databases of fuel consumption in maritime transport with a similar accuracy. Rather the best available estimates of global emissions have a margin of error of ± 20% (Buhaug et al., 2009).

the charter contract, the amount of fuel onboard the ship is then established by an independent party or jointly by the ship crew and a representative of the charterer.

Quantities loaded are usually determined by pre and post delivery tank measurements on both the bunker tanker and the receiving vessel. A drip sample is collected during fuel loading. Taking such a sample is a legal obligation. This sample, know as the MARPOL sample, is sealed and stored onboard the ship for possible analysis by a port based state control. This sample is to verify the correctness of the bunker delivery note supplied with the sample. Additionally, it is common practice to take additional samples for commercial analysis.

Fuel consumption related claims and disputes
There are principally two types of claims with respect to fuel bunkered. These are:
− Over-consumption, claims that the vessel is consuming more fuel than agreed.
− Disputes regarding the amount of fuel bunkered.

Claims for over-consumption are generally related to ships using more fuel compared to the speed achieved than what is agreed in the charter contract. Since fuel consumption figures in charter contract are subject to weather, ships may tend to claim bad weather to avoid fuel claims. It is not uncommon for charterers to attempt to verify weather claims from ships using satellite weather data, which may result in discussion. Generally, this type of controversy emphasise fulfilment contract obligations, it is uncommon that actual amount fuel used onboard the ship is questioned. This said, there are stories of chief engineers manipulating fuel consumption report to take advantage of adverse weather conditions to report excessive fuel consumption. However, to do this it may be necessary to falsify the engine logbook which is a serious offence in many states and may even result in criminal prosecution.

Disputes may occasionally arise between the ship and the bunker supplier regarding the amount of fuel bunkered. To reduce disputes, the presence of a neutral third party may be beneficial. At the time of the bunkering, the ship will invite the supplier to take part in taking a drip sample (the MARPOL sample) and in an estimated 50% of bunkerings also a commercial sample that the ship will dispatch to a fuel analysis service. The ship will only sign for 'volume at temperature' and the amount of fuel received may be finally determined following analysis of the test sample.

EU legal competence
The method by which fuel is monitored is usually a part of the ship's construction, design and equipment and such issues are generally under the jurisdiction of the flag state in line with generally accepted international regulations. The MARPOL regulations referred to above set out regulations for sampling to be carried out on bunker fuel together with records to be kept and samples to be retained. These regulations are related to the delivery and use of lower, and low, sulphur fuel.

Port states do not usually require equipment on board which is in excess of the generally required standards of international shipping. However, in a number of cases, port states are requiring standards of visiting ships to be higher than those required under the international conventions as discussed above. As the

port state has sovereignty over its port, then it may require compliance with whatever domestic laws it chooses to put into place, subject only to general international law and the sanctions required to be put in place to obtain compliance.

It would arguably not be outside the competence of the EU, for instance, to require that vessels calling at its ports installed fuel monitoring equipment particularly as such equipment is not expensive to install and would not require major work to do so. Enforcement would be more problematic - if a vessel was detained until the equipment had been installed could be seen as discrimination in favour of European installers of such equipment. Release of the vessel on condition that such equipment was installed at another port may be effective but may cause a problem of proportionality and reasonableness if the EU were to ban a serviceable ship from its ports for not having installed the equipment on its next visit.

Documentation of fuel consumption in a regulatory setting

In the regulatory perspective, there are two principal options for documenting fuel consumption. One is inventory control and the other is direct fuel consumption measurement.

– Inventory control would involve monitoring of fuel consumption by documenting all fuel onboard the ship at start and end of the period in question as well as all supply (and possible de-bunkering) of fuel within the period.
– Measurement would involve installation and maintaining an approved system for documenting fuel consumption. This would system would be different from what is presently used onboard ships today.

Generally, flow measurement is more accurate for short time intervals, while for extended time frames, inventory management is equally or possibly more accurate depending on measuring device used. Some comments regarding the merits of these options with respect to different applications is given below.

Table 43   Comments on verification in different settings

Geographical scope	Inventory control
All voyages to EU ports	Inventory could be established at start and end of each voyage e.g. by sounding. Verification could be done by comparing to log books and other documents that may be available on the ship.
Annual reporting	Inventory could be established at start and end of each period. Verification of ship record books could be cross checked with company account, etc., however this type of information may be difficult to access in many cases.

Fuel carbon content

The amount of CO_2 emissions from the combustion of each tonne fuel depends on the mass fraction carbon in the fuel. The mass fraction carbon depends on the chemical composition of the fuel, content of water, sulphur and more. The mass fraction carbon is not part of marine fuel specification and not shown in available documentation such as BDNs. Using the actual carbon content of the fuel is thus not practically feasible as it would involve an additional analysis of the bunker samples on board. Rather, it is necessary to find a compromise solution based on a set of default values.

In order to determine the CO_2 emissions from marine fuel, the fuel consumption can be multiplied with a CO_2 emissions factor which expresses the number of tonnes CO_2 that is emitted for each tonne fuel that is burned. The following CO_2 emissions factors have been derived from the IPCC guidelines.

Table 44   Energy based CO_2 emissions factor (kg/TJ) - IPCC Guidelines

	Default	Low	High
Marine diesel and marine gas oils (distillate)	74 100	72 600	74 800
Residual fuel oils	77 400	75 500	78 800

Using fuel density data from the same guideline it is possible to convert these figures to mass basis which is convenient for ship emission.

Table 45   Fuel based CO_2 emissions factor (tonne/tonne fuel) - IPCC Guidelines

	Default	Low	High
Marine diesel and marine gas oils (distillate)	3.19	3.01	3.24
Residual fuel oils	3.13	3.00	3.29

A pragmatic approach to determining fuel carbon content would be to classify fuels as either distillate or residual and assign emission factors as per the IPCC guideline defaults. The difference in emissions factor is already small. A more refined breakdown of fuel qualities would appear to give little in terms of increased accuracy or incentive for better performance, however the issue of classifying fuels would become more challenging since a legal definition of the fuel grades is needed and the information required must be available to all ships. Distinction between residual and distillate fuels may be done by density where any fuel with density < 890 kg/m^3 would be classified as distillate and receive the higher emission factor.

Outline of an emissions monitoring, reporting and verification scheme

A monitoring, reporting and verification scheme for ship emissions would comprise the following elements:

1   The responsible entity submits an emissions monitoring and verification plan to the competent authority, based on the most accurate fuel measurements possible on his ship(s).
2   The responsible entity establishes the amount of CO_2 emissions from his or her activities that are subject to the regulation in a manner that facilitates verification at a later time.
3   The documentation necessary for verification is kept by the responsible entity for a specified period of time.
4   The verifier verifies the accuracy of the monitoring report.
5   The responsible entity reports verified emissions to the responsible entity.

It could be necessary to provide guidance with respect to what documentation would be suitable. Fuel consumption data established by the use of an appropriately approved fuel consumption measuring and recording device should probably be an option. However, since this would involve installing equipment onboard ships, this cannot be the only option. Alternative documentation could be ship log books, etc. These logs could be based on fuel consumption based on tank sounding.

The emission estimates can be verified using ship movement data and fuel purchase data. Both are available from company records. In addition, a number of sources can be used to verify ship movement data, including SafeSeaNet data on ships over 300 GT arriving in EU ports. Currently, SafeSeaNet data comprises ship identification (name, call sign, IMO number or MMSI number); port of destination, Estimated time of arrival and estimated time of departure of that port; total number of persons on board. So on this basis it can be established whether the ship was in an EU port and if so, how many times during the reporting period. If the last port of call could be added to SafeSeaNet, this information can also be used to assess the quality of fuel consumption data. SafeSeaNet's legal basis is Directive 2002/59/EC.

Costs of monitoring fuel consumption

The outline of the scheme above identifies two major cost items. First, fuel consumption has to be monitored and collated in a report. Second, the monitoring report needs to be verified. Here, we estimate the costs of these items.

Monitoring and reporting of fuel consumption is normal practice in the maritime industry. While not a legal requirement, tank soundings or flow meters are utilized due to fuel bunkering, charterer party agreements or voyage management practices. This means that while the accuracy of this data might be in question the mechanisms for monitoring and reporting of emissions from an individual ship are already established and any costs associated with this would be limited to manpower to establish practices to meet the requirements and increase accuracy of fuel consumption reporting.

In a system where the geographical scope is all voyages to the EU port, monitoring fuel would have to be done in ports. Hence the costs are correlated to the number of port calls in the geographical scope of the system. For ships that have many port calls, such as ferries, a requirement to monitor fuel per voyage may increase the administrative burden. For these ships, a choice should be given to monitor fuel consumption annually.

The cost to verify annual CO_2 emissions from an individual ship will be dependent on the requirements detailed in the approved monitoring plan, level of assurance required, quality of data and operational profile of the ship, with potential different requirements for example, vessels operating solely between European countries (fuel purchased) and voyage analysis for vessels entering EU ports that have departed from a port outside EU waters. Taking the unknowns into account one can understand that it is hard to calculate an accurate cost figure. However, comparing with current CO_2 certification practices the costs would be expected to be less than US$ 10,000 (approximately € 6,700) per ship.

6.10.3 Conclusion

Fuel consumption is routinely monitored on board ships. Records are being kept of both annual fuel purchases and per voyage fuel use. Most larger vessels have fuel flow meters that are able to record fuel use with an accuracy of ± 0.2%. Other vessels may have to rely on sounding tanks which has a lower accuracy.

Upon implementation of an emissions trading scheme for maritime shipping, ships could be given two choices:
1   Monitor fuel per voyage.
2   Monitor fuel use per annum.

The latter option would be attractive for ships that operate exclusively or predominantly between EU ports. In both cases, ships would have to indicate how they will monitor fuel use.

The main costs associated with monitoring and reporting emissions would stem from the verification of the data. These costs are hard to estimate, but unlikely to exceed US$ 10,000 (approximately € 6,700) per ship.

6.11 Administration of reporting emissions and surrendering allowances

6.11.1 Options

Ships would have the obligation to report verified emissions and surrender allowances to an authority. The frequency of reporting and surrendering allowances could either be per voyage or annually.

In addition, a choice has to be made with regards to the authority. There are two options:
1   A central European regulator.
2   Member States.

And finally, emissions reports will have to be verified.

6.11.2 Assessment of the options

Frequency of reporting and surrendering
Both options on the frequency have their advantages and disadvantages, which are summarised below.

Reporting emissions per voyages
Advantages:
−   Ensures all relevant voyages are reported, recorded, inspections can take place and enforcement if necessary.
−   Ensures infrequent visitors are included in the scheme.
−   Evasion can be identified as it happens as opposed to annual.
−   Limits effect of changes or owners/charterers.
Disadvantages:
−   Reporting requirements relatively high, especially for vessels with frequent EU port calls – SSS, ferries, RoRo, RoPax, offshore, fishing, etc.
−   Inspection, Verification and enforcement of every vessel calling into an EU port is not feasible (Paris MOU has target to inspect 25% of foreign vessels? - inspects over 20,000 vessels per year).
−   Increased burden on crew that already have to verify bunker and stores, deal with customs, immigration, Port State Control, class, Flag, agents and any number of vetting agencies in relatively short period of time
−   Potential increase in delays and port congestion – delay in bunkering for inspection.
−   Adds a reporting stream – If CO_2 accounts are going to be verified by third party.

Reporting emissions annually
Advantages
−   Lower Administrative burden for both ship and administration.
−   Reduced burden on crew for reporting, this can be handled shore side.
−   Annual verification of CO_2 account by independent 3rd party.

Disadvantages
- Dependant on voyage definition, reporting and recording requirements might need to be modified.
- Changes of owners or charterers might add some complexity account maintained and unique to ship.
- Potential new reporting lines will be required as person liable for paying for emissions might not be paying for fuel.
- Enforcement issues for non-payers outside the EU.

Both methodologies pose significant issues to any scheme. Voyage reporting will ensure all ships are captured and enable effective enforcement but the administrative burden would be large, especially if all reports have to be verified. In addition, there may be costs associated with longer times in port. Annual reporting would simplify the administrative burden but poses issues of enforcement for ships infrequently entering EU jurisdiction.

On balance, annual surrendering of allowances is to be recommended as it would reduce the administrative burden both on the ships and on the authorities.

Choice of the administrative authority

To whom would ships need to report annually? As indicated in section 6.11.1, it could be either to Member States or to a central European authority. In the former, the question is to which Member State each ship would have to report. In aviation, the aircraft operator is the responsible entity. Each non-EU aircraft operator is assigned to the Member State in which it provides most of the transport work. Transposing this system to the maritime sector could be attractive at first glance, but it could be complicated because of the choice to make the ship the accounting entity. If, for example, each ship would have to report to the Member State in which it has most port visits, it could mean that a ship owner or operator who has several ships would have to report to several Member States. This could be administratively complex.

In order to reduce the administrative burden on ship operators, it would be possible to require that each ship wishing to enter an EU port would need to register in the Member State of its choice. In that way, operators could report and surrender allowances for all their ships to a single Member State. In practice, upon approach to an EU harbour each ship could be required to indicate to which Member State it will report its emissions. A central register could be set-up to be able to check the information provided by the ship. If the ship indicates that it has not yet chosen a Member State, it can either do so at that time or be assigned to the Member State whose port it is about to enter.

If there would be a central European authority, each ship wishing to enter an EU port would need to indicate whether it has registered with that authority. Again, the State could check this information in the central registry of the European authority.

In both cases, it would probably be useful to have a central registry of port calls in order to facilitate the verification of the emission reports.

Verification

As in the EU ETS, each emission report will have to be verified by an independent verifier. Depending on whether the report will be based on per voyage emissions or on total annual emissions, the report will need to contain different types of information.

A report based on per voyage emissions during a year needs to contain at least:
- Voyages to the EU in that year, both number and routes.
- Fuel use on these voyages.

A report based on annual emissions needs to contain the following information:
- Level of the fuel tanks at the beginning of the year.
- Number of fuel purchases.
- Types and quantities of fuel purchased.
- Emissions factors.
- Level of the fuel tanks at the end of the year.
- Number of port calls and distances sailed.

6.11.3 Conclusion

In order to limit the administrative burden on the ships, reporting and surrendering allowances should be annual.

Whether ships should report to Member States or to a central authority needs to be further assessed.

6.12 Compliance and enforcement

6.12.1 Options

Ships and their owners are regulated by three entities: flag state, port state and to an extent by classification societies, although these are paid consultants of the ship owner/operator.
- The principal authority and jurisdiction is with the flag State. It is the Flag States' obligation to 'exercise its jurisdiction and control in administrative, technical and social matters over ships flying its flag' (UNCLOS).
- A port state exercises port state control, i.e. the inspection of foreign flagged ships in ports of a State to verify that the condition of the ship and its equipment comply with the requirements of international conventions and that it is manned and operated in compliance with applicable international laws. Ships may be detained for unseaworthiness or non-compliance and, in the worst cases, banned from trading to the ports of that state. Moreover, port states may carry out other inspections either through port state control or other port based agencies.
- Whilst classification societies have a role in ensuring that vessels are built and maintained to internationally agreed standards, they are paid by and answer to the ship owner and are limited to providing reports and certification in this regard.

Since the emissions trading scheme will be flag neutral in order not to distort the competitive market, and since enforcement can best be organized by port states.

6.12.2 Further elaboration of the option

In general, the enforcement by the EU of any scheme with the aim of reducing carbon emissions would in practice have to be carried out at EU ports as member states exercise exclusive jurisdiction over their ports and ships calling at EU ports are required to comply with the laws of that port state.

Member States will transpose EU legislation into national legislation with the ship being accountable for reporting to the appointed authority in that member State. The ship will take steps to independently verify the emissions reported. In most jurisdictions, the administrative authority would need to be given specific statutory power to demand compliance and to detain vessels that do not comply.

As for the costs of enforcement, enforcement of any EU action to reduce CO_2 emissions from international shipping would be flag neutral being enforced through port based state control for foreign flagged vessels and the Flag State Authority for vessels falling under national jurisdiction. These are already established systems across the EU and compliance and enforcement would become just another requirement under their inspection regimes. Therefore, as long as there are no major non-compliance issues, any increase in cost by the addition of another requirement can be considered minimal. Any potential significant costs that could arise would be in relation to any detentions and legal challenges, which at this stage can not be quantified.

6.13 Expandability to third countries

The European Union has made clear that in making international shipping contribute to greenhouse gas mitigation it would prefer a global scheme. Its reason for preparing unilateral action is a fear that the International Maritime Organisation may currently not decide on the introduction of a global model. Acting unilaterally therefore does not mean wanting to stay alone. To make the emissions trading scheme fully effective it must gradually expand to countries in other parts of the world. Therefore Europe has good reasons to try to design its scheme in a way that makes expandability possible and easy.

One can envisage four different ways of future geographical expansion of emissions trading in the shipping sector:
1   The European system is expanded to cover emissions from traffic to non-EU countries.
2   Complementary national or regional schemes are developed in other parts of the world.
3   The EU initiates a convention that establishes an international scheme primarily aimed at Annex 1 countries.
4   The European system is scrapped at some future date in favour of a future global emissions trading scheme under the auspices of the IMO (or the UNFCCC).

The latter of these four ways of expansion means that the European system will cease to exist in the moment when the EU enters the global scheme. It may nevertheless be important to try to design the European scheme in such away that most of its features could be incorporated in the global scheme. The European scheme would then act as a model for the design of a future global scheme.

The first of the options for expansion mentioned above is complicated and would, if shipping is part of the EU ETS, require that the Directive is changed for every new entry. An alternative may be to create a Maritime Emissions Trading Scheme (METS), separate from the EU ETS, which would allow the EU to negotiate with non-EU States, who may later want to join the scheme, without having to consider the inclusion of emissions from non-maritime sources of the candidate countries. However, also in this case every expansion to new countries would require the EU to change the Directive. If such an expansion is foreseen when drafting the Directive it could be designed as to make new entrants require a minimum of change. However, as the environment is an area of shared competence between the EC and its Member States, any extension of the METS to non-EU States in the form of an international agreement would nevertheless require the consent of both the EC and each of the Member States individually. Such a ratification process may turn out to be lengthy. It may be possible to implement the expansion on a provisional basis, though this would depend on the national law of the Member States.

The second of the above alternatives means refraining from expanding the European system in favour of engaging in bilateral agreements with non-EU States who want to introduce caps on emissions from international transport by ships. The preferred option for geographical scope in this report is 'port of loading to EU port' which in section 2.3.2 is defined as 'the distance from the port where most of the cargo was loaded'. The bilateral agreements therefore must as a minimum handle the issue of double counting and may include the creation of mechanisms for compensating ships that have been forced to submit allowances to two different schemes for the same amount of cargo or distance. However, any bilateral agreement would also have to be ratified by all Member States, and negotiations with non-EU countries may result in pressure to change some of the basic elements of the METS.

The third possibility mentioned above would be for the EU to invite non-Member States to participate in the creation of a new international treaty (convention) which additional countries may enter and ratify at a later stage (without having an opportunity to change the rules). This option would, of course, require the ratification of the European Union and all EU Member States. Trade between a maritime emissions trading scheme and the EU ETS could be made possible by establishing a link between them. This may require an amendment to the current EU ETS directive.

The countries and regions that currently appear likely to contemplate maritime emissions trading in a case when the IMO does not decide on a global system are Annex 1 countries whose governments have expressed their intention to introduce caps on domestic emissions in accordance with the Kyoto Protocol, e.g. the United States, Australia and Japan. However, all of these have not yet made clear in the IMO process whether they prefer maritime emissions trading to the Danish proposal for a levy that would finance a fund that would pay for greenhouse gas abatement projects in developing countries that can offset any emissions above a global cap on emissions from shipping. However, it is worth noting that the American legislation, if based on the Waxman-Markey Bill, will include (by an up-stream approach) any bunker fuel sold to aviation and shipping, including aircraft and ships used in international voyages. At the moment of writing, the Senate discusses a similar proposal by senators Boxer and Kerry, and the issue of allowing a rebate for emissions from bunker fuels that may later be covered by a future international agreement has been brought to the Senate's attention.

An expansion of a European scheme to all or most Annex 1 countries would extend its scope to a clear majority of all carbon emissions from international shipping as all emissions from journeys between Annex 1 countries would be covered, and in addition emissions from journeys from non-Annex 1 to Annex 1 countries. CE et al., 2009 estimates that emissions on routes to Annex 1 countries accounted for 468 Mt CO_2 (47% of global emissions) in 2006.

Regardless of which of the above options becomes the final choice of the EC it is essential to facilitate the entry of new participants by designing the scheme in a way that makes it easy to include additional countries and ports. When this happens the system must be able to adjust the emission cap accordingly and to allow the newcomers a proportional influence over the scheme and its administration.

In order to facilitate a gradual expansion of the scheme it is essential to allow ships to choose between a trip-based and a time-based emission liability. Ships that are used only for journeys between participating ports and ships that only occasionally travel outside the geographical area covered by the scheme would naturally choose to report fuel consumption and surrender allowances within the framework of a time-based system. As the scheme expands geographically a growing percentage of all ships will end-up belonging to the categories for which a time-based liability would function well. One advantage of this is that ships will not have to break-down fuel deliveries on different journeys or trip-legs; another is that any combustion of fuel that takes place at berth would automatically be covered. With universal coverage (the final stage) there would no longer be any need to distinguish between fuels used on different voyages as the liability would cover emissions from traffic to all ports of the world.

In a case where there would not be a global scheme in time to meet the EU deadline, the European Union and its potential partners may have reasons to try to make the IMO support, or at least accept, its unilateral action. One way of achieving this could be to urge the IMO to endorse the idea of an international maritime emissions trading scheme that is open to voluntary participation by states and ports. Such a scheme could initially aim at the participation of all or most Annex 1 countries and later grow to include newly industrialised nations. At some future stage such a scheme would probably be taken over by the IMO. One way of making non-Annex 1 countries support an IMO decision to endorse the scheme would be to allocate some of the revenues raised by auctioning CO_2 allowances to programmes aimed at climate change mitigation and adaptation in developing countries.

It may be in the interest of the European Union to develop a strategy for how to advance its maritime emissions trading scheme even before it is launched. If so, the EU will have to consider how to tackle the conflict within the IMO over how to reconcile the principles of the UNFCCC with those of the IMO. Delegations to the IMO representing developing countries claim that the principle of common but differentiated responsibility under the UNFCCC means that any mandatory regime aimed at reducing GHG emissions from ships should be applicable to the Annex 1 countries only. Delegations representing Annex 1 countries, on the other hand, underline that the IMO has a global mandate and should never discriminate among ships as special treatment would distort trade and competition. In this context it is important to recognize that about three quarters of the world's merchant fleet fly the flags of countries not listed in Annex 1 and that many of these ships are owned by firms in industrialised nations. Therefore any regulatory regime for combating

GHG from shipping would be ineffective if applied only on ships registered in Annex 1 countries.

Kågeson (2007) suggests that away around this problem may be to start with freight transport carried out on behalf of Annex 1 countries and to seek support among developing countries for the inclusion of emissions from voyages not only to ports of Annex 1 countries but also from traffic in the opposite direction. A global scheme designed in this way may have a chance of being recognised as fair as it would cover all emissions generated by ships travelling solely in the waters of Annex 1 countries and, in addition, all ships travelling to and from the ports of these countries on transcontinental voyages. This means that countries in other parts of the world would be affected only to the extent that they use shipping for trade with Annex 1 countries. The ports of these countries would not have to participate as the port based state control would only take place in Annex 1 countries. Local and regional trade in non-Annex 1 areas would not be affected at all, and neither would long-distance voyages between non-Annex 1 countries. The geographical scope would thus be global, albeit limited to ships that call at ports of the participating states.

The EU could rightly argue that including trade between Annex 1 and non-Annex 1 countries would be away of making developing countries pay a small part of the mitigation of greenhouse gases caused by international shipping. The scheme would thus honour the principle of common but differentiated responsibility, while asking nothing from the developing nations would not. If the proceeds from auctioning allowances to ships that are subject to the scheme were used for greenhouse gas mitigation and adaptation primarily in the developing nations, they would gain a lot more from their limited participation than they would contribute.

6.13.1 Conclusion

To make it possible to gradually extend the scheme and finally turn it into a global system, an international convention with the participation of the United States and other Annex 1 countries may be considered as an alternative to including maritime transport emissions in the EU ETS directive. Trade between the Maritime Emissions Trading Scheme (METS) and the EU ETS could be made possible by establishing a link between them.

6.14 Emissions trading and the policy objectives

Section 4.6 states two policy objectives.

The first policy objective is to limit or reduce maritime GHG emissions.

The secondary policy objective is to remove barriers and market failures that prevent measures to improve fuel efficiency from being implemented, so that the first objective can be met in the most cost-effective way.

An emissions trading system for maritime transport would effectively limit the maritime GHG emissions to the cap. There would be some carbon leakage as a result of avoidance, but the amount seems to be limited and this can be taken into account when setting the cap.

As for the market barriers and market failures, since the emissions trading scheme would internalise the costs of CO_2, it would create an additional incentive to reduce emissions, thus increasing the importance that ship owners

and operators attach to this issue. Monitoring and reporting requirements may also draw ship owners attention to emissions and to emissions abatement measures. However, emissions trading does little to reduce the market failures and barriers that were considered to remain the most important, i.e. the split incentive in parts of the shipping market, transaction costs and the time lag.

6.15 Emissions trading: summary of policy design

The responsible entity for surrendering allowances in an emissions trading scheme for maritime transport should be the ship owner. The accounting entity should be the ship. Hence, a ship owner is required to report emissions and surrender allowances for each ship he owns and enforcement can target both the ship owner and the ship.

The geographical scope proposed here is all voyages to EU ports, starting from the port of loading for ships with a single bill of lading and the last port call for sips with multiple bills of lading or non-cargo ships. This scope has a large environmental effectiveness; offers relatively little scope for avoidance; and does not have a large chance of successful legal action.

All ship types can be included. The scheme can include inland shipping, if this is considered to be desirable.

The size threshold could be set low, e.g. at 400 GT in line with the MARPOL threshold. Such a threshold would not create additional market distortions and there seems to be little benefit in raising the threshold.

CO_2 is the only greenhouse gas emitted by maritime transport that is emitted in large quantities and for which a Global Warming Potential has been established. Therefore, the traded unit can be a tonne of CO_2.

If the emissions trading scheme needs to be implemented soon, a political decision is the only feasible way to set the cap, as the degree of uncertainty in current emissions is quite high. The political decision could be informed by emission estimates presented in this reports, by equity considerations and by natural science arguments relating to climate stabilisation scenarios. If a delay of two year and a perverse incentive during one of these years is acceptable, the cap can be set on empirical emissions data collected prior to the implementation of the scheme.

As for the initial allocation, auctioning allowances has major economic advantages:
– It promotes economic efficiency if the auction revenues are used to reduce distortionary taxes.
– It avoids the windfall gains associated with free allocation. And,
– It has positive effects on industry dynamics as it treats new entrants, closing entities; growing and declining entities alike.

Yet, there are two reasons to allocate allowances for free:
1 Ensure equal treatment of industries covered by the EU ETS.
2 Temporarily allocate freely in order to give a sector time to adjust to new circumstances.

It is not possible to set an output based benchmark for the entire shipping sector. Neither is it possible to set a historical baseline per ship, as the amount of emissions a ship has under the scope of the ETS may vary significantly from year to year. Therefore, we recommend to recycle the allowances.

The revenues from the auction could be hypothecated, although hypothecation seems to be restricted legally. Still, in some cases there could be arguments for using part of the revenue for funding R&D and/or financing climate policy in developing countries.

As for monitoring and reporting, fuel consumption is routinely monitored on board ships. Records are being kept of both annual fuel purchases and per voyage fuel use. Most larger vessels have fuel flow meters that are able to record fuel use with an accuracy of ± 0.2%. Other vessels may have to rely on sounding tanks which has a lower accuracy.

Upon implementation of an emissions trading scheme for maritime shipping, ships could be given two choices:
1   Monitor fuel per voyage.
2   Monitor fuel use per annum.

The latter option would be attractive for ships that operate exclusively or predominantly between EU ports. In both cases, ships would have to indicate how they will monitor fuel use.

The main costs associated with monitoring and reporting emissions would stem from the verification of the data. These costs are hard to estimate, but unlikely to exceed US$ 10,000 (approximately € 6,700) per ship.

In order to limit the administrative burden on the ships, reporting and surrendering allowances should be annual.

Whether ships should report to Member States or to a central authority needs to be further assessed.

In general, the enforcement by the EU of any scheme with the aim of reducing carbon emissions would in practice have to be carried out at EU ports as member states exercise exclusive jurisdiction over their ports and ships calling at EU ports are required to comply with the laws of that port state.

Member States will transpose EU legislation into national legislation with the ship being accountable for reporting to the appointed authority in that member State. The ship owner will take steps to independently verify the emissions reported. In most jurisdictions, the administrative authority would need to be given specific statutory power to demand compliance and to detain vessels that do not comply.

As for the costs of enforcement, enforcement of any EU action to reduce CO_2 emissions from international shipping would be flag neutral being enforced through port based state control for foreign flagged vessels and the Flag State Authority for vessels falling under national jurisdiction. These are already established systems across the EU and compliance and enforcement would become just another requirement under their inspection regimes. Therefore, as long as there are no major non-compliance issues, any increase in cost by the addition of another requirement can be considered minimal. Any potential

significant costs that could arise would be in relation to any detentions and legal challenges, which at this stage can not be quantified.

To make it possible to gradually extend the scheme and finally turn it into a global system, an international convention with the participation of the United States and other Annex 1 countries may be considered as an alternative to including maritime transport emissions in the EU ETS directive. Trade between the Maritime Emissions Trading Scheme (METS) and the EU ETS could be made possible by establishing a link between them.

7 Design of an emissions tax for maritime transport

7.1 Introduction

The design of an emissions tax for shipping comprises the following design elements:
1. Responsible entity.
2. Geographical scope.
3. Tax basis.
4. Level of the tax.
5. Use of revenues.
6. Monitoring emissions.
7. Administration of reporting emissions.
8. Compliance and enforcement.
9. Expandability to third countries.
10. Ship size scope.
11. Ship type scope.

Each of these will be discussed in detail in this chapter. As many of the arguments are the same as for emissions trading, this chapter contains many cross-references to chapter 6 on emissions trading.

7.2 Responsible entity

The issues to be taken into consideration when selecting the entity which would be responsible for paying a CO_2 tax on emissions caused by ships are similar to those set out in section 6.2 regarding emissions trading.

A large number of responsible entities is in theory conceivable, e.g.:
- The ship.
- The registered owner.
- The ship operator, e.g. the DOC holder.
- The ship manager.
- The charterer.
- The consignee.
- The fuel supplier.

7.2.1 Assessment of the options
The choice of the responsible entity cannot be assessed in isolation with other design choices. Especially the choice on the point of enforcement and the administration of the tax are interconnected. For the choice of the responsible entity, especially the point of enforcement is relevant. As section 6.12 concludes, enforcement can best be organised in ports. Failure to pay the tax will result in that ship being denied the right to call voluntarily at EU ports and such denial would be exercised by port based state control in accordance with Article 25.2 UNCLOS.

In such a system it makes sense to make the owner of the ship, the vessels' operator (e.g. the bareboat charterer or the disponent owner, or the DOC holder), or the charterer liable. They are the three entities involved in making use of seagoing vessels, and they are also to an extent in a position to make decisions that influence the amount of CO_2 emitted.

However, the ownership of a vessel may change, and during the course of a single year several operators, charters and consignees could potentially make use of a vessel and such could equally be the case even where ownership of the vessel has not changed. Such changes will complicate monitoring and enforcement.

The option of making the fuel supplier the responsible entity would imply that fuel bunkered in the scope of a scheme would be more expensive than fuel bunkered outside the scope of a scheme. Experience with a fuel tax introduced at the port of Long Beach in California suggests that many ships can easily bunker elsewhere, even in other parts of the world (Michaelis, 1997; LAO, 2001). Moreover, many ship owners and operators have indicated to us that they currently choose to bunker most where fuel is cheapest, and this can be anywhere on the route that they sail. Hence it is likely that making the fuel supplier the responsible entity would lead to many ships bunkering outside the EU and this would significantly limit the environmental effectiveness of such a system.

Norway taxes emissions of nitrogen oxides. In the shipping sector, ship owners are required to register for the tax. Foreign owners of taxable vessels with no place or business or domicile in Norway are not required to register in Norway. Undertakings of this nature may pay tax through a representative on their taxable traffic. Upon arrival in Norway the master or pilot of a foreign vessel must notify the customs authorities of the identity of the representative who will pay the tax. The owner of the ship and the representative are jointly and severally liable for the tax.

Sweden enforces mandatory fairway dues on all ships calling at Swedish ports. In an effort to facilitate and simplify the submission of data, the Swedish Maritime Administration, SMA, in 2005 introduced electronic reporting of the declaration for fairway dues. According to the ordinance, 'those who sign' declarations for fairway dues assume payment liability for these dues. The ordinance does not say whether signing the declaration and paying the due is a duty of the owner, the charter or the ships master. According to the SMA, some customers use agents for submitting declarations for fairway dues on their behalf. This is allowed provided that an agreement has been signed with the company to which invoices are to be sent.

In the case of the Swedish fairway dues, the ordinance does not specifically place the liability with any legal entity. It is understood to be the ship that needs to comply with the regulation. If it is deemed necessary to make a defined legal entity liable it would be natural to require the owner to register the ship and open a CO_2 account in its name. Also, from a legal point of view it may be better to place all responsibilities with the owner, who can then choose to delegate to the operator, the charterer or an agent to report and submit allowances that match the fuel consumed.

What may also argue in favour of making the owner legally responsible is that in a case where the shipping sector would be allocated some of the CO_2 allowances free of charge, the owner, or by agreement his agent, would be the only entity to which these allowances could be transferred.

This report therefore advices to make the ship the accounting entity and the ship owner the legally responsible entity. Making the ship the accounting entity has a number of advantages:

- The ship can be identified on the basis of its IMO number. In international shipping, every ship needs to have an IMO number, which is a permanent number that can be used for registration purposes (IMO resolution A.600(15); SOLAS Chapter XI).
- Anybody who has an interest in the continued operation of a ship on voyages to EU ports can pay the tax on behalf of the ship, whether this is the owner, the charterer or the consignee.
- In case of non-compliance, the ship can be denied the right to call voluntarily at EU ports.

Making the ship the accounting entity puts a number of obligations on the ship.
- All participating ships that call at EU or EEA ports have to register with the relevant authority in charge of the scheme, identifying them by their IMO number.
- All participating ships that call at EU or EEA ports have to monitor emissions and submit verified emission reports to the relevant authority in charge of the scheme. In order to limit the administrative burden for ship owners, operators or charterers that are responsible for more than one ships, reports could be submitted on the emissions of more than one ship.
- All participating ships that call at EU or EEA ports have to pay taxes over their emissions. Again, in order to reduce the administrative burden, it would be allowed to pay taxes for more than one ship.

7.2.2 Conclusion

The responsible entity for paying the emissions tax should be the ship owner. The accounting entity should be the ship. Hence, a ship owner is required to report emissions and pay the tax for each ship he owns, and enforcement can target both the ship owner and the ship.

7.3 Geographical scope

There are four options for defining the geographical scope:
1. Territorial sea option 21. In this option, the policy would be applied only to the GHG emissions that were released within the limits of the territorial sea. Within this option, all the ships loading or unloading their cargo within the territorial waters of the EU (thus either in the EU ports or via ship-to-ship transfer) would be obliged to submit allowances for all emissions of GHG released within the territorial zone of the EU (of any country being the EU Member). The ships that are only passing through the territorial zone, without making a port call or unloading the cargo would be excluded on the basis of the law on innocent passage. Data needed to calculate the required number of allowances would include emissions (fuel use) in the territorial waters of EU Member States (alternatively, emissions can be approximated by using data on tonne-miles travelled within the EU territorial zone, average fuel use per tonne-mile for a given ship and type of fuel used).
2. Only intra-EU shipping. In this option, the policy would apply only to the ships which travel from one EU port to another EU port.

---

21 Alternatively, contiguous zone or continental shelf option could be considered, which would allow to extend the geographical scope of the policy, subject to legal feasibility.

3   All distance to the EU, all cargo option[22]. This option would aim at covering all GHG emissions related to the whole distance to any EU port travelled by ships which make port calls at the EU ports or unload their cargo within the EU territorial waters zone. We assume that the EU port would be the point of calculation of GHG emissions for each ship. However, a question arises: where the measurement of emissions should start? This leads us to considering the following sub-options:
    a   Including emissions only from the last port call to the EU port.
    b   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU.
    c   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and from the last port call for ships with multiple bills of lading. For non-cargo ships, such as passenger ships, the port of last embarkation may be considered and for other ships, such as offshore support vessels, distance from last operation and transit to EU waters and then the time on station (as such vessels may loiter for long periods of time).

4   All distance to the EU, EU-bound cargo only option. This option would be similar to the option 3, with the difference that only the cargo with destination to the EU would be covered with the policy. Thus, allowances would have to be calculated for every unit of cargo (container or barrel of oil, etc.) which would be dispatched at any port worldwide with the destination of any EU Member State. The number of the required allowances would be calculated based on the data on transport work in tonne-miles travelled by all the EU-destined cargo, fuel type and index of fuel used per tonne-mile specific for the ship.

7.3.1 Assessment of the options
The assessment of the options will focus on the following elements:
−   Environmental effectiveness. The environmental effectiveness of a policy is determined, among other factors, by the amount of emissions under the scheme. The larger this amount, the larger the environmental effect can be, other things being equal. Hence, we use the amount of emissions within the geographical scope as a measure for it's environmental effectiveness.
−   Possibilities for avoidance. Annex H analyses the potential for avoidance of a certain geographical scope based on the assumption that a scheme will be avoided if the benefits of doing so outweigh the costs. We use the findings of this annex to evaluate the possibilities for avoidance.
−   Legal feasibility. This aspect relates to the risk of a successful legal action against the scheme.
−   Administrative complexity. This feature is related mostly to the need of collecting and reporting data on CO_2 emissions.

Environmental effectiveness
The basis for the assessment of the environmental effectiveness is the results of the model calculations of emissions presented in chapter 2.

1   Territorial sea option. Territorial waters extend only up to 12 nautical miles i.e. about 20 km from the coast line so for most voyages this distance would account for a small percentage of the distance travelled. Hence, the environmental effectiveness of this option as compared to most other options is very limited as ships emit most outside territorial

---

[22]   'All cargo' as opposed to 'EU cargo' i.e. the cargo with destination to any EU country.

waters. We cannot estimate exactly how large the emissions are. Table 21 in section 2.6 of this report shows that according to Entec (2005), CO_2 emissions in territorial waters of the EMEP region amounted to approximately 38 Mt. However the territorial waters are only a fraction of the EMEP region and this estimate was not considered to be reliable for reasons explained in section 2.6. If we assume that ships sailing on intra-EU voyages emit 25% of the CO_2 generated on these voyages in territorial waters and ships sailing intercontinental voyages do so for 5% of their emissions, the emissions can be estimated at 16% of emissions on routes to EU ports (33 Mt CO_2) and 12% of emissions on routes to and from EU ports (38 Mt CO_2).

2   Only intra-EU shipping. As shown in chapter 2, emissions on intra-EU voyages accounted for 112 Mt CO_2 in 2006, being 36% of emissions on voyages to and from EU ports and for 54% of emissions on voyages to EU ports.

3   All distance to the EU, all cargo option.
  • Including emissions only from the last port call to the EU port. The scope of emissions covered by the policy can be estimated to be at the level of approximately 208 Mt CO_2 per year, based on the modelling described in chapter 2.
  • Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. The emissions in this scope are hard to assess, as they depend on the length of the period. If this period is short, e.g. days or weeks, the scope will be in the order of 208 Mt or less. If the scope is longer, e.g. one year, most likely many emissions on voyages between two non-EU ports will be included in the scope, so the amount of emissions would be considerably higher.
  • Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. The scope of emissions covered by the policy can be estimated to be at the level of approximately 208 Mt CO_2 per year, based on the modelling described in chapter 2.

4   All distance to the EU, EU-bound cargo only option. The scope of emissions covered by the policy can be estimated to be below 208 Mt per year (the estimated general scope for the option 3), however the percentage of cargo not destined to the EU for ships arriving at the EU ports would not expected to be high thus the scope would not be expected to be much different from the scope of option 3.

Possibilities for avoidance
Annex H analyses the potential for avoidance of a certain geographical scope based on the assumption that a scheme will be avoided if the benefits of doing so outweigh the costs. Analysing the costs and benefits for a number of ship types and routes, it concludes that:
−   If a voyage is defined so that no transshipment of cargo is necessary, the potential for avoidance is quite high, as the costs savings related to lower CO_2 fees are not counterbalanced with substantial costs related to such an additional port call.
−   In options where a voyage is defined so that transshipment is necessary to start a new voyage, the potential for avoidance from an economic point of view would be very limited. However, based on the analyzed examples, some risk of avoidance can be observed in a situation of low freight rates and high CO_2 costs.

For some cargoes, a voyage can be defined so that avoidance can be reduced. For most bulk cargoes, there is a single port of loading and a single port of discharge, and the bill of lading identifies both (see box on bill of lading). For break bulk and containerized cargo, there is often not a single port of loading and there may be numerous bills of lading associated with the ship movement, many of which would have different ports. So for these voyages, a definition cannot be based on the port of lading and the port of discharge.

A definition of voyage that requires transshipment for starting a new voyage is the route from the port of loading to the port of discharge for ships with a single bill of lading and from the last port call for ships with multiple bills of lading or ships in ballast. For non-cargo ships, such as passenger ships, the port of last embarkation may be considered and for other ships, such as offshore support vessels, distance from last operation and transit to EU waters and then the time on station (as such vessels may loiter for long periods of time).

We can apply these findings to the options under consideration in the following way:

1   Territorial sea option. The possibilities for avoidance in this option would be small, as ships sailing to EU ports would have to pass through territorial waters.

2   Only intra-EU shipping. Avoidance can take several forms, depending on the definition of a 'port call'. If port calls without transhipment would mark the beginning of a new voyage, it would result in avoidance in areas where non-EU ports are not too far away from the intra-EU route. Routes in the Mediterranean, from the Mediterranean to other ports vice versa, in and to the Baltic are susceptible for avoidance. If, on the other hand, port calls are defined so that transshipment is necessary for bulk cargoes, avoidance would be possible in the same regions, but just for containerized and break bulk cargoes. We assume that avoidance would not be attractive for passenger ferries because of the associated additional time of the voyage (see, however, section 13.3 on cruise ships). Assuming that avoidance occurs for container ships, general cargo ships, and RoRo ships, and assuming that they could reduce their emissions under an intra-EU scheme to zero for half of their voyages, we estimate that the maximal potential for avoidance would be 22 Mt of emissions (19% of intra-EU emissions).

3   All distance to the EU, all cargo option:
    a   Including emissions only from the last port call to the EU port. This is likely to cause avoidance by inducing ship operators to make additional port calls in non-EU country. If we assume that all ships sailing from non-EU ports could reduce their emissions under the scope by 75% by making an additional call at a non-EU port near the EU and half of the ships sailing on intra-EU routes could reduce their emissions by 50%, the scope for avoidance can be estimated at 73 Mt in 2006 (35% of emissions on voyages to EU ports).
    b   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. This scope can be avoided by transhipping cargo, both in bulk and in break bulk. Even for break bulk cargoes, this option would require them to offload all of their cargo and loading it on another ship that is dedicated to transport within the EU. This would be costly and hence we conclude that avoidance of this option is probably small.

c   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. This is likely to cause avoidance by inducing operators with break bulk cargoes to make additional port calls in non-EU country. If we assume that all container ships, general cargo ships, and RoRo ships sailing from non-EU ports could reduce their emissions under the scope by 75% by making an additional call at a non-EU port near the EU and half of these ship types on intra-EU voyages could reduce their emissions by 50%, the scope for avoidance can be estimated at 32 Mt in 2006 (16% of emissions on voyages to EU ports).

4   All distance to the EU, EU-bound cargo only option. This scheme can only be avoided by offloading cargo in a non-EU port and transporting it overland to the EU. As Table 46 suggests, the major European ports, with the possible exception of Algeciras, are far away from non-EU ports. Therefore we conclude that avoidance will be very small under this scheme.

Table 46   Major EU ports, 2007

Total cargo volume 1,000 tonnes		Container traffic TEUs	
Rotterdam	401,181	Rotterdam	10,790,604
Antwerp	182,897	Hamburg	9,917,180
Hamburg	140,923	Antwerp	8,175,951
Marseilles	96,282	Bremen/Bremerhaven	4,892,056
Amsterdam Ports	87,840	Gioia Tauro	3,445,337
Le Havre	78,885	Algeciras-La Linea	3,414,345
Bremen/Bremerhaven	69,095	Felixstowe	3,341,787
Grimsby and Immingham	66,279	Valencia	3,042,665
Genoa	57,189	Le Havre	2,638,000
Dunkirk	57,091	Barcelona	2,610,099

Source: American Association of Port Authorities.

Bills of lading

When a ship is loaded with cargo, the master of the ship, or the charterer of the ship (or their agents) is required to sign a bill of lading. The bill is often prepared by the shipper of the goods. Such document acts as evidence of receipt of the cargo, as a transferable document of title to the cargo and evidence of the contract of carriage between the holder of the bill and the ship owner or charterer (the carrier).

The bill is a private commercial document - it does not serve a regulatory function although it is often required by customs authorities to calculate import dues and so on. In commercial law, it is often vital, for contractual reasons, that the bill of lading reflects accurately the amount of cargo on board and the date and place the cargo was shipped. For instance, with respect to an oil cargo, the date of shipment will determine the price to be paid by the buyer to the seller. A bill issued for a single container of furniture to be shipped by liner container service will reflect the date and place of loading but such information is unlikely to be so important

In a usual transaction the bill will be prepared by the shipper (usually the seller of goods) issued by the master or charterer and physically transferred (directly by the shipper or more usually through a banking chain) to the buyer of the cargo in return for payment. Possession of the bill allows the receiver to demand delivery of the goods at the discharge port. If

international letters of credit are involved, then the bill will pass between banks in the country of export and the country of import. If the cargo is traded whilst en route, such as an oil cargo, then the bill will pass down a chain from buyer to buyer (or more usually, their banks). This often takes longer than the voyage so the cargo arrives at the discharge port before the bill. In such case, the ship owner usually will discharge the cargo to the receiver in the absence of a bill but in return for a letter of indemnity from the receiver holding the ship owner harmless in case the person receiving the cargo turns out not to be the person to whom the cargo should have been delivered.

Whilst the bill of lading is good, reliable evidence of the date and place of shipment of the goods, and therefore a reliable indicator of the voyage undertaken, the delay in the bill arriving at the load port after the ship has discharged and sailed might make practical problems for their use in the scheme. That said, customs authorities always obtain copies of the bill for import duty purposes and would be able to provide this evidence to any emissions authority who would, in turn, be able to check the details of the voyage against those provided by the ship's master, agent, or emissions allowance accounting agent.

It would be wrong to say that there is no instance of bills of lading being forged but such instances are, as far as the writer is aware, rare. The bill is an important document due to the three functions it performs and therefore more than one party would have to be involved in the fraud. This risk may decrease as the industry moves away from paper bills to electronic bills over the next few years.

Legal feasibility

This section assesses the legal enforceability of a scheme and the risk of a successful legal action against the scheme.

In general, with regard to enforcement, a route based scheme would appear to be a more attractive option. In particular it will be relatively easy for the port state authority to assess the level of emissions from a ship during its journey from its load port to the discharge port in the EU according to the records held onboard the ship and the ability to assess emissions and the carbon efficiency of the vessel during the voyage. Formal notices can be provided to the ship regarding the emissions. Accounts for each ship can be held and maintained in the EU so that balancing payments can be made in relation to the ship at the end of the accounting period.

1   Territorial sea option. Inclusion of emissions of CO_2 within territorial waters for ships loading/unloading cargo in the EU ports does not seem to be challenging from a legal point of view. However the ships in innocent passage would need to be excluded from the scheme.

2   Only intra-EU shipping. From a legal point of view, the EU has no right to impose extraterritorial rules where it has no sovereignty or jurisdiction and a legal challenge is likely may be made. In response, the EU could argue that it was not attempting to exercise jurisdiction over waters outside its territorial sea. The scheme would simply apply as a condition of entry into EU ports. Both UNCLOS and GATT allow regional measures to be put into place to preserve and protect the environment. However the introduction of any such scheme is likely to be challenged by non-EU states on jurisdiction grounds and there are no provisions in UNCLOS or any other IMO conventions which could fully protect the EU from such challenges to the extraterritorial effect of the regulations.

3   All distance to the EU, all cargo option.
    a   Including emissions only from the last port call to the EU port. The legal feasibility of this option is the same as for option 2.
    b   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. Depending on the length of the period, there may be more extraterritorial emissions under the scope of the scheme which could aggravate the issue raised under option 2. A further issue, which will have trade and economic consequences, is that charterers or operators will not want to take on a vessel for a single journey to an EU port if upon entry to that port it is going to become liable for that ships' emissions for the specific allocated period of time prior to entry. These might have been incurred by previous operators and charterers; in such circumstances it is highly unlikely that the previous operator/charterer would agree to be liable for the allowances required to be made and as such a time based scheme would likely result in a distortion of competition. It would also be very unpopular as the lack of transparency would mean that passing such costs onto cargo and sub-charters would be problematic. Further, in terms of the integrity of an emissions tax, it would appear that the operation of such a scheme should at least be based on a link between emissions in the EU and the ships' entry into EU waters. In circumstances where operators could be held liable not only for emissions incurred outside EU waters but further as in respect of journeys which were in no way connected with or destined for the EU, it is highly unlikely that the operation of such a scheme would be met with a warm reception by the international industry.
    c   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. The legal feasibility of this option is the same as for option 2.

4   All distance to the EU, EU-bound cargo only option. The legal feasibility of this option is the same as for option 2.

Administrative complexity

This section assesses the need to monitor and report data on CO_2 emissions. As a measure of administrative complexity directly associated with the choice of the geographical scope.

1   Territorial sea option. This option would require ships to monitor their fuel use from the point of entry of territorial waters to the point of exit. For ships that rely on tank soundings (see section 6.10), this may require additional tank soundings which, if taken at rough seas, would not always be very accurate. Moreover, it could be challenging to verify whether these measurements were indeed made at the right location. Note that a ship sailing at 12 knots passes through the territorial waters in one hour, so taking the measurement 5 or 10 minutes too early or too late could have a large impact on the emissions.

2   Only intra-EU shipping. This option would require ships to monitor their fuel use and emissions on every voyage between two EU ports. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions.

3   All distance to the EU, all cargo option.
    a   Including emissions only from the last port call to the EU port. This option would require ships to monitor their fuel use and emissions on every voyage to an EU port. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions.
    b   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. This option would require ships to monitor their fuel use and emissions on a period prior to calling at an EU port. If this period is sufficiently long so that the ship operator may not yet know whether he will sail to an EU port in this period, he may have to monitor fuel use on a daily basis. This is actually the current practice for most ships who send noon reports including data on fuel use to the ship owner and/or operator. Whether the quality of these noon reports is sufficient for an emissions tax remains to be established.
    c   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. This option would require ships to monitor their fuel use and emissions on every voyage to an EU port. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions. In addition, ships would have to monitor whether or not a new bill of lading was issued at a port.
    d   All distance to the EU, EU-bound cargo only option. This option would require ships to monitor their fuel use and emissions on every voyage to an EU port. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions. Moreover, they would have to monitor the share of cargo destined for the EU. This option would be administratively complex for ships carrying break bulk cargo or containers, where there may be multiple bills of lading. Ship owners would have to allocate emissions on every leg of every voyage to the various items of cargo on board.

Discussion
The assessments in this section are summarised in Table 47 below.

Table 47   Assessment of geographical scope options for an emissions tax

		1: territorial waters	2: intra-EU	3a: last port of call to EU port	3b: period before entry in EU port	3c: port of laden to EU port	4: EU-bound cargo only
Environmental effect	Emissions under the scope (2006)	33-38 Mt CO_2	112 Mt CO_2	208 Mt CO_2	More or less than 208 Mt, depending on length of period	208 Mt CO_2	Less than 208 Mt CO_2
	Possibilities for avoidance	Small	22 Mt CO_2	73 Mt CO_2	Small	32 Mt CO_2	Small
Legal feasibility		Best	Second best	Second best	Third best	Second best	Second best
Administrative complexity		Less complex than 4, more complex than 2, 3a, and 3c	Less complex than 4, more complex than 3b	Less complex than 4, more complex than 3b	Least complex	Less complex than 4, more complex than 2 and 3a	Most complex

Option 3c has the largest amount of emissions under its scope, even when accounting for avoidance. Note, however, that the estimate of emissions that could be subject to avoidance depends on assumptions that have been hard to substantiate. Option 3c has a slightly higher administrative complexity than option 3a. The choice between 3a and 3c is one between environmental effectiveness and administrative complexity.

7.3.2   Conclusion

Among the identified options, option 3c, distance from the port of loading for ships with a single bill of lading and distance from the last port call for sips with multiple bills of lading or non-cargo ships, is the most recommended because:
- It has a large environmental effectiveness.
- It offers relatively little scope for avoidance.
- It does not have a large chance of successful legal action.

7.4   Ship size scope

The considerations of which ships to include are much the same as for an emissions trading scheme, discussed in section 6.4.

Small ships tend to be small emitters. If administrative costs are relatively independent of ship size, the administrative burden for small ships would be large compared to their emissions. Hence, a size threshold could increase the overall cost-effectiveness of an emissions trading scheme by reducing the total administrative burden while not affecting the amount of emissions under the scope to the same degree.

A possible negative effect of a size threshold could be that it would distort the competitive market, by increasing the operating costs for ships above the threshold wile not affecting the costs for ships below the threshold. This could also impact the environmental effectiveness of the scheme by encouraging avoidance through using ships below the threshold.

This section assesses the ship size scope. It looks at the structure of the administrative costs.
This design choice depends on the emission calculations that yet have to be finalized.

7.4.1 Options

A ship size threshold that coincides with a threshold that is already used in the regulation of maritime transport does not create new market distortions. It may exacerbate current distortions, but the sector has learned to deal with those distortions.

In maritime regulation, two universal thresholds are used. IMO conventions such as MARPOL and the International Convention on the Control of Harmful Anti-fouling Systems on Ships have thresholds of 400 GT; SOLAS uses a threshold of 500 GT.

In addition, some conventions have a stepwise increase in liability based on size, but these conventions generally apply to specific ship types. The International Convention on Civil Liability for Oil Pollution Damage applies to all seagoing vessels actually carrying oil in bulk as cargo, but only ships carrying more than 2,000 tons of oil are required to maintain insurance in respect of oil pollution damage. Moreover, it specifies different compensation limits for ships of less than 5,000 GT, ships larger than 5,000 GT but smaller than 140,000 GT, and ships over 140,000 GT. The Convention on Limitation of Liability for Maritime Claims (LLMC) limits the liability for claims for loss of life or personal injury for ships up to 2,000 GT; between 2,000 and 30,000 GT; between 30,000 and 70,000 GT; and over 70,000 GT.

Chapter 2 shows that ships up to 5,000 GT account for 21.1% of emissions. We consider this to be a significant share. Increasing this share would undermine the environmental effectiveness of the scheme. Hence, we consider the following size thresholds:
1   No threshold.
2   400 GT.
3   500 GT.
4   5,000 GT.

7.4.2 Assessment of the options

Section 6.12 concludes that the administrative costs of an ETS are mainly in verification and reporting of emissions. Monitoring emissions carries little additional costs, as fuel use is monitored regularly on ships (see section 6.10). The costs of verification per ship owner are probably correlated with the number of ships the owner has, and there would probably be economies of scale as the verifier can use the same company information systems for each ship. This means that the choice for a threshold should be based on the emissions per ship owner.

Unfortunately, this assessment is limited by the availability of data. We do not have data on emissions and/or number of ships per ship owner (see chapter 2). Moreover, we are not allowed to publish data on the number of unique ships or their port calls from the Lloyds MIU database. Instead, we

report on the emissions per ship in relation to its size. Table 48 shows the emissions of vessels in different size classes and the number of calls of vessels of these size classes in major EU ports.

Table 48   Emissions of different size classes

	Port calls in major EU ports (2006)		Emissions on routes to Europe (2006)	
	Number	Share of total	Amount	Share of total
< 400[a]	166,190	1.2%	7.5	2.7%
400-500[a]	54,262	0.4%	1.3	0.5%
500-5,000	168,6470	12.4%	49.7	18.0%
> 5,000	11745565	86.0%	218.2	78.9%

Source: EUROSTAT; SEAKLIM

(a)   Assuming that 25% of vessels in the class 100-500 GT are 400-500 GT large.

Table 48 shows that for the four size classes considered, the number of calls at major EU ports correlates well with the amount of emissions of these size classes. In fact, smaller ships emit more than their number of port calls in the EU. Hence, it is not possible to exclude a large number of ships from the scheme with only a limited impact on the emissions under the scope. Note, however, that this is a tentative conclusion and a more thorough analysis, including an analysis of the number of ships and their sizes per ship owner, would be warranted.

Because it does not seem possible to reduce the number of ships in the scheme without reducing the amount of emissions under the scheme even more, we advice to have a low size threshold for ships. A threshold of 400 GT seems best, as ships over this threshold have to comply with MARPOL regulations and thus can be expected to have adequate management systems on which monitoring and verification could be based.

7.4.3   Conclusion
Although more research may be needed, our tentative conclusion is that the threshold should be set low, e.g. at 400 GT in line with the MARPOL threshold.

7.5   Ship type scope

7.5.1   Options
A number of ship types have different operating characteristics than cargo vessels. For example, cruise ships, dredging vessels, offshore support vessels, tugs and fishing vessels do not transport cargo between ports. This section will assess whether the different mode of operations of these vessels constitutes a reason to exclude them from the scheme.

A second, related question, is whether inland ships can and/or should be incorporated in the scheme.

The considerations of which ships to include are much the same as for an emissions trading scheme, discussed in section 6.5.

7.5.2 Assessment of the options

This section assesses if any ship types need to be excluded from the scheme and if so, which ones. On the basis of the preceding sections, ships need to satisfy a number of criteria in order to able to participate:

− They have to be identifiable, either by their IMO number or otherwise.
− They have to operate in the geographical scope of the scheme, i.e. they have to call at EU ports.

Non-cargo ships

The International Convention for the Safety of Life at Sea (SOLAS) provides that all passenger ships of 100 gross tonnage and above and all cargo ships of 300 gross tonnage and above shall be provided with an identification number conforming to the IMO ship identification number scheme, as adopted by resolution A.600(15) in 1987.

Although the requirement seems to be limited to passenger and cargo ships, an overview of the ships with an IMO number shows that many non-cargo and non-passenger ships also have an IMO number.

Table 49   Number of ships with an IMO number, 2007

Ship type	Ship size	Number of vessels with an IMO number
Ferry	Pax Only, 25kn+	984
Ferry	Pax Only, <25kn	2108
Ferry	RoPax, 25kn+	177
Ferry	RoPax, <25kn	3144
Cruise	100,000+ GT	24
Cruise	60-99,999 GT	69
Cruise	10-59,999 GT	130
Cruise	2-9,999 GT	74
Cruise	-1,999 GT	202
Yacht	Yacht	1051
Offshore	Crew/Supply Vessel	607
Offshore	Platform Supply Ship	1733
Offshore	Offshore Tug/Supply Ship	550
Offshore	Anchor Handling Tug Supply	1190
Offshore	Support/safety	487
Offshore	Pipe (various)	246
Offshore	FPSO, drill	273
Service	Research	895
Service	Tug	12330
Service	Dredging	1206
Service	SAR & Patrol	992
Service	Workboats	1067
Service	Other	813
Miscellaneous	Fishing	12849
Miscellaneous	Trawlers	9709
Miscellaneous	Other fishing	1291
Miscellaneous	Other	667

Source: Buhaug et al., 2009.

So in practice, all self-propelled seagoing ships over 100 or 300 GT have an IMO number.

Inland ships

Inland navigation in Europe is concentrated on the Rhine and Scheldt estuary and the Danube (Eurostat, 2007). In total, inland navigation provided 138 billion tonne kilometres in 2006, which is 5.6% of total transport work within the EU (Eurostat, 2008). In the Rhine and Scheldt estuary, about 10,000 self-propelled inland vessels were registered in 2008 (CCNR, 2008).

Emissions of inland ships are not reported regularly for the EU-27. For the Netherlands and Germany, estimations have been carried out of the actual emissions of inland water vessels on the national territory. For the Netherlands 1.79 Mt CO_2 emissions are reported for 2006 (PBL et al., 2009). Thereby emissions from commercial inland navigation, from passenger ships and ferries, as well as from recreational craft are taken into account (Klein et al., 2007). For Germany 2.19 Mt CO_2 are reported for 2004 (ITP and BVU, 2007). Here only the transport of goods is being considered. Taken the emission data of Netherlands and Germany together this results in about 4 Mt of CO_2.

Another way to estimate of the CO_2 emissions is to make use of the total transport work of the vessels and to apply an average emission factor. In the estimation of the German emissions an average emission factor of about 35 g CO_2/tkm is being used. IFEU (2005) reports an average of 30-49g/tkm for Europe. Applying this latter emission factor range to the 138 billion tkm reported this results into about 4-7 Mt of CO_2 related to the transport of goods on EU-27 inland water ways.

As inland vessels are registered in EU countries and regularly call at EU ports, it would be feasible to include them in an emissions trading scheme.

Note that if the initial allocation of allowances (see section 6.8) would be done on the basis of an output benchmark, or of the revenues would be recycled on the basis of output, it would be much harder if not impossible to incorporate these vessel types in the scheme as their output cannot be measured in tonne-miles.

7.5.3 Conclusion

All ship types can be included. The scheme can include inland shipping, if this is considered to be desirable.

7.6 Tax basis

An environmental tax should be levied on the pollutant for optimal effectiveness. Only if this is not possible, can it be levied on activities that cause the pollution.

CO_2 is the only greenhouse gas emitted by maritime transport that is emitted in large quantities and for which a Global Warming Potential has been established.

Emissions of methane for 2007 are estimated at 240 kilotonne for the world fleet, or 6 Mt CO_2 eq. (Buhaug et al., 2009). Emissions on voyages to the EU, assuming that they are proportional to fuel use, would total 1 Mt CO_2 eq. About 60% of these emissions are associated with the transport of crude oil and are hard to monitor (Buhaug et al., 2009). Therefore, it does not seem to be feasible to include methane emissions in the emissions trading scheme.

Emissions of HFCs for 2007 are estimated at 400 tonne for the world fleet, or less than 6 Mt CO_2 eq. (Buhaug et al., 2009). Again assuming that the share of these emissions on voyages to the EU is proportional to the share of fuel used on voyages to the EU, the emissions under the scope of the system equal less than 1 Mt CO_2 eq.

Some other gases emitted by shipping have indirect climate impacts. However, there is currently no scientific consensus on the GWP of these gases (CE et al., 2008). Consequently, they cannot be included in an emissions trading scheme.

Because CO_2 is the main greenhouse gas emitted by maritime transport, the tax should be on CO_2 emissions. In order to minimise avoidance, the tax should not be levied on fuel sold in the jurisdiction of EU Member States (see section 7.3). Rather, emissions generated on voyages to and/or from EU ports could be taxed.

7.7 Level of the tax

In this section we analyze the option of imposing a tax (also referred to as a levy or a charge) on CO_2 emissions from maritime shipping. The taxes can either be set:
− On the basis of the social costs of CO_2.
− On the basis of the tax level needed to achieve a certain target.
Sections below give assessment of these two options.

7.7.1 Setting the tax based on social costs of CO_2

There is no need to assess benefits from abatement of CO_2 specifically from shipping because the global warming effect is independent on location. Estimates of the benefits related to CO_2 reduction are very diverse. Two main approaches for benefit assessment exist: the approach based on damage cost and the approach based on abatement costs. Both approaches show that external costs of GHG emissions are rising over time, which is due mainly to two factors. For damage costs approach it is the fact that as global temperature rises, the negative effects of global warming become more severe. For the abatement cost approach, it is the fact that the cheapest abatement options are used at the beginning but over time more and more expensive options have to be implemented.

In theory, damage costs approach would be more suitable for deciding about the socially optimal rate of an environmental tax/charge. Ideally, true social costs of pollution should guide the decision rather than the abatement costs, which refer to a specific policy target. However damage cost assessments related to climate change are still quite immature and uncertain. Therefore, often in practice abatement costs are used as a fair proxy of damage costs. Quite often also the price in the EU ETS is used as an approximation of abatement/damage costs of global warming although one should note that this is likely to be an overestimation, as ETS is applied only to the selected installations in Europe, for which specific targets have been set. Allowing purchase of more CDM credits would most probably drive the EU ETS price down, to reflect differences between the abatement costs in the European installations covered with the scheme and costs of CO_2 reduction in other parts of the world.

With regard to damage costs approach, several computer models exist (so-called Integrated Assessment Models, IAMs) which model economic growth together with impacts from climate change. During the last several years, the term 'Social Cost of Carbon' (SCC) representing the value of discounted damages related to emission of one unit of carbon is gaining popularity, and increasing number of studies are related to monetary assessment of SCC. Tol (2008) provides a meta-analysis of 211 studies on SCC, with the mean at 3% discount rate being equal to US$ 23/tonne of C. This figure would be equivalent to approximately US$ 6.3/tonne of CO_2 (or about € 5/tonne of CO_2). The range of the estimates reported in this paper is very high – the lowest estimates are below zero and the highest exceed US$ 2,000/tonne of C (however the extreme values come from publications that were not peer-reviewed).

Studies performed for the EU, such as those within the framework of the ExternE[23], suggest that under a full flexibility EU-wide allocation of CO_2 emission permits, the marginal abatement costs oscillate around € 20 per tonne. These estimates are based both on top-down and bottom-up approaches. The marginal costs of abatement in individual Member States may be much higher; on the other hand, allowing trading outside the EU may lower the compliance costs to perhaps € 5 per tonne.

Estimates of the avoidance costs critically depend on the target chosen and, as mentioned before, rise over time. With an ambitious goal of limiting global warming to 2 centigrades above the pre-industrial level, the forecasted mitigation costs for CO_2 rise to the level of € 198 per tonne in 2050 (NEEDS, 2008). In the long run, the EU ETS prices could be a better indicator than the current data from technical-economic studies. The example of EU ETS is mentioned here because the EU ETS is the largest system of tradable permits for CO_2 emission allowances existing to date.

Different values can be recommended as estimates of damage costs for GHG for the next several decades. Estimates from various studies have been summarized within the NEEDS project[24], - see Table 68. In the table, the first row reflects damage cost approach based on the results of the FUND model[25], and the second and third row reflect the marginal abatement cost approach on the basis of different policy targets.

---

[23] ExternE (External costs of Energy) is a series of research projects of the European Commission aimed at estimation of socio-environmenal damages related to energy conversion. Since 1991, the ExternE network has involved over 50 research teams from more than 20 countries. Despite difficulties and uncertainties, ExternE has become a well-recognised source for method and results of externalities estimation. For more information see www.externe.info.

[24] New Energy Externalities Developments for Sustainability, European Commission research project implemented during the period 2004-2008, part of the ExternE series.

[25] FUND is a kind of an Integrated Assessment Model (IAM), a computer model of economic growth with a controllable externality of greenhouse warming effects.

Table 50   Recommended values of damage costs for CO_2 (Euro 2005 per tonne CO_2)

Scenario	2005	2010	2015	2025	2035	2045	2050	2055
MDC_NoEW[1]	7	9	11	14	15	17	22	27
PP_MAC_Kyoto plus[2]	-	23.5	27	32	37	66	77	-
PP_MAC_2 °[3]	-	23.5	31	51	87	146	198	-

(1)   Pure economic cost-benefit analysis with no equity weighting.
(2)   Use of agreed objectives (20% reduction of GHG by 2020).
(3)   Ambitious goal of 2 centigrades increase as compared to pre-industrial levels.
Source: NEEDS, 2008.

Damage and prevention costs related to global warming have also been summarized in IMPACT handbook (Infras et al., 2008) - damage costs are shown in Figure 35 below.

Figure 35   Overview of the damage costs of climate change (in €/tonne CO_2) as estimated by various studies
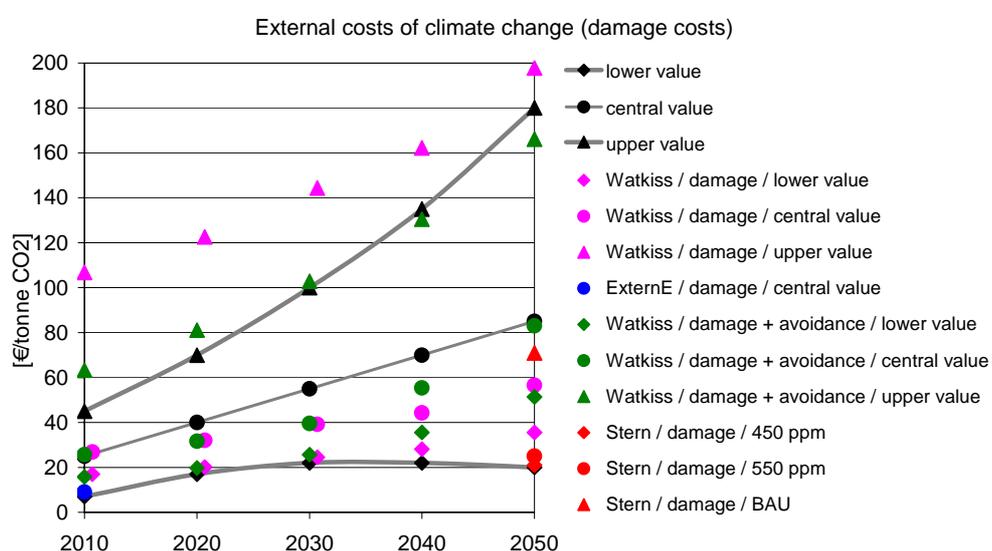
Source: Infras et al., 2008.

Comparison of the estimates of CO_2 external costs based on damage and avoidance costs approach can be summarized as follows (based on INFRAS et al., 2008):

− Damage costs estimates tend to be *lower* than the estimates based on abatement costs, certainly in the short run.
− The spread in estimates for short term external costs between different studies is smaller for avoidance costs than for damage costs.
− Central values for the long term (i.e. 2050) damage and avoidance cost as calculated by recent studies tend to be in the same range: € 50–100/tonne CO_2.
− Both damage costs and avoidance costs are expected to increase over time.

7.7.2 Conclusion and recommended values

We take here the approach recommended in the IMPACT study (Infras et al., 2008) based on a literature review of the various estimates for CO_2. In this approach, the avoidance costs are being used for the time frame until 2020, and after that damage costs are being used. The reason to use prevention costs in the short run at least is based on the notion that current environmental policies obviously impose stricter targets than one would expect based on damage costs. The average avoidance cost of € 25/tonne CO_2 for 20% reduction for the year 2010 is much higher than the median damage costs based on Tol (2008), which are equal to approximately € 5/tonne CO_2, and also much lower than the estimates presented within the NEEDS project (about € 13/tonne CO_2). The reason is that politicians obviously place a higher value on preserving the climate than economists would advocate. This may be due to various reasons, such as omissions in the damage estimates (excluding indirect effects), lower time preference of politicians than estimated by economists, moral imperatives such as 'global stewardship'. However, policies have only been formulated until the year 2020. For emissions occurring after that, IMPACT refers to damage costs to estimate the impacts on the longer-run.

The recommended values for CO_2 shadow prices are presented in Table 51. The recommended values are specified for different years of application.

Table 51   Recommended values for the external costs of climate change (in €/tonne CO_2), expressed as single values for a central estimate and lower and upper values

Year of application	Central values (€/tonne CO_2)		
	Lower value	Central value	Upper value
2010	7	25	45
2020	17	40	70
2030	22	55	100
2040	22	70	135
2050	20	85	180

Source: Infras et al., 2008

Summing up, according to our selection of data sources, the best estimates of damages related to global warming for the current period oscillate around € 25 per tonne CO_2, with lower bound of 7 and upper bound of € 45 per tonne. For the year 2030 we propose to use the central value of € 55 per tonne of CO_2, with lower and higher bounds of € 22 and € 100, respectively. The values proposed as shadow prices of CO_2 for the year 2030 will be used in the chapters 12 and 13 devoted to the assessment of specific impacts.

7.7.3 Tax level needed to achieve a certain target

In addition to looking at the costs and benefits of CO_2 abatement we would like to propose another approach by referring our assessment to the indicative EU policy targets. We will limit time horizon to the year 2020, as going beyond this date would increase uncertainty even more.
The general goal of the EU is to reduce overall EU emissions of CO_2 to 20% below the 1990 level. This goal seems to be very restrictive for the maritime shipping sector when we look at a sharply rising trend in maritime transport services over the last 20 years. According to Buhaug et al. (2009), total emissions from maritime shipping in 1990 amounted to 562 Mt. This would mean that the goal of bringing CO_2 emissions down to 20% below the 1990

would translate to over 50% cut in emissions. By looking at the MACC curve presented in Chapter 4 shows that such a target may not be achievable with technologies that are currently available and would require significant reductions in transport work. This would have implications for welfare that have not been assessed in this report.

The position of the EU on the Copenhagen agreement states that maritime emissions should be included in a global agreement and proposes an indicative goals for maritime emissions by 2020: the maritime emissions should be brought to the level below 2005[26]. It is questionable whether this target can be reached with technologies that are currently available. As section 4.1.2 shows, emissions are likely to increase driven by transport demand even when significant efficiency improvements are realised.

Of course it is possible that more measures will be developed in the timeframe up to 2020, and Buhaug et al. (2009) suggest that even today more measures exist than are included in their MACC. In that case, a tax of less than € 75 per tonne would be sufficient to bring emissions back to the level of 2007. However, it is also likely that the MACC, like most other MACCs, does not represent all costs and that there are non-financial barriers to the implementation of various measures. In that case, the level of the tax would need to be higher than € 75 in order to reach this goal.

So it appears that the level of the tax can not be set at a level that would make it possible to reach one of the two aforementioned targets without using some of the tax revenue to offset maritime emissions.

7.7.4 Conclusion
Final conclusions of this section are the following:
- Precise calculation of the socially optimal CO_2 tax rate for maritime shipping is impossible because of uncertainty with respect to data on marginal costs of emissions and marginal benefits of emission reduction;
- The attempt to calculate the recommended tax rate based on the theory of socially optimal tax results for the current period in a range of € 7-45, with central estimate of € 25.
- The second method of calculation refers to policy targets. The least stringent policy target considered here, reducing CO_2 emissions from maritime shipping in 2020 to the level of 2005, would probably require considerably higher tax rate than the socially optimal tax, at the approximate level of € 75 per tonne of CO_2.

7.8 Use of revenues

A significant share of the environmental effect of an emissions tax would need to come from the use of the revenues, as the anticipated environmental effect of abatement measures and reduced demand do not seem sufficient to reach any of the policy goals.

---

[26] http://www.euractiv.com/25/images/Draft_Communication_Copenhaguen.pdf.

7.8.1 Options

Emission reductions can be financed through a number of ways:
1   Buying credits from one of the flexible mechanisms, such as CDM or another mechanism under a future global climate agreement.
2   Buying allowances from emissions trading schemes.
3   Financing domestic emission reductions.

7.8.2 Assessment of the options

The supply of CDM credits is estimated at over three thousand megatonnes of CO_2 annually in 2020 at a price of less than € 20 per tonne of CO_2 (ECN, 2007)[27]. Hence, there is a sufficient supply of credits to offset maritime emissions. However, since CDM projects create credits by reducing emissions below a forecasted baseline, there is debate about the extent to which CDM credits represent real emission reductions.

Buying allowances from emissions trading schemes is more clearly associated with actual emission reductions. However, it could be considered strange for the EU first to set a cap in its ETS and then to buy allowances from the ETS, thus lowering the cap further.

Financing domestic emission reductions would represent real emission reductions only if the internationally agreed target of a country would be lowered. Otherwise, the emissions would be allowed elsewhere in the economy.

7.8.3 Conclusion

In order to be environmentally effective, the revenues of the tax have to be spent at least partially on emission reductions. Emission reductions in non-Annex 1 countries seem the best way to improve the environmental effectiveness.

7.9 Monitoring and reporting emissions

The data monitoring and reporting requirements for a tax would be the same as for an emissions trading scheme since both would need to have accurate data on CO_2 emissions within the scope of the scheme (see section 6.10).

7.9.1 Options

A policy addressing CO_2 emissions from shipping would require the establishment of emissions from individual ships in a consistent and verifiable manner. Since CO_2 emissions are proportional to fuel consumption it is necessary to establish the fuel consumption from ships.

There are two basic approaches to tracking fuel consumption onboard ships:
1   Fuel inventory management.
2   Measuring and recording fuel consumption directly as it happens.

All ships have some knowledge and record of the amount of fuel carried at certain points in time, and many ships record fuel consumption on a daily basis, although not all ships have equipment needed for measuring fuel consumption directly.

---

[27]   Carbon credit supply potential beyond 2012: A bottom-up assessment of mitigation options

7.9.2 Assessment of the options

The main data sources that are available to monitor fuel use are:
1 Total amount fuel purchased by (or on behalf of) the ship.
2 Total amount bunkered.
3 Measuring fuel tank levels (or tank pressure, etc.).
4 Measuring flow to engines/day tanks/settling tanks

Each will be discussed in more detail below. After this review, this section will review current practice of fuel monitoring on board ships and design a monitoring scheme that can be used for the inclusion of vessels in an emissions trading scheme.

Total amount fuel purchased by (or on behalf of) the ship

Information necessary to establish the total amount of fuel purchased is normally contained within the budgets, accounts and records kept at a ship operator, however it needs not be readily available.

The amount purchased within a certain timeframe can differ from the amount of fuel used within the same time frame; hence fuel inventory information is also needed to establish periodic consumption. To establish the inventory it would be necessary to measure fuel tank levels (see below). In the event that geographic criteria are used to define emissions covered, this cannot be determined by accounts alone. With respect to verification/audit, it may be difficult to document that as ship has not received fuel purchased by a third party.

Total amount fuel bunkered

There are existing requirements (Regulation 18 of MARPOL Annex VI) that a bunker delivery note (BDN) containing information the quantity of fuel in metric tons loaded is to be kept onboard for a period of 3 years.
BDN information may also be made available by the ship to the ship operator/ management office, however it can be relied on to be available onboard the ship.

A BDN states the total quantity of fuel bunkered (metric tonnes) and density at 15°C (kg/m^3), as well as sulphur content (% m/m).

The quantity of fuel bunkered stated on the BDN is measured using ASTM look-up tables to correct the volume to 15°C and a density measurement in conjunction with 'dipping' the sounding pipes to measure tank volume to calculate the total mass of the bunker fuel delivered. BDNs have an accuracy level of 1% to 5%.[28]

The amount bunkered within a certain timeframe can differ from the amount of fuel used within the same time frame, hence fuel inventory information is also needed to establish periodic consumption. In the event that geographic criteria are used to define emissions covered, this cannot be determined by bunkered amounts alone. With respect to verification/audit, it may be difficult to document that a bunker delivery note is presented for all bunkering operations undertaken and that the quantity of the bunker delivery note is correct (i.e. not forged, etc.).

---

[28] Bunkerspot, Vol. 6, No.1, Feb/March 2009.

Measuring fuel tank levels

Fuel tank levels are commonly measured onboard ships. In modern ships, tank soundings are normally taken using built-in automatic systems, such as pitot tubes (which measure pressure) or radar tank level indication systems, both of which transmit readings to the engine control room. These devices need to be regularly calibrated to ensure accuracy (calibration dates should be recorded), and this may currently not always be done as there are no regulations for this.

Additionally, tank soundings can be manually taken with a measuring tape and digital thermometer via sounding pipes (need to be kept free of sludges that may cause inaccuracies in measurements), although this method is less common as it takes a greater amount of time.

Sounding is a very common since it is a transparent way of measuring the fuel level that can be done also by third parties. When sounding is done to the benefit of third parties, the dipstick may be coated with a chemical that changes colour if contacted with (pure) water

Sounding tables are necessary to convert tank level to volume. Typically, this is available in an approved form through the ship stability documentation. Fuel density information is necessary to calculate the corresponding mass. This is available from the BDN, however blending onboard may cause slight complications. Fuel temperature will also affect volume.

A ship may have a large number of fuel tanks, with different quantities and grades of fuel. Accuracy of sounding is limited, and may be affected by trim, heeling etc. Manual sounding may be very inaccurate at sea if the ship is moving.

Alternatively, fuel mass in the tank can be measured by way of measuring the pressure in the bottom of the tank. Fuel density and temperature information is not needed in this case.

Fuel tank level can be measured at specified times to establish an inventory. Changes in tank levels correspond to consumption provided that fuel is not transferred between tanks or supplied from shore, hence this must be controlled.

Measuring fuel flow

Net fuel flow to the engine can be measured directly using various types fuel flow meters. Flow meters record the actual fuel used on any voyage; the data can be used to prove fuel consumption, however, the seal must be intact to ensure validity.

Fuel Consumption Monitoring Systems incorporating electronic fuel flow meters (with digital display) are the most accurate and reliable method of measuring fuel consumption in marine diesel engines. Flow meters are fitted to the main engine fuel supply and return lines and are used to constantly monitor fuel consumption. The values recorded by the flow meters are calculated in the fuel flow calculation unit and form the basis for all other functions in the system; fuel consumed over a given distance/period of time can be mapped to within an accuracy of ± 0.2%

Flow meters of turbine type are common in bigger ships while many smaller ships do not have fuel flow meters. In many cases, fuel flow to the settling tank or day tank is measured rather than net flow to the engine which requires two flow meters (supply and return flow). Turbine flow meters measure rotational speed of a turbine in the pipe which can be converted to volumetric flow. The accuracy depends inter alia on accurate information on fuel viscosity and density.

Fuel flow measurement will allow breakdown by time interval. Geographical breakdown can be done if combined with a positioning information system e.g. GPS.

Current practice

Different practices are used for monitoring fuel consumption onboard ships depending on needs and means. For accounting and budgeting, information on a ships' accumulated fuel consumption over extended periods (e.g. a year) can be obtained with reasonable accuracy, however a certain lack of consistency must be expected between values determined from measurements onboard and those from bunker delivery notes and what can be determined by bunker bills[29]. Differences may be attributed to lack of accuracy in onboard measurements, however the accuracy in determining the amount of fuel loaded may also vary between the various bunker barges and facilities around the world.

In case of contracts where the ship is chartered to a third party who pays the fuel bill, fuel consumption is commonly establishes as follows: At the start of the charter contract, the amount of fuel onboard the ship is established by sounding of tanks by an independent party or jointly by the ship crew and a representative of the charterer. When a chartered ship is bunkering, the amount of fuel received is determined by tank sounding and a declaration of how much fuel has been received is prepared by the ship for the charterer. Each day of voyage the ship reports speed and consumption to the charterer in a so-called noon report covering. The consumption at sea is established by flow meters. Usually, at the end of the voyage the tanks are sounded to establish true fuel consumption at sea. Fuel consumption reported during voyages in noon reports is the corrected to maintain consistency. At the end of the charter contract, the amount of fuel onboard the ship is then established by an independent party or jointly by the ship crew and a representative of the charterer.

Quantities loaded are usually determined by pre and post delivery tank measurements on both the bunker tanker and the receiving vessel. A drip sample is collected during fuel loading. Taking such a sample is a legal obligation. This sample, know as the MARPOL sample, is sealed and stored onboard the ship for possible analysis by a port state control. This sample is to verify the correctness of the bunker delivery note supplied with the sample. Additionally, it is common practice to take additional samples for commercial analysis.

---

[29]   Note that while a ship's fuel consumption can be established with a reasonable accuracy, ship owners are not obliged to report fuel consumption. Hence, there are no central databases of fuel consumption in maritime transport with a similar accuracy. Rather the best available estimates of global emissions have a margin of error of ± 20% (Buhaug et al., 2009)

Fuel consumption related claims and disputes

There are principally two types of claims with respect to fuel bunkered. These are:
- Over consumption, claims that the vessel is consuming more fuel than agreed.
- Disputes regarding the amount of fuel bunkered.

Claims for over-consumption are generally related to ships using more fuel compared to the speed achieved than what is agreed in the charter contract. Since fuel consumption figures in charter contract are subject to weather, ships may tend to claim bad weather to avoid fuel claims. It is not uncommon for charterers to attempt to verify weather claims from ships using satellite weather data, which may result in discussion. Generally, this type of controversy emphasise fulfilment contract obligations, it is uncommon that actual amount fuel used onboard the ship is questioned. This said, there are stories of chief Engineers manipulating fuel consumption report to take advantage of adverse weather conditions to report excessive fuel consumption. However, to do this it may be necessary to falsify the engine logbook which is a serious offence in many states and may even result in criminal prosecution.

Disputes may occasionally arise between the ship and the bunker supplier regarding the amount of fuel bunkered. To reduce disputes, the presence of a neutral third party may be beneficial. At the time of the bunkering, the ship will invite the supplier to take part in taking a drip sample (the MARPOL sample) and in an estimated 50% of bunkerings also a commercial sample that the ship will dispatch to a fuel analysis service. The ship will only sign for 'volume at temperature' and the amount of fuel received may be finally determined following analysis of the test sample.

EU legal competence

Note that the EU cannot prescribe the method by which fuel has to be monitored as this would in fact be a regulation on a ship's construction, design, equipment and manning (CDEM). Under international law only the flag state is permitted to exercise jurisdiction over its vessel with regard to the implementation of CDEM standards and such exercise must only extend to requiring vessels to comply with internationally accepted standards. As such flag states would not be under any duty and could not be required, by virtue of customary international law, UNCLOS or otherwise, to require its vessel to comply with any EU scheme relation to altering the CDEM standards of vessel on the high seas or visiting foreign ports.

As a result the EU would not have the competence to require the compliance of all vessels with a mandatory or operational efficiency limit value as a condition of entry into its ports. Aside from the fact that such a requirement may involve vessels having to comply with CDEM standards which fall above the standards generally accepted in international law which is not permitted under UNCLOS in any event, it is difficult to see how the EU could successfully impose compliance with an efficiency limit value on flag states which are outside the EU.

Such technical CDEM standards have successfully been agreed by international convention through the IMO and any unilateral attempt to alter CDEM standards required in any one region would strike a serious blow against this consensus and may lead to differing regional standards causing a reduction in safety and efficiency of the shipping industry as a whole.

Documentation of fuel consumption in a regulatory setting

In the regulatory perspective, there are two principal options for documenting fuel consumption. One is inventory control and the other is direct fuel consumption measurement.

- Inventory control would involve monitoring of fuel consumption by documenting all fuel onboard the ship at start and end of the period in question as well as all supply (and possible de-bunkering) of fuel within the period.
- Measurement would involve installation and maintaining an approved system for documenting fuel consumption. This would system would be different from what is presently used onboard ships today.

Generally, flow measurement is more accurate for short time intervals, while for extended time frames, inventory management is equally or possibly more accurate depending on measuring device used. Some comments regarding the merits of these options with respect to different applications is given below.

Table 52   Comments on verification in different settings

Geographical scope	Inventory control
All voyages to EU ports	Inventory could be established at start and end of each voyage e.g. by sounding. Verification could be done by comparing to log books and other documents that may be available on the ship.
Annual reporting	Inventory could be established at start and end of each period. Verification of ship record books could be cross checked with company account, etc., however this type of information may be difficult to access in many cases.

Fuel carbon content

The amount of CO_2 emissions from the combustion of each tonne fuel depends on the mass fraction carbon in the fuel. The mass fraction carbon depends on the chemical composition of the fuel, content of water, sulphur and more. The mass fraction carbon is not part of marine fuel specification and not shown in available documentation such as BDNs. Using the actual carbon content of the fuel is thus not practically feasible as it would involve an additional analysis of the bunker samples on board. Rather, it is necessary to find a compromise solution based on a set of default values

In order to determine the CO_2 emissions from marine fuel, the fuel consumption can be multiplied with a CO_2 emissions factor which expresses the number of tonnes CO_2 that is emitted for each tonne fuel that is burned. The following CO_2 emissions factors have been derived from the IPCC guidelines.

Table 53   Energy based CO_2 emissions factor (kg/TJ) - IPCC Guidelines

	Default	Low	High
Marine diesel and marine gas oils (distillate)	74 100	72 600	74 800
Residual fuel oils	77 400	75 500	78 800

Using fuel density data from the same guideline it is possible to convert these figures to mass basis which is convenient for ship emission.

Table 54   Fuel based CO_2 emissions factor (tonne/tonne fuel) - IPCC Guidelines

	Default	Low	High
Marine diesel and marine gas oils (distillate)	3.19	3.01	3.24
Residual fuel oils	3.13	3.00	3.29

A pragmatic approach to determining fuel carbon content would be to classify fuels as either distillate or residual and assign emission factors as per the IPCC guideline defaults. The difference in emissions factor is already small. A more refined breakdown of fuel qualities would appear to give little in terms of increased accuracy or incentive for better performance, however the issue of classifying fuels would become more challenging since a legal definition of the fuel grades is needed and the information required must be available to all ships. Distinction between residual and distillate fuels may be done by density where any fuel with density < 890 kg/m^3 would be classified as distillate and receive the higher emission factor.

Outline of an emissions monitoring, reporting and verification scheme

A monitoring, reporting and verification scheme for ship emissions would comprise the following elements:

1   The responsible entity submits an emissions monitoring and verification plan to the competent authority, based on the most accurate fuel measurements possible on his ship(s).
2   The responsible entity establishes the amount of CO_2 emissions from his or her activities that are subject to the regulation in a manner that facilitates verification at a later time.
3   The documentation necessary for verification is kept by the responsible entity for a specified period of time.
4   The verifier verifies the accuracy of the monitoring report.
5   The responsible entity reports verified emissions to the responsible entity.

It could be necessary to provide guidance with respect to what documentation would be suitable. Fuel consumption data established by the use of an appropriately approved fuel consumption measuring and recording device should probably be an option. However, since this would involve installing equipment onboard ships, this cannot be the only option. Alternative documentation could be ship log books, etc. These logs could be based on fuel consumption based on tank sounding.

The emission estimates can be verified using ship movement data and fuel purchase data. Both are available from company records. In addition, a number of sources can be used to verify ship movement data, including SafeSeaNet data on ships over 300 GT arriving in EU ports. Currently, SafeSeaNet data comprises ship identification (name, call sign, IMO number or

MMSI number); port of destination, Estimated time of arrival and estimated time of departure of that port; total number of persons on board. So on this basis it can be established whether the ship was in an EU port and if so, how many times during the reporting period. If the last port of call could be added to SafeSeaNet, this information can also be used to assess the quality of fuel consumption data. SafeSeaNet's legal basis is Directive 2002/59/EC.

Costs of monitoring fuel consumption

The outline of the scheme above identifies two major cost items. First, fuel consumption has to be monitored and collated in a report. Second, the monitoring report needs to be verified. Here, we estimate the costs of these items.

Monitoring and reporting of fuel consumption is normal practice in the maritime industry. While not a legal requirement, tank soundings or flow meters are utilized due to fuel bunkering, charterer party agreements or voyage management practices. This means that while the accuracy of this data might be in question the mechanisms for monitoring and reporting of emissions from an individual ship are already established and any costs associated with this would be limited to manpower to establish practices to meet the requirements and increase accuracy of fuel consumption reporting.

In a system where the geographical scope is all voyages to the EU port, monitoring fuel would have to be done in ports. Hence the costs are correlated to the number of port calls in the geographical scope of the system. For ships that have many port calls, such as ferries, a requirement to monitor fuel per voyage may increase the administrative burden. For these ships, a choice should be given to monitor fuel consumption annually.

The cost to verify annual CO_2 emissions from an individual ship will be dependent on the requirements detailed in the approved monitoring plan, level of assurance required, quality of data and operational profile of the ship, with potential different requirements for example, vessels operating solely between European countries (fuel purchased) and voyage analysis for vessels entering EU ports that have departed from a port outside EU waters. Taking the unknowns into account one can understand that it is hard to calculate an accurate cost figure. However, comparing with current CO_2 certification practices the costs would be expected to be less than US$ 10,000 (approximately € 6,700) per ship.

7.9.3 Conclusion

Fuel consumption is routinely monitored on board ships. Records are being kept of both annual fuel purchases and per voyage fuel use. Most larger vessels have fuel flow meters that are able to record fuel use with an accuracy of ± 0.2%. Other vessels may have to rely on sounding tanks which has a lower accuracy.

Upon implementation of an emissions trading scheme for maritime shipping, ships could be given two choices:
1 Monitor fuel per voyage.
2 Monitor fuel use per annum.

The latter option would be attractive for ships that operate exclusively or predominantly between EU ports. In both cases, ships would have to indicate how they will monitor fuel use.

7.10 Compliance and enforcement

A general description of roles of various enforcement agencies in the shipping sector is given in section 6.12. This section builds on this description.

Depending on who is ultimately the responsible entity for payment of an emissions tax for ships entering EU ports, in the case of ships registered in EU states, taxes can be expected to be paid under national taxes or via a centralised European fund. For non-EU flagged vessels, payment of the tax would need to made to the appropriate tax collecting organisation, with the result that vessels will be detained at port in the event the owner/operator fails to pay.

Enforcement potentially can be through national tax regimes or local tax bodies such as customs. Again, it would be necessary to avoid discrimination between EU and non-EU vessels in collecting this tax and it might be necessary to allow all owners to settle on a periodic basis rather than after each call. Failure to pay taxes over a period would result in 'banning' non-compliant companies or individual ships from calling in EU ports.

7.10.1 Conclusion
We propose that the tax be paid through national tax regimes or local tax bodies such as customs. Failure to pay taxes over a period would result in banning non-compliant ships from calling in EU ports.

7.11 Expandability to third countries

Denmark has submitted a proposal to the IMO MEPC that calls for a global fuel levy (MEPC59/4/5). The revenues of the levy would be used, inter alia, to buy offsets for emissions. While the proposal explicitly states that the levy is not a tax, it is clear that there are some similarities.

The design of an emissions tax presented here is not congruent with the Danish proposal, as in the case of a regional policy the tax base is emissions rather than fuel. As argued in section 7.2, a regional fuel tax would have a very limited environmental effect. As a consequence, the emissions tax would need to be redesigned to become part of the global fuel levy.

Apart from expansion to a global system as proposed by Denmark, one could envisage that other countries introduce emission taxes for maritime transport with hypothecated revenues. Since the European tax would only apply to emissions on voyages to EU ports, a tax in other countries could be fully compatible with the European tax as long as it has the same tax basis.

7.12 An emissions tax and the policy objectives

Section 4.6 states two policy objectives.

The first policy objective is to limit or reduce maritime GHG emissions.

The secondary policy objective is to remove barriers and market failures that prevent measures to improve fuel efficiency from being implemented, so that the first objective can be met in the most cost-effective way.

An emissions tax for maritime transport would in itself not reduce emissions (see also section 12.2). The impact on GHG emissions would have to be achieved by using the tax revenue to finance emission reductions in other sectors.

As for the market barriers and market failures, since the emissions tax scheme would internalise the costs of CO_2, it would create an additional incentive to reduce emissions, thus increasing the importance that ship owners and operators attach to this issue. Monitoring and reporting requirements may also draw ship owners attention to emissions and to emissions abatement measures. However, an emissions tax does little to reduce the market failures and barriers that were considered to remain the most important, i.e. the split incentive in parts of the shipping market, transaction costs and the time lag.

7.13 Emissions tax: summary of policy design

The responsible entity for paying the emissions tax should be the ship owner. The accounting entity should be the ship. Hence, a ship owner is required to report emissions and pay the tax for each ship he owns, and enforcement can target both the ship owner and the ship.

The geographical scope proposed here is all voyages to EU ports, starting from the port of loading for ships with a single bill of lading and the last port call for sips with multiple bills of lading or non-cargo ships. This scope has a large environmental effectiveness; offers relatively little scope for avoidance; and does not have a large chance of successful legal action.

All ship types can be included. The scheme can include inland shipping, if this is considered to be desirable.

The size threshold could be set low, e.g. at 400 GT in line with the MARPOL threshold. Such a threshold would not create additional market distortions and there seems to be little benefit in raising the threshold.

CO_2 is the only greenhouse gas emitted by maritime transport that is emitted in large quantities and for which a Global Warming Potential has been established. Therefore, the tax should be levied on the amount of CO_2 emitted in the scope of the scheme.

A Precise calculation of the socially optimal CO_2 tax rate for maritime shipping is impossible because of uncertainty with respect to data on marginal costs of emissions and marginal benefits of emission reduction. An attempt to calculate the recommended tax rate based on the theory of socially optimal tax results for the current period in a range of € 7-45, with central estimate of € 25.

In order to be environmentally effective, the revenues of the tax have to be spent at least partially on emission reductions. Emission reductions in non-Annex 1 countries seem the best way to improve the environmental effectiveness.

As for monitoring and reporting, fuel consumption is routinely monitored on board ships. Records are being kept of both annual fuel purchases and per voyage fuel use. Most larger vessels have fuel flow meters that are able to record fuel use with an accuracy of ± 0.2%. Other vessels may have to rely on sounding tanks which has a lower accuracy.

Upon implementation of an emissions trading scheme for maritime shipping, ships could be given two choices:

1   Monitor fuel per voyage.
2   Monitor fuel use per annum.

The latter option would be attractive for ships that operate exclusively or predominantly between EU ports. In both cases, ships would have to indicate how they will monitor fuel use.

The main costs associated with monitoring and reporting emissions would stem from the verification of the data. These costs are hard to estimate, but unlikely to exceed US$ 10,000 (approximately € 6,700) per ship.

We propose that the tax be paid through national tax regimes or local tax bodies such as customs. Failure to pay taxes over a period would result in banning non-compliant ships from calling in EU ports.

8 Design of a mandatory efficiency standard

8.1 Introduction

The design of a mandatory efficiency standard comprises the following design elements:
- Choice of the indicator.
- Geographical scope.
- Ship size scope.
- Ship type scope.
- Baseline.
- Legal feasibility.

Each of these will be discussed in detail in this chapter.

8.2 Choice of the indicator

While in principle any measure of efficiency could be chosen, this section focuses on the two measures that have been discussed extensively by IMO's MEPC, viz. the EEDI and the EEOI. We consider these to be the most developed efficiency indicators, which have been subject to more analysis that any of the other possible indicators. Choosing another indicator would require a large amount of technical analysis and postpone the implementation of any policy considerably.

The issue of indicator choice has several aspects. This section analyses the emissions covered by the indicator, the emission reduction options rewarded under each indicator, the views on the application of the indicator, and current experience with it.

8.2.1 Definitions of EEOI and EEDI
The EEOI is defined as (MEPC.1/Circ.684):

$$EEOI = \frac{\sum_i \sum_j FC_{i,j} \times C_{F,j}}{\sum_i m_{cargo,i} \times D_i}$$

Where:
- j is the fuel type.
- i is the voyage number.
- $FC_{i}j$ is the mass of consumed fuel j at voyage i.
- CF_j is the fuel mass to CO_2 mass conversion factor for fuel j.
- $m$cargo is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships. And,
- D is the distance in nautical miles corresponding to the cargo carried or work done.

The EEDI is currently defined as (MEPC.1/Circ.681):

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}^{*}\right) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

Where:
- *CF* is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content. The subscripts *MEi* and *AEi* refer to the main and auxiliary engine(s) respectively.
- *Vref* is the ship speed, measured in nautical miles per hour (knot), on deep water in the maximum design load condition.
- *Capacity* is deadweight for dry cargo carriers, tankers, gas tankers, containerships, RoRo cargo and general cargo ships, gross tonnage for passenger ships and RoRo passenger ships, and 65% of deadweight for container ships.
- *Deadweight* means the difference in tonnes between the displacement of a ship in water of relative density of 1,025 kg/m^3 at the deepest operational draught and the lightweight of the ship.
- *P* is the power of the main and auxiliary engines, measured in kW. The subscripts *ME* and *AE* refer to the main and auxiliary engine(s), respectively.
- *SFC* is the certified specific fuel consumption, measured in g/kWh, of the engines.
- *fj* is a correction factor to account for ship specific design elements.
- *fw* is a non-dimensional coefficient indicating the decrease of speed in
- representative sea conditions of wave height, wave frequency and wind speed.
- *feff(i)* is the availability factor of each innovative energy efficiency technology.

8.2.2 Emissions covered by the EEOI and EEDI
Both the EEDI and the EEOI in their current forms are applied to cargo ships, which accounted for 71% of emissions on ships sailing to EU harbours in 2006 and 84% of global CO_2 emissions from maritime transport in 2007 (Buhaug et al., 2009).

As the EEDI is fixed for a ship, save for major modifications, a mandatory limit value of the EEDI of ships in EU ports would also affect the EEDI of these ships outside the EU. The geographical scope of such an instrument would be unlimited. So the emissions under the instrument would be all emissions of ships that visit EU ports.

In general, all IMO technical standards have a grandfather's clause. This means that the new legislation will only affect new buildings. If a mandatory EEDI limit would also implement a grandfather clause, the emissions under the scope of the instrument would increase gradually. As the economic life of a ship is on average 25 to 30 years, it will take decades for the policy to extend to all ships that visit EU ports.

However, we note that the majority of analyses of the EEDI presented to date have been based on existing ships. This is possible because, with the possible exception of the factors *fj*, *fw* and *feff(i)* (see section 8.2.1), the data that are needed to calculate an EEDI are available from a ship's technical documentation and often verified by class societies. It seems therefore to be possible to calculate the EEDI for existing ships. However, before a policy would be implemented based on the EEDI, this assumption may need to be assessed in more detail.

The EEOI is not fixed for a ship, but calculated over a certain time period. During this time period, even when a ship is not sailing to or from an EU port, its emissions would still be within the scope of the policy instrument. Thus the emissions of all ships that visit EU ports in a certain time period would be covered by such a scheme.

8.2.3 Emission reduction options rewarded under EEOI and EEDI

The most fundamental difference between EEDI and the EEOI is that the first one relates exclusively to the technical state of a vessel, while the EEOI covers also the operation of a vessels. The table below shows the main difference between coverage by the EEDI and the EEOI. The table shows that technical policy options target design measures in new ships. Operational policy options will, in principle, cover both design options in new ships and operational options in all ships.

Table 55   Comparison of areas which are covered by EEDI and/or EEOI

	Areas which are covered by the EEDI (1)	Areas which are covered by the EEOI (2)
DESIGN (New ships)		
Concept, speed & capability	Key aspects can be accounted for in the EEDI or technical standard.	All design and operational elements may implicitly be covered, as the resulting performance is the basis for the instrument.
Hull and superstructure		
Power and propulsion systems		
Low-carbon fuels	Capability can be included, but not necessarily used.	
Renewable energy		
OPERATION (all ships)		
Fleet management, logistics & incentives	No	
Voyage optimization	No	
Energy management	No	

According to the marginal abatement cost curves presented in chapter 3, technical measures account for 47% of total emission reduction options in 2030 and also for 47% of the cost-effective options.

8.2.4 Views on the application of the EEOI and EEDI

Both the EEOI and the EEDI have been extensively debated in the IMO. In these debates, views on the applicability of both measures in a policy setting have been discussed. This section presents a concise overview of the current state of the debate.

In 2009, the IMO has issued Guidelines For Voluntary Use Of The Ship Energy Efficiency Operational Indicator (MEPC.1/Circ.684). As the title suggests, these guidelines exclusively mention the voluntary use of the EEOI. There is no consideration of a mandatory application and/or the use of the EEOI as a basis for a mandatory policy in these guidelines or in the report of the meeting in which they were adopted (MEPC59/24). However, note that the first Intercessional Meeting of the Working Group on Greenhouse Gas Emissions from Ships concluded that 'the operational index should not be mandatory, but recommendatory in nature, but this does not mean that it could not be made mandatory in the future' (MEPC 58/4).

The Guidelines put forward the EEOI as a way to 'assist ship owners, ship operators and parties concerned in the evaluation of the performance of their fleet with regard to CO_2 emissions' (MEPC.1/Circ.684). The preceding guidelines (MEPC/Circ.471, 29 July 2005) also do not mention any mandatory use of the index.

The current formula for the EEDI has been established by MEPC59 in July 2009 (MEPC59/24). It's current status is described as 'interim guidelines for the purpose of tests and trials on a voluntary basis' (MEPC.1/Circ.681). So the formula has not been determined with the aim of serving as a basis for a mandatory policy. Probably, much more testing would have to be done in order to establish an efficiency baseline and determine the number of ship types for which such a baseline could be established. Moreover, more studies would be needed to establish the potential for efficiency improvements and the rate at which they could be achieved.

Many delegations have proposed ways to use the EEDI in a policy context, but this subject has not been discussed at MEPC.

In conclusion, the general view on the application of the EEOI is that it should be used internally by ship owners and operators to evaluate the efficiency of their ships, although it is not ruled out that the EEOI could become mandatory in the future. There is currently no consensus view on the application of the EEDI. The view on the current formula is that it is intended for testing purposes.

8.2.5 Current experience with EEOI and EEDI

Under this section we have included not only the work focusing strictly on fleet efficiency indicator, but also studies which covers sea transport emissions and bunker consumptions as such.

The EEOI has been studied in CE et al. (2006). At this point it is not yet clear how a standard could be defined that is able to distinguish efficient from inefficient sea transport. Key questions relate to (based on CE et al., 2006):

- Baseline: Transport efficiency potential depends on location of origin and destination, cargo volumes, ability to find return goods (trade triangles, etc.) type of goods and more.
- Allocation: Distribution of emissions in cases where multiple cargo types are carried (e.g. container vessels, RoRo vessels, etc.).
- Baseline drift: Changes in transport demand and fleet size cause changes in relative cargo availability hence efficiency. To be effective, the baseline must be more or less continuously adjusted.
- Regional impacts: A side effect of this approach could be that transport cost increase in remote and sparsely populated areas due to the inherent lower efficiency.

- Ownership and verification: The CO_2 efficiency of a ship depends on its operation which may be controlled by a charterer that is not the ship owner. In this case, if a ship is sold or transferred, who owns the index.
- Density of the cargo. Bulk carriers can transport weight restricted cargo (high density cargo such as coal or ore) or volume restricted cargo. Since the formula is expressed in mass of CO_2 per tonne-mile of transport work, the former ship would always have a better index than the latter.

The Danish Maritime Authority 2008–2009 (11) has made a number of submissions to IMO (official proposal documents) regarding calculations of EEDI baselines for the different vessel types where the x-axis represents the dwt and the y-axis represents the gram CO_2 per ton nm.
This curves shows that when the vessel size increases the gram CO_2 is reduced, so that the smallest vessels have the highest emissions. The methodology used are based on the same approach as Hans Otto Kristensen 2007 (6), but the basis is now that the EEDI calculation now are done with MCR = 75% while he used 85%. With 75% of maximum power taken out of the engine instead of 85% the gram CO_2 per ton nm becomes lower since lower speed reduces the power consumption with the speed multiplied with itself three times.

The Ministry of Transport, Public Works and Water Management of The Netherlands 2009 (12) asked Centre for Maritime Technology and Innovation' (CMTI) to carry out a study into the effects and robustness of the proposed index suggested by IMO per vessel type. The study focuses on the seagoing ships built and/or registered in the Netherlands. The first part exists of analysing the index formula and collecting data from Dutch ship owners and builders. After collecting the data, a trend analysis has been made of the following ship types: tankers, general purpose vessels, dredgers container vessels and offshore vessels. For tankers and general purpose vessels a trend analysis has been done on the development of efficiency during the past 30 years. The last part of the study consists of a detailed analysis of the formula. In total 1,150 ships have been analysed with the proposed EEDI formula. The analysis leads to the conclusion that no clear trend could be established for vessels of any type smaller than 15,000 Mt DWT. For vessels larger than 15,000 Mt DWT the EEDI index values correlate much better. For tanker vessels larger than 15,000 Mt DWT, the correlation of EEDI values is sufficiently high to establish a clear trend. With increasing DWT values, the index values of vessels of all types converged. The analysis shows that the EEDI index formula is not suitable for complex special ships like dredgers and offshore work vessels. These ships are not designed for transport of cargo at an average sea speed, but for other functions. A specific index formula should be developed for each of these vessel types, containing a parameter expressing the benefit to society that fits the ship type. As an example a proposal for an index formula for dredger vessels is added to the report.

The Community of European Shipyards' Associations (CESA) supports the development of CO_2 index systems for information purposes and provide technical background for the necessary improvement of the draft design index. CESA however believes that a mandatory design index would not be an optimal tool as it would fail to achieve a rapid reduction of the specific CO_2 emissions from international maritime transport. It's the view of CESA that further in depth investigations are needed to consider the feasibility of this approach and to obtain the necessary improvements of the formula of the CO_2 design index. CESA also recommends that the scope of the index should be limited to a hull/propulsion and engine/fuel related CO_2 efficiency. The development should be focussed on identifying a well defined set of

parameters that can be used with all ship types without discriminating certain speed ranges or specific types of cargo. Instead of implying that only large and slow ships are acceptable, the index should define a consistent index for all ships against which the improvements in hull / propulsion performance (*P/V* ratio) and engine/fuel efficiency
(*SFC*) can be measured, which represent a significant CO_2 reduction potential.

8.2.6 Conclusion

We conclude that the EEOI is not fit as a basic parameter for a mandatory policy for the following reasons:

- The EEOI dos not take changes in efficiency due to the business cycle, the specific trade or the region where a ship operates into account and could therefore be considered to be inequitable.
- It is hard if not impossible to compare the EEOI across ship types, even across the most important ship types in terms of CO_2 emissions: bulkers, tankers, container ships and RoRo ships.
- The IMO has endorsed the use of the EEOI as a voluntary measure to evaluate the performance of ships by ship owners and operators, not as a metric for a ship's performance in a mandatory policy.

The EEDI may be developed into a good indicator for a ship's design efficiency. Currently, it is not mature as the formula for the EEDI has only recently been established and is subject to trials at the moment.

8.3 Geographical scope

8.3.1 Legal aspects of the geographical scope

In terms of exercising jurisdiction and requiring vessels to comply with a mandatory design or operational efficiency limit value, consideration will have to be given as to apply a geographical scope during which the EEOI is to be complied with. Clearly while it may be tempting to require that all vessels entering the EU's EEZs comply with the efficiency limit value, the EU is not permitted under UNCLOS to exercise and extend the sovereign jurisdiction of its member states to cover all activities in its EEZs. Similarly the EU would not be entitled to take any action which would constitute a regulation of innocent passage through the territorial sea. UNCLOS requires measures to be taken to avoid the inspection of vessels at sea and therefore compliance would have to be monitored in retrospect or in advance, at an EU port. If no geographical limit on the applicability of the regulation is set out, then there will be an extraterritorial effect which has been discussed above. If it was limited to when the vessel was actually in EU waters, then the usefulness of the measure would be severely compromised and ships may take evasive routeing to avoid EU waters for as long as possible, increasing overall emissions.

EU ports

Given that the application of such a scheme can only properly apply to EU territorial waters, we must now turn our attention to how the scheme would in practice be complied with, monitored and enforced.

Under Article 17 UNCLOS all vessels have the right of innocent passage through a state's territorial waters and as a practical consequence of this it will not be possible to simply require that all vessels transiting EU territorial waters and not calling at EU ports comply with a mandatory design or operational limit value, not only because this may infringe on the right of innocent passage but also because the enforcement of such a requirement would be almost impossible. In practice it may also cause ship owners to take circuitous routes

to avoid the EU zone thereby causing more fuel to be used and more carbon to be emitted.

Rather it seems that the only option for enforcing any such scheme would be to make compliance with the mandatory operational or design efficiency limit value a condition of entry to all EU ports with the port state having responsibility for monitoring and enforcing the scheme to ensure that all vessels are in full compliance with either the design or operational standards.

Where these did not comply with internationally accepted CDEM standards, then the legal challenges and difficulties set out above would apply and in addition would cause a significant distortion in the industry as two classes of ship would develop - those that could trade to the EU as they comply and those that could not - unless a 'de minimis' provision was included permitting, say, one visit per year by non-conforming shipping. Again this would lead to added complication.

8.3.2 Emissions within the scope - avoidance

If the mandatory EEDI would be applied to all cargo ships in EU ports, all emissions of these ships would be under the scope of the policy, even emissions that these ships generate on voyages between two non-EU ports. We do not know which share of ships in the world fleet visits an EU port during a certain time period, but it is likely to be significant. The share of emissions on voyages to and from EU ports is 31% of global emissions, and the share of emissions on ships that visit an EU port in a year is perhaps 10 or 20 percentage point higher. The share of ships that visit an EU port at some point in their economic life may even approach 80 or 90%. In this sense, the share of emissions within the scope of this policy would be very large.

However, the scope for avoidance is also large.

The available analysis of EEDIs shows that there is a considerable variance in the EEDI values of similar ships, as can be seen in Figure 36 below for dry bulk carriers. It the mandatory EEDI limit value is set at the current fleet average, 50% of the ships would be banned from EU ports while the other 50% would comply with the value.
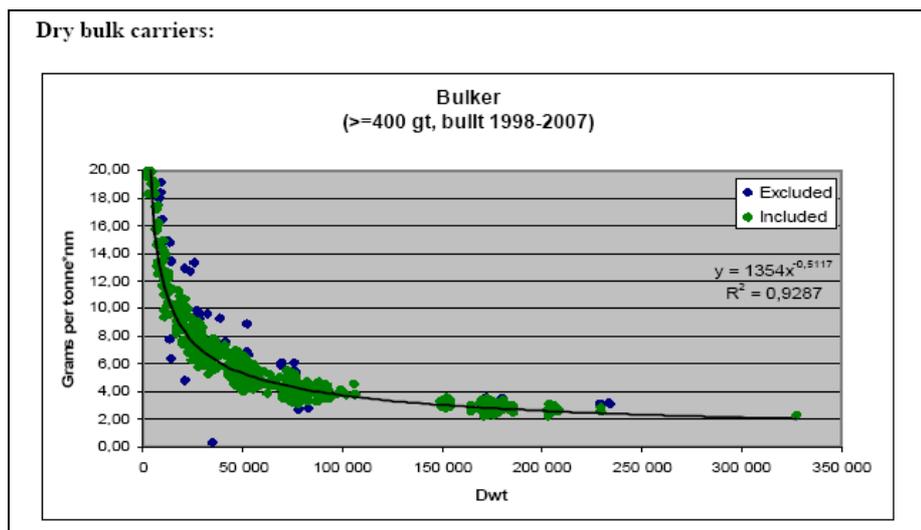
Source: Danish Maritime Authority.

One of the likely reactions to the implementation of a mandatory EEDI limit value in EU ports would be that ship owners and operators shift their fleet in such a way that only compliant ships visit the EU ports. There seem to be very few barriers to do so, if any, given the fact that ships are movable objects. If the fleet is shifted on a large scale, the large majority of ships in EU ports would be below the baseline, and on average, ships that do not visit EU ports would be above the baseline. Hence, emissions would be exported out of the geographical scope of the system, and the environmental effectiveness of the policy would be significantly reduced.

8.3.3   Conclusion

In summary, if at all, a mandatory EEDI limit can only be enforced in EU ports. While the scope of emissions under this policy would be large, so would the scope for avoidance. Because ships are moveable objects, it is quite easy to deploy ships with an EEDI over the baseline outside the EU, and deploy compliant ships in the EU. Such a reaction would relocate emissions, but would not significantly reduce them.

8.4   Ship size scope

There is an ongoing discussion in IMO regarding which vessels can be included in an EEDI. One proposal has been to include only vessels above 15,000 dwt. This is amongst other based on an analysis by CMTI (2008). Its report concludes that a threshold should be set excluding vessels bellow a certain size. Their main argument is that in the regression lines which they have plotted for the different vessel types, they have found results indicating that the variance between vessels in their calculated EEDI performance is bigger in the smaller vessel segments that for the bigger ones above 20,000 dwt. At first glance this looks correct, however if this variance is plotted as a percentage value for the different vessel segments instead it's easy to see that the percentage variance value is not that different between small and big vessels.

In Table 56 the World fleet are divided into three size groups which are vessels bellow 5,000 dwt, between 5–15,000 dwt and above 15,000 dwt. The vessels bellow 5 000 dwt adds up to 75% of the total fleet and they use 22% of the bunker oil. The vessels between 5–15,000 dwt add up to 10% of the fleet and they use 15% of the bunker oil. Vessels above 15,000 dwt adds up to 15% of the fleet and they use 63% of the bunker oil. So if only vessels above 15,000 dwt are included 85% of the fleet will be exclude from the scheme. These figures are based on Lindstad and Mørkve, 2009 (10).

Table 56   Size distribution of the world fleet and share of bunker oil consumption

Vessel size Group	Number of vessels	Bunker fuel in million ton	Percentage of the vessels	Percentage of bunker fuel
Bellow 5,000 dwt	75,463	72	75%	22%
5,000-15,000 dwt	10,132	51	10%	15%
Abow 15,000 dwt	15,535	208	15%	63%
Total	101,130	331	100%	100%

Our recommendation is therefore to set the size threshold rather low, e.g. at 400 GT which is the threshold for MARPOL or 500 GT which is the threshold for SOLAS.

8.5   Ship type scope

In their current forms, neither the EEDI nor the EEOI can be calculated for vessels whose main purpose is not to transport cargo and/or passengers. Therefore no EEDI or EEOI can be calculated for example for dredging, offshore supply, fishing and tugs. Together, these groups account for an estimated 12% global maritime emissions (Buhaug et al., 2009).

The main problem regarding the vessel types which has been questioned marked are that the main design criteria is not carriage of cargo but a function of the various functions and tasks.

Offshore supply vessels has as an example been designed for a combination of various functions and tasks. Therefore these ships cannot be compared to cargo carrying ship types. The vessels are not optimized on the deadweight/speed/energy consumption aspects. Similar to the dredger vessels, carriage of cargo at an average speed is not the main design driver

Dredger vessels are another good example of a typical complex special ship type. These vessels are designed to fulfil a special task, in this case vertical and horizontal transport of soil. For some of the dredger vessels the huge pump capacity is driving factor for the installed power. The emphasis of the design is on the pump trough function and not on maximizing transport capacity. Therefore vessels like some cutter suction dredgers don't have a very high deadweight. The only cargo they have to carry is the fuel and the spare parts they need. On the other hand, because they are designed to pump the soil over very long distances, they are equipped with big power plants.

In order to include dredgers, offshore supply vessels, fishing vessels and tugs, a specific index formula which focuses on these specific types of vessels would need to be developed.

8.6 Baseline

8.6.1 Energy Efficiency Design Index (EEDI)

The Energy Efficiency Index provides, for each ship, a figure that expresses its design performance. By collecting data on EEDI for a number of ships within a category, it will be possible to establish baselines that express typical efficiencies of these ships. Figure 37 shows the effect of deadweight of a ship on the CO_2 design index for some categories of ship. The formula that was used to calculate the CO_2 design index is similar to the EEDI, and the EEDI is expected to show the same behaviour.

Based on this type of analysis, EEDI baselines have been proposed for different ship categories that are functions of ship size, where size is expressed e.g. as deadweight tonnage or gross tonnage. EEDI baselines could be part of different policies using the EEDI.

Figure 37   The effect of ship deadweight on CO_2 design index (11) – Danish Maritime Authority

Establishing an EEDI baseline, using different datasets for the different ship sizes, will result in different baselines for the different vessel sizes. Presently, the EEDI is not finalised and baseline data have been approximated by using data from existing ship databases rather than being obtained through the process of establishing the EEDI for individual ships. The Average Index Values are used as the basis for calculating an exponential regression line. The regression line expresses the baseline value, which can then be calculated by using the following formula:

$$Baseline\ value = a\ \ Capacity^c$$

Where a and c are constants deriving from the regression line. In a study initiated by the Danish maritime authority of Denmark (11) and where the results where submitted to the Intercessional IMO GHG meeting in March 2009 the following values for a and c was calculated. R2 describes the correlation of the baseline value. A correlation close to 1 or -1 represents a high degree of correlation.

Table 57   Possible EEDI baselines for different ship types

Ship type	A	Capacity	C	Number of samples	Excluded	R2
Dry bulk carriers	2503.2	DWT	0.5601	995	28	0.92
Tankers	2401.1	DWT	0.5400	1,209	58	0.97
Gas carriers	1649.7	Tank volume	0.4855	178	10	0.96
Container ships	105.77	DWT	0.1761	188	9	0.42
General cargo ships	280.85	DWT	0.3051	238	8	0.62
RoRo cargo ships	20792	GT	0.7223	205	33	0.87
Passenger ships	1517.0	GT	0.4092	192	73	0.79

Source: Methodology for Design CO_2 Index Baselines and Recalculation thereof, MEPC 58/4/8

At MEPC 59 it was decided to further split the RoRo group into three subgroups which are weight carriers, volume carriers and car carriers, however these new baselines has not been calculated.

8.6.2   Conclusion

From this discussion it is clear that there is no single baseline for the EEDI of the shipping sector, but a set of baselines for different vessel types. The number of vessel types with different baselines is still growing. At this point, we cannot assess where this process will end.

8.7   Legal feasibility

As discussed above (section 5.4), whilst the introduction by the EU of either a mandatory design or operational index limit value would potentially interfere with existing internationally accepted international rules and standards, it is arguable whether such would be a breach of UNCLOS, international marine conventions or general international law. It is therefore essential to discuss the legal feasibility of and the legal limitations to such a policy instrument in detail before addressing the other design elements.

In considering the imposition of a design or operational efficiency limit value at an EU-wide level and its relationship with existing internationally accepted CDEM standards in the context of pollution from GHG emissions from ships, it is important to consider the relevant provisions of UNCLOS both in terms of the role of generally accepted international rules and standards and states' duties and rights in controlling, reducing and preventing pollution and the parameters within which a state is entitled to exercise jurisdiction.

UNCLOS - pollution

Article 1(4) UNCLOS defines 'pollution of the marine environment' as:

> *"The introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities".*

Article 21.1(f) UNCLOS states that:

> *"the coastal state may adopt laws and regulations, in conformity with the provisions of this Convention and other rules of international law, relating to innocent passage through the territorial sea, in respect of…the preservation of the environment of the coastal state and the prevention, reduction and control of pollution thereof"*.

UNCLOS does not go on to state what precisely may be imposed on a foreign flagged ship when it arrives at the port of the coastal state. It is clear that the right of access to a port is not a right: the port state can ban and does ban ships from ports for a number of reasons including for reasons of health or failure to comply with the minimum standards required by the MARPOL convention (Article 5.3) or for persistent failure to meet international standards of maintenance and operation and inclusion of the ship on a 'black list'.

As discussed above, there is an ongoing legal debate as to whether it is open to a port state to impose regulations on ships calling at its ports voluntarily that are more stringent than those agreed by way, for instance, of international convention. Foreign ships have been visiting port states for many centuries and a high measure of custom and understanding based on comity has developed. On top of this lies general international law and the system of international conventions including the United Nations Convention on the Law of the Sea, (UNCLOS) and conventions agreed at the International Maritime Organisation, the marine agency of the UN. Additionally, agreements originating from the World Trade Organisation (WTO) such as the General Agreement on Tariffs and Trade (GATT) and the General Agreement on Tariffs and Services (GATS) further complicates the issue.

However, the large measure of consensus on the international regulation of shipping has arguably been undermined by an increasing willingness on the part of national and regional administrations to apply more stringent standards than those found in the international conventions where they are deemed to be lacking or insufficiently firm. Numerous legal reasons have been stated to justify the legality of such measures: the sovereignty of states exercising their authority over ports and internal waters as they would over their land; the fact that international conventions refer to minimum standards whereas more exacting standards are deemed to be appropriate or where there is an absence of international regulation which should be remedied for the protection of the port and coastal states.

Both the United States and the European Union has taken such measures in relation to oil pollution, for instance, in the accelerated phase out of single hull tankers and requirement that all tankers visiting ports be double hulled - in advance of the MARPOL regulations. Such measures were justified by the United States and the European Union on the basis of the extraordinary harm that might be done should such measures not be put in place.

That said the legality of such measures continues to be debated and decisions have been made both in favour of and against the proposition that port states can impose higher standards than those generally accepted. Certainly the view of the EU is that it is entitled to take such steps where it feels there is a clear and present risk of a serious incident occurring or serious harm being done. This view is shared by the United States and other countries such as Australia, where there is a high degree of, particularly, environmental sensitivity

The imposition of a mandatory efficiency design limit may require significant changes to the construction, machinery, equipment of vessels visiting EU ports and as such fall outside the generally accepted international rules and standards presently applicable to international commercial shipping. Imposing an operational index would have little effect if it only applied to the ports and territorial sea of the EU. Consequently, it would be necessary to make the EEOI mandatory extraterritorially. Where a change is made to the equipment of a ship as a condition of entry to an EU port, this has an extraterritorial effect in that the piece of equipment stays with the ship whether or not it is in EU waters.

However, requiring certain operational measures to be taken would alter the nature of the extraterritoriality. For instance, if the ship is only able to achieve its required EEOI by the use of kite sails or certain weather routeing when the ship is outside EU waters, then such requirement will be open to challenge on the basis that operational matters whilst the ship is on the high seas is a matter for the flag state and should not be, in the absence of broad international agreement by way of convention, imposed on foreign flag ships. It could be argued that such regulation was neither reasonable nor proportionate.

A further consideration in relation to such measures would be the nature of a mandatory efficiency limit and the enforcement of such rules. A vessel not meeting the standards required may not be capable of economic modification to achieve the required standards and therefore detention of the offending vessel and permission to sail to a repair yard would not be a useful sanction to impose. Instead, the banning of vessels not meeting the standards would be required for those ships that could not be modified. In our view, such action would be disproportionate given the potentially wide effect that meaningful regulations in this regard would have, bearing in mind that the life of a commercial vessel is 25 years and the vast majority were not built with fuel economy in mind.

It is considered that such a measure would lead to legal challenge on the basis of a departure from generally accepted international standards and a disproportionate response to the issue at hand when compared with the alternatives considered further in this study.

In addition it would be very challenging to establish an operational index with fair baseline levels as it would not be able to take account of external factors which can affect a ship's efficiency, even if it were based on annual data. A further challenge would be for the EU to create and be able to enforce an operational index which could equally be applied to all types of ships and shipping without resulting in indirect discrimination against certain types of vessels. In particular the EU would have to consider excluding some tramp shipping from any such scheme due to the infrequency with which such vessels would be visiting EU ports.

Article 211.3 UNCLOS provides that:
> *"states which establish particular requirements for the prevention, reduction and control of pollution of the marine environment as a condition for the entry of foreign vessels into their port or internal waters or for a call at their off-shore terminals shall give due publicity to such requirements and shall communicate them to the competent international organisation...*

UNCLOS clearly contemplates making such measures in relation to pollution a condition of entry to ports although such reference was intended to cover pollution of the sea water and it is doubtful that the intention covered air pollution, although clearly the extension of the definition is arguable as the language is not limited here.

Article 25.2 UNCLOS states that:
"in the case of ships proceeding to internal waters or a call at a port facility outside internal waters, the coastal state also has the right to take the necessary steps to prevent any breach of the conditions to which admission of those ships to internal waters or such a call is subject".

However, it is not clear whether the exercise of a port state's right to take such action against a vessel is unlimited - that the state could require any measure to be complied with before permitting entry. General international law, including principles of proportionality, reasonableness and comity will restrict the port State's right to impose such regulations on visiting shipping. Where alternative measures which are at least as effective as mandatory standards and which are less onerous to comply with, in that they do not distort competition, do not discriminate against certain types and age of ship and which results in numerous ships being banned from EU waters may face legal challenge from both ship owners and also the users of ships.

Energy Efficiency Design Index (EEDI)

In contemplating whether to impose unilaterally either a design or operational index in circumstances where the IMO is currently in the process of finalising an EEDI, it is important to consider the scope of the EEDI and the intention for its use.

The Marine Environmental Protection Committee (MEPC) of the IMO has undertaken to develop a number of measures to reduce the emission of greenhouse gases from international shipping. One of these measures is the development of a CO_2 index, which is an indication of the CO_2 output of a merchant ship. At MEPC 58 the CO_2 design index was renamed the Energy Efficiency Design Index (EEDI), and a formulation was released for dissemination by IMO delegations and industry observers. The results of this dissemination will be used in preparation for a final index formula, to be discussed during an intercessional meeting of the working group on 9-13 March 2009.

The working group has been charged with finalising the EEDI and most notably the method of calculation, the regulatory text, verification procedures and any necessary guidelines in advance of MEPC 59. The current formula for the EEDI has been established by MEPC59 in July 2009 (MEPC59/24). It's current status is described as 'interim guidelines for the purpose of tests and trials on a voluntary basis' (MEPC.1/Circ.681). So the formula has not been determined with the aim of serving as a basis for a mandatory policy.

Once finalised, the index will serve as a fuel-efficiency tool at the design stage of ships, enabling the fuel efficiency of different ship designs, or a specific design with different input such as design speed, choice of propeller or the use of waste heat recovery systems, to be compared.

The design index will contain a required minimum level of fuel efficiency related to a baseline, which will be established based on fuel efficiency for ships delivered between 1995 and 2005.

It is important to note that the EEDI has been created to deal with the construction and design of new build vessels going forward and will not require existing vessels to comply with its standards.

As such if the EU were to implement a mandatory design efficiency limit value, despite the restrictions imposed on such actions under UNCLOS, detailed consideration would need to be given to whether the value would be imposed on new build vessels only or to all ships entering EU ports.

Albeit that the IMO is aiming to introduce the EEDI in the foreseeable future, the EU would nonetheless be in breach of its obligations under UNCLOS if it were to introduce its own design efficiency limit value in anticipation of the IMO's action as this would nonetheless constitute an attempt to impose unilaterally on the shipping industry a set of design standards which are above and beyond the current internationally accepted standard.

Energy Efficiency Operational Indicator (EEOI)

The CO_2 operational index meanwhile applies to existing ships and was renamed by the IMO as the Energy Efficiency Operational Indicator (EEOI).

An interim CO_2 operational index was initially adopted by MEPC 53 in July 2005 and has been used by a number of flag States and industry organisations to determine the fuel efficiency of their ship operations. The IMO has received the outcome from thousands of trials and a large amount of data exists.

The interim CO_2 operational index has been used to establish a common approach for trials on voluntary CO_2 emission indexing, enabling ship owners and operators to evaluate the performance of their fleet with regard to CO_2 emissions. As the amount of CO_2 emitted from a ship is directly related to the consumption of fuel oil, CO_2 indexing also provides useful information on a ship's performance with regard to fuel efficiency.

The draft CO_2 operational index was not finalised at MEPC 58 and a review of this index continued through a discussion by a Correspondence Group on Review of the EEOI co-ordinated by Japan. MEPC 59 renamed the EEOI from Energy Efficiency Operational Index to Energy Efficiency Operational Indicator. Moreover, it adopted Guidelines For Voluntary Use Of The Ship Energy Efficiency Operational Indicator (MEPC.1/Circ.684). As the title suggests, these guidelines exclusively mention the voluntary use of the EEOI. There is no consideration of a mandatory application and/or the use of the EEOI as a basis for a mandatory policy in these guidelines or in the report of the meeting in which they were adopted (MEPC59/24).

As such, the unilateral introduction of a mandatory operational efficiency limit value faces the same challenges as a design value and could equally constitute a breach of UNCLOS.

8.7.1 Conclusion

Imposing a mandatory design or operational index is not without the risk of legal challenge. The imposition of an EEDI may have significant effects on the vessel, may require expensive modification and may, in extreme cases, result in a perfectly safe and seaworthy ship being banned from EU waters due to its age and inability to meet the requirements. Legal challenge may come from ship owners who can no longer trade their vessels or the users of such ships - charterers and shippers who cannot find sufficient tonnage for their uses. That said, minor modifications, such as fuel monitoring ma not have such an effect.

Imposing and EEOI on the ship will have an extraterritorial effect which may lead to legal challenge, particularly from ship owners and others in the supply chain where the vessel is trading outside the EU for significant periods of time.

8.8   A mandatory efficiency standard and the policy objectives

Section 4.6 states two policy objectives.

The first policy objective is to limit or reduce maritime GHG emissions.

The secondary policy objective is to remove barriers and market failures that prevent measures to improve fuel efficiency from being implemented, so that the first objective can be met in the most cost-effective way.

An mandatory efficiency standard can in principle increase the design efficiency of the fleet and thus to some extent emissions. However, emissions can continue to rise if demand growth outpaces efficiency improvement rate, as is likely (see section 4.1.2). Moreover, emission reductions depend on the amount of avoidance which potentially could be large.

As for the market barriers and market failures, the mandatory EEDI value would induce innovations in design of both new ships and existing ships. It would not induce ship owners or operators to take operational measures to reduce emissions. By requiring ships in the EU to have efficient designs, it would to some extent address the split incentive between ship owners and time charterers. After all, time charterers would have no choice but to charter an efficient ship. A mandatory EEDI limit does little to reduce the other market failures and barriers that were considered to remain the most important, i.e. the transaction costs and the time lag.

8.9   Conclusions

There are two main reasons why a mandatory value for the efficiency of ships visiting European ports is not a feasible policy instrument at this time.

There is currently no internationally agreed measure of a ship's efficiency. The EEOI is not considered to be a useful measure by the IMO as its value depends largely on the type of cargo carried, the specific trade a ship's engaged in, and other similar ship specific factors.

The EEDI could become a generally accepted measure of a ship's technical efficiency, but its formula is currently still under development. Once its formula will have been established, the improvement potential per ship type would need to be assessed, a process that could take some time.

The proposal may be open to legal challenge:
- EEDI - the possibility of a legal challenge to this depends on how this index evolves and the practical effect it has on ships trading to EU ports. If the index can be complied with at little cost or disturbance to the ship's trading pattern, then such a challenge may not emerge. If compliance with the index requires major modifications taking time in shipyards and leads to ships being banned permanently from EU ports due to their inherent design and inability to comply with the EEDI, then this may lead to legal challenge from ship owners and the users of such tonnage.

− EEOI - it is difficult to see how this index would be effective it is was limited to EU waters and therefore it would need to have extraterritorial effect. This would be difficult to monitor, may cause evasion and would be open to legal challenge on a number of grounds.

9 Design of a baseline-and-credit trading scheme

9.1 Introduction

The design of a baseline-and-credit trading scheme comprises the following design elements:
- Traded unit.
- Choice of indicator.
- Baseline – principle.
- Baseline – value.
- Scope – geographical scope.
- Scope – ship size.
- Scope – ship types.
- Administrative set-up.

Each of these elements will be discussed below.

9.2 Baseline-and-credit trading schemes

In this section we consider using baseline-and-credit trading mechanism for reduction of GHG emissions from sea ships. Because of the fact that especially in Europe, the most well known type of emissions trading is cap-and-trade, we think that it is useful to start this section with a short description of the mechanism of baseline-and-credit trading system and comparison to cap-and-trade scheme.

In baseline-and-credit trading[30] scheme, emissions reduction above and beyond legal requirements can be certified as tradable credits. The benchmark for credits is usually provided by traditional technology-based standards. Baseline-and-credit trading provides a more flexible means of achieving the source specific goals than the source-based standards were designed to achieve (Tietenberg, 2006).

In our proposal for maritime shipping, the benchmark refers to an operational or technical index set at a certain level. As long as the efficiency with regard to CO_2 emissions from a ship is higher or equal to the index, the ship operator (or the entity responsible for complying with the policy) does not have to get involved in emissions trading. However, a situation where the efficiency of a ship is worse than imposed by an index automatically triggers an obligation to submit credits for emissions that are excessive as compared to the index (a baseline). Credits can be bought from the ships which perform better than indicated in an index. In long-term equilibrium (when the supply of credits equals the demand) the average effect regarding CO_2 efficiency for all ships covered with this policy should be more or less equal to the allowable index.

---

[30] Tietenberg (2006) refers to this type of trading simply as 'credit trading', which should be based on pre-existing standards. Another name for such a type of policy is offsetting. Other definitions are possible; according to EPA (2009) trading of credits where the regulatory authority sets a constant or declining emission rate performance standard (thus not pre-existing) as a benchmark can be classified as 'rate-based trading' or 'averaging'.

In such a scheme it is also possible to allow banking, when the credits created in one accounting period can be used in another accounting period.

The most striking distinction between the cap and trade system and baseline-and-credit trading is in addressing activity growth. In a cap-an-trade scheme, the total amount of emission is capped. Under a cap, sources must determine how to operate new facilities or increase utilisation of existing facilities and still comply with the emission cap. Baseline-and-credit trading system, on the other hand, attempts to establish an efficiency standard for each source that will, in aggregate, produce the desired environmental improvement. However, emissions can increase if the existing ships increase their transport work level or if new ships are introduced to the system. Therefore, under a baseline-and-credit trading scenario, similar as with environmental taxes, the regulating authority must periodically impose new rate standards to achieve and maintain an emission target and prevent (or correct for) additional emissions that may result from increased production. Such revisions can create a less certain regulatory environment for sources than under cap-and-trade (EPA, 2003).

Baseline-and-credit trading scheme can be viewed as a tradable standard, where simplicity of a command-and-control instrument is combined with flexibility and resulting cost-effectiveness of an economic instrument. From an economic point of view, a baseline-and-credit trading scheme will always be superior to a uniform technical or operational standard provided that administrative costs related to establishing a market for credits will be lower than cost-effectiveness gains due to flexibility (i.e. leaving the decision which ships will reduce the emissions and which ones will buy the credits to the market).

Several baseline-and-credit schemes have been implemented, including a Sulphur Emissions Offsetting Pilot for ships (BMT, 2006) and the reduction of benzene content in fuels in the US (Schary, 2008).

9.3 Traded unit

As mentioned in section 9.2, within credit-based trading schemes there is no absolute cap on emissions. Instead, a relative standard has to be defined. In the context of maritime shipping, two indexes can potentially be used as a baseline: Energy Efficiency Operational Index (EEOI) and Energy Efficiency Design Index (EEDI). In the sections below, we will focus first on the operational index EEOI and then on the technical (design) index EEDI. Even if the standard is defined in relative terms (e.g. in tonnes of CO_2 per tonne-mile of transport work), trading units will be defined in absolute terms, i.e. in tonnes of CO_2. The basis for calculating emission credits in a given calculation period would be slightly different for the operational index and the technical index, as described below.

9.3.1 The traded unit if the EEOI is the index

We propose that credits based on operational index baseline are calculated as follows:

$$C_{i,j} = (\text{Baseline\_EEOI}_i - \text{EEOI}_{i,j}) * \Sigma V_{i,j}$$

Where:
- $C_{i,j}$ = number of CO_2 credits generated by ship i during period j, in tonnes of CO_2.
- Baseline_EEOI_i = the baseline EEOI value for ship I, depending on the ship type and size.
- $\text{EEOI}_{i,j}$ = actual EEOI of ship i during period j in tonnes per tonne-mile of transport work.
- $\Sigma V_{i,j}$ = sum of all policy-eligible[31] transport work of ship i during period j (in tonne-miles).

According to this definition, the ships create credits if their efficiency is higher than imposed by the baseline of the index (i.e. if the emissions of CO_2 per tonne-mile of transportation work are lower than imposed with an index). By analogy, if the efficiency of the ship is lower than required (higher than allowed average CO_2 emissions per tonne-mile), a purchase requirement is created.

Thus defined, the traded unit would signify a ship-average quantity of CO_2 emissions over or under the baseline. Its unit would be tonnes of CO_2, but the traded unit would not be the amount emitted for two reasons. First, it is the difference with the baseline rather than the total amount that is traded. Second, it is the average efficiency of the ship over a certain period rather than the efficiency of one voyage that determines the EEOI and thus the amount of traded units. The efficiency on the voyage to the EU port may be different than the ship's EEOI, e.g. because of the load factor or weather conditions.

Because the traded unit is not absolute quantities of actually emitted CO_2, it would be difficult to link this scheme to cap-and-trade schemes like the EU ETS or even to flexible mechanisms under the Kyoto Protocol.

---

[31] Depending on geographical scope and possible other considerations.

9.3.2 The traded unit if the EEDI is the index

In case of EEDI, defining the unit of trade would be less straightforward as compared to the operational index, as EEDI index is expressed with a formula related to measurement of ship design characteristics in 'standard conditions'. Effectively, the index EEDI is calculated in units of CO_2 emissions per tonne-miles per day. Therefore, we could propose the following basis for calculating emission credits in a given calculation period:

$$C_{i,j} = (Baseline\_EEDI_i - EEDI_i) * \Sigma V_{i,j}$$

Where:
- $C_{i,j}$ = number of CO_2 credits generated by ship i during period j, in tonnes of CO_2.
- $Baseline\_EEDI_i$ = the baseline EEDI value for ship I, depending on the ship type and size.
- $EEDI_i$ = actual EEDI of ship i.
- $\Sigma V_{i,j}$ = sum of all policy-eligible[32] work of ship i during period j (in capacity-miles).

As the EEDI is defined as mass of CO_2 emitted per capacity-mile under standardised circumstances, the traded unit signifies mass of CO_2 under standardised circumstances, which we will call in short attributed mass of CO_2. Note that the traded unit is not tonnes of CO_2 actually emitted for two reasons. First, because credits are generated for ships with an efficiency below the baseline, credits are not related to actual emissions but to emissions above or below the baseline. Second, because the EEDI is determined in standardised conditions, and ships seldom sail under such conditions, actual emissions per capacity-mile will differ from the emissions calculated.

9.4 Choice of indicator

The choice of the indicator is made on the same grounds as in section 8.2.

While in principle any measure of efficiency could be chosen, this section focuses on the two measures that have been discussed extensively by IMO's MEPC, viz. the EEDI and the EEOI. We consider these to be the most developed efficiency indicators, which have been subject to more analysis that any of the other possible indicators. Choosing another indicator would require a large amount of technical analysis and postpone the implementation of any policy considerably.

The issue of indicator choice has several aspects. This section analyses the emissions covered by the indicator, the emission reduction options rewarded under each indicator, the views on the application of the indicator, and current experience with it.

---

[32] Depending on geographical scope and possible other considerations.

9.4.1 Definitions of EEOI and EEDI

The EEOI is defined as (MEPC.1/Circ.684):

$$EEOI = \frac{\sum_i \sum_j FC_{i,j} \times C_{F,j}}{\sum_i m_{cargo,i} \times D_i}$$

Where:
- j is the fuel type.
- i is the voyage number.
- $FC_{i\ j}$ is the mass of consumed fuel j at voyage i.
- CF_j is the fuel mass to CO_2 mass conversion factor for fuel j.
- m_{cargo} is cargo carried (tonnes) or work done (number of TEU or passengers) or gross tonnes for passenger ships. And,
- D is the distance in nautical miles corresponding to the cargo carried or work done.

The EEDI is currently defined as (MEPC.1/Circ.681):

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}^*\right) + \left(\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

Where:
- CF is a non-dimensional conversion factor between fuel consumption measured in g and CO_2 emission also measured in g based on carbon content. The subscripts MEi and AEi refer to the main and auxiliary engine(s) respectively.
- $Vref$ is the ship speed, measured in nautical miles per hour (knot), on deep water in the maximum design load condition.
- $Capacity$ is deadweight for dry cargo carriers, tankers, gas tankers, containerships, RoRo cargo and general cargo ships, gross tonnage for passenger ships and RoRo passenger ships, and 65% of deadweight for container ships.
- $Deadweight$ means the difference in tonnes between the displacement of a ship in water of relative density of 1,025 kg/m^3 at the deepest operational draught and the lightweight of the ship.
- P is the power of the main and auxiliary engines, measured in kW. The subscripts ME and AE refer to the main and auxiliary engine(s), respectively.
- SFC is the certified specific fuel consumption, measured in g/kWh, of the engines.
- fj is a correction factor to account for ship specific design elements.
- fw is a non-dimensional coefficient indicating the decrease of speed in
- representative sea conditions of wave height, wave frequency and wind speed.
- $feff(i)$ is the availability factor of each innovative energy efficiency technology.

9.4.2 Emissions covered by the EEOI and EEDI

Both the EEDI and the EEOI in their current forms are applied to cargo ships, which accounted for 71% of emissions on ships sailing to EU harbours in 2006 and 84% of global CO_2 emissions from maritime transport in 2007 (Buhaug et al., 2009).

As the EEDI is fixed for a ship, save for major modifications, a mandatory limit value of the EEDI of ships in EU ports would also affect the EEDI of these ships outside the EU. The geographical scope of such an instrument would be unlimited. So the emissions under the instrument would be all emissions of ships that visit EU ports.

In general, all IMO technical standards have a grandfather's clause. This means that the new legislation will only affect new buildings. If a mandatory EEDI limit would also implement a grandfather clause, the emissions under the scope of the instrument would increase gradually. As the economic life of a ship is on average 25 to 30 years, it will take decades for the policy to extend to all ships that visit EU ports.

However, we note that the majority of analyses of the EEDI presented to date have been based on existing ships. This is possible because, with the possible exception of the factors *fj*, *fw* and *feff(i)* (see section 8.2.1), the data that are needed to calculate an EEDI are available from a ship's technical documentation and often verified by class societies. It seems therefore to be possible to calculate the EEDI for existing ships. However, before a policy would be implemented based on the EEDI, this assumption may need to be assessed in more detail.

The EEOI is not fixed for a ship, but calculated over a certain time period. During this time period, even when a ship is not sailing to or from an EU port, its emissions would still be within the scope of the policy instrument. Thus the emissions of all ships that visit EU ports in a certain time period would be covered by such a scheme.

9.4.3 Emission reduction options rewarded under EEOI and EEDI

The most fundamental difference between EEDI and the EEOI is that the first one relates exclusively to the technical state of a vessel, while the EEOI covers also the operation of a vessels. The next table shows the main difference between coverage by the EEDI and the EEOI. The table shows that technical policy options target design measures in new ships. Operational policy options will, in principle, cover both design options in new ships and operational options in all ships.

Table 58   Comparison of areas which are covered by EEDI and/or EEOI

	Areas which are covered by the EEDI (1)	Areas which are covered by the EEOI (2)
DESIGN (New ships)		
Concept, speed & capability	Key aspects can be accounted for in the EEDI or technical standard	All design and operational elements may implicitly be covered, as the resulting performance is the basis for the instrument.
Hull and superstructure		
Power and propulsion systems		
Low-carbon fuels	Capability can be included, but not necessarily used	
Renewable energy		
OPERATION (all ships)		
Fleet management, logistics & incentives	No	
Voyage optimization	No	
Energy management	No	

According to the marginal abatement cost curves presented in chapter 3, technical measures account for 47% of total emission reduction options in 2030 and also for 47% of the cost-effective options.

9.4.4 Views on the application of the EEOI and EEDI

Both the EEOI and the EEDI have been extensively debated in the IMO. In these debates, views on the applicability of both measures in a policy setting have been discussed. This section presents a concise overview of the current state of the debate.

In 2009, the IMO has issued Guidelines For Voluntary Use Of The Ship Energy Efficiency Operational Indicator (MEPC.1/Circ.684). As the title suggests, these guidelines exclusively mention the voluntary use of the EEOI. There is no consideration of a mandatory application and/or the use of the EEOI as a basis for a mandatory policy in these guidelines or in the report of the meeting in which they were adopted (MEPC59/24). However, note that the first Intercessional Meeting of the Working Group on Greenhouse Gas Emissions from Ships concluded that 'the operational index should not be mandatory, but recommendatory in nature, but this does not mean that it could not be made mandatory in the future' (MEPC 58/4).

The Guidelines put forward the EEOI as a way to 'assist ship owners, ship operators and parties concerned in the evaluation of the performance of their fleet with regard to CO_2 emissions' (MEPC.1/Circ.684). The preceding guidelines (MEPC/Circ.471, 29 July 2005) also do not mention any mandatory use of the index.

The current formula for the EEDI has been established by MEPC59 in July 2009 (MEPC59/24). It's current status is described as 'interim guidelines for the purpose of tests and trials on a voluntary basis' (MEPC.1/Circ.681). So the formula has not been determined with the aim of serving as a basis for a mandatory policy. Probably, much more testing would have to be done in order to establish an efficiency baseline and determine the number of ship types for which such a baseline could be established. Moreover, more studies would be needed to establish the potential for efficiency improvements and the rate at which they could be achieved.

Many delegations have proposed ways to use the EEDI in a policy context, but this subject has not been discussed at MEPC.

In conclusion, the general view on the application of the EEOI is that it should be used internally by ship owners and operators to evaluate the efficiency of their ships, although it is not ruled out that the EEOI could become mandatory in the future. There is currently no consensus view on the application of the EEDI. The view on the current formula is that it is intended for testing purposes.

9.4.5 Current experience with EEOI and EEDI
Under this section we have included not only the work focusing strictly on fleet efficiency indicator, but also studies which covers sea transport emissions and bunker consumptions as such.

The EEOI has been studied in CE et al. (2006). At this point it is not yet clear how a standard could be defined that is able to distinguish efficient from inefficient sea transport. Key questions relate to (based on CE et al., 2006):
– Baseline: Transport efficiency potential depends on location of origin and destination, cargo volumes, ability to find return goods (trade triangles, etc.) type of goods and more.
– Allocation: Distribution of emissions in cases where multiple cargo types are carried (e.g. container vessels, RoRo vessels, etc.).
– Baseline drift: Changes in transport demand and fleet size cause changes in relative cargo availability hence efficiency. To be effective, the baseline must be more or less continuously adjusted.
– Regional impacts: A side effect of this approach could be that transport cost increase in remote and sparsely populated areas due to the inherent lower efficiency.
– Ownership and verification: The CO_2 efficiency of a ship depends on its operation which may be controlled by a charterer that is not the ship owner. In this case, if a ship is sold or transferred, who owns the index.
– Density of the cargo. Bulk carriers can transport weight restricted cargo (high density cargo such as coal or ore) or volume restricted cargo. Since the formula is expressed in mass of CO_2 per tonne-mile of transport work, the former ship would always have a better index than the latter.

The Danish Maritime Authority 2008-2009 (11) has made a number of submissions to IMO (official proposal documents) regarding calculations of EEDI baselines for the different vessel types where the x-axis represents the dwt and the y-axis represents the gram CO_2 per ton nm.
This curves shows that when the vessel size increases the gram CO_2 is reduced, so that the smallest vessels have the highest emissions. The methodology used are based on the same approach as Hans Otto Kristensen, 2007 (6), but the basis is now that the EEDI calculation now are done with MCR = 75% while he used 85%. With 75% of maximum power taken out of the engine instead of 85% the gram CO_2 per ton nm becomes lower since lower speed reduces the power consumption with the speed multiplied with itself three times.

The Ministry of Transport, Public Works and Water Management of The Netherlands 2009 (12) asked Centre for Maritime Technology and Innovation' (CMTI) to carry out a study into the effects and robustness of the proposed index suggested by IMO per vessel type. The study focuses on the seagoing ships built and/or registered in the Netherlands. The first part exists of analysing the index formula and collecting data from Dutch ship owners and builders. After collecting the data, a trend analysis has been made of the following ship types: tankers, general purpose vessels, dredgers container

vessels and offshore vessels. For tankers and general purpose vessels a trend analysis has been done on the development of efficiency during the past 30 years. The last part of the study consists of a detailed analysis of the formula. In total 1.150 ships have been analysed with the proposed EEDI formula. The analysis leads to the conclusion that no clear trend could be established for vessels of any type smaller than 15,000 Mt DWT. For vessels larger than 15,000 Mt DWT the EEDI index values correlate much better. For tanker vessels larger than 15,000 Mt DWT, the correlation of EEDI values is sufficiently high to establish a clear trend. With increasing DWT values, the index values of vessels of all types converged. The analysis shows that the EEDI index formula is not suitable for complex special ships like dredgers and offshore work vessels. These ships are not designed for transport of cargo at an average sea speed, but for other functions. A specific index formula should be developed for each of these vessel types, containing a parameter expressing the benefit to society that fits the ship type. As an example a proposal for an index formula for dredger vessels is added to the report.

The Community of European Shipyards' Associations (CESA) supports the development of CO_2 index systems for information purposes and provide technical background for the necessary improvement of the draft design index. CESA however believes that a mandatory design index would not be an optimal tool as it would fail to achieve a rapid reduction of the specific CO_2 emissions from international maritime transport. It's the view of CESA that further in depth investigations are needed to consider the feasibility of this approach and to obtain the necessary improvements of the formula of the CO_2 design index. CESA also recommends that the scope of the index should be limited to a hull/propulsion and engine/fuel related CO_2 efficiency. The development should be focussed on identifying a well defined set of parameters that can be used with all ship types without discriminating certain speed ranges or specific types of cargo. Instead of implying that only large and slow ships are acceptable, the index should define a consistent index for all ships against which the improvements in hull/propulsion performance (*P/V* ratio) and engine/fuel efficiency
(*SFC*) can be measured, which represent a significant CO_2 reduction potential.

9.4.6 Conclusion

We conclude that the EEOI is not fit as a basic parameter for a mandatory policy for the following reasons:
- The EEOI does not take changes in efficiency due to the business cycle, the specific trade or the region where a ship operates into account and could therefore be considered to be inequitable.
- It is hard if not impossible to compare the EEOI across ship types, even across the most important ship types in terms of CO_2 emissions: bulkers, tankers, container ships and RoRo ships.
- The IMO has endorsed the use of the EEOI as a voluntary measure to evaluate the performance of ships by ship owners and operators, not as a metric for a ship's performance in a mandatory policy.

The EEDI may be developed into a good indicator for a ship's design efficiency. Currently, it is not mature as the formula for the EEDI has only recently been established and is subject to trials at the moment.

9.5 Baseline

In a baseline-and-credit scheme, the baseline is an essential element of the design. The baseline determines to a large extent the supply and demand for credits. Section 8.6 summarises the current discussion in IMO on the baseline.

9.5.1 Energy Efficiency Design Index (EEDI)

The Energy Efficiency Index provides, for each ship, a figure that expresses its design performance. By collecting data on EEDI for a number of ships within a category, it will be possible to establish baselines that express typical efficiencies of these ships. Figure 38 shows the effect of deadweight of a ship on the CO_2 design index for some categories of ship. The formula that was used to calculate the CO_2 design index is similar to the EEDI, and the EEDI is expected to show the same behaviour.

Based on this type of analysis, EEDI baselines have been proposed for different ship categories that are functions of ship size, where size is expressed e.g. as deadweight tonnage or gross tonnage. EEDI baselines could be part of different policies using the EEDI.

Figure 38   The effect of ship deadweight on CO_2 design index (11) – Danish Maritime Authority

Establishing an EEDI baseline, using different datasets for the different ship sizes, will result in different baselines for the different vessel sizes. Presently, the EEDI is not finalised and baseline data have been approximated by using data from existing ship databases rather than being obtained through the process of establishing the EEDI for individual ships. The Average Index Values are used as the basis for calculating an exponential regression line. The regression line expresses the baseline value, which can then be calculated by using the following formula:

$$\textit{Baseline value} = a \; \textit{Capacity}^{c}$$

Where *a* and *c* are constants deriving from the regression line. In a study initiated by the Danish maritime authority of Denmark (11) and where the results where submitted to the Intercessional IMO GHG meeting in March 2009 the following values for a and c was calculated. R2 describes the correlation of the baseline value. A correlation close to 1 or -1 represents a high degree of correlation.

Table 59   Possible EEDI baselines for different ship types

Ship type	A	Capacity	C	Number of samples	Excluded	R2
Dry bulk carriers	2503.2	DWT	0.5601	995	28	0.92
Tankers	2401.1	DWT	0.5400	1,209	58	0.97
Gas carriers	1649.7	Tank volume	0.4855	178	10	0.96
Container ships	105.77	DWT	0.1761	188	9	0.42
General cargo ships	280.85	DWT	0.3051	238	8	0.62
RoRo cargo ships	20792	GT	0.7223	205	33	0.87
Passenger ships	1517.0	GT	0.4092	192	73	0.79

Source: Methodology for Design CO_2 Index Baselines and Recalculation thereof, MEPC 58/4/8

At MEPC 59 it was decided to further split the RoRo group into three subgroups which are weight carriers, volume carriers and car carriers, however these new baselines has not been calculated.

9.5.2   Conclusion

From this discussion it is clear that there is no single baseline for the EEDI of the shipping sector, but a set of baselines for different vessel types. The number of vessel types with different baselines is still growing. At this point, we cannot assess where this process will end.

9.6   Scope – geographical scope

As is clear from section 9.3, the amount of credits generated or needed depends on the geographical scope of the baseline-and-credit scheme. Hence, the magnitude of the incentive to improve the efficiency is directly related to the geographical scope. Therefore, the impact of the scheme on the efficiency of the fleet visiting EU ports is directly related to its scope. The larger the scope, the more the efficiency will improve.

The geographical scope can be assessed on the basis of the same arguments as those provided in section 6.3.

9.6.1 Options

There are four options for defining the geographical scope:

1   Territorial sea option[33]. In this option, the policy would be applied only to the GHG emissions that were released within the limits of the territorial sea. Within this option, all the ships loading or unloading their cargo within the territorial waters of the EU (thus either in the EU ports or via ship-to-ship transfer) would be obliged to submit allowances for all emissions of GHG released within the territorial zone of the EU (of any country being the EU Member). The ships that are only passing through the territorial zone, without making a port call or unloading the cargo would be excluded on the basis of the law on innocent passage. Data needed to calculate the required number of allowances would include emissions (fuel use) in the territorial waters of EU Member States (alternatively, emissions can be approximated by using data on tonne-miles travelled within the EU territorial zone, average fuel use per tonne-mile for a given ship and type of fuel used).

2   Only intra-EU shipping. In this option, the policy would apply only to the ships which travel from one EU port to another EU port.

3   All distance to the EU, all cargo option[34]. This option would aim at covering all GHG emissions related to the whole distance to any EU port travelled by ships which make port calls at the EU ports or unload their cargo within the EU territorial waters zone. We assume that the EU port would be the point of calculation of GHG emissions for each ship. However, a question arises: where the measurement of emissions should start? This leads us to considering the following sub-options:
    a   Including emissions only from the last port call to the EU port.
    b   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU.
    c   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and from the last port call for ships with multiple bills of lading. For non-cargo ships, such as passenger ships, the port of last embarkation may be considered and for other ships, such as offshore support vessels, distance from last operation and transit to EU waters and then the time on station (as such vessels may loiter for long periods of time).

4   All distance to the EU, EU-bound cargo only option. This option would be similar to the option 3, with the difference that only the cargo with destination to the EU would be covered with the policy. Thus, allowances would have to be calculated for every unit of cargo (container or barrel of oil, etc.) which would be dispatched at any port worldwide with the destination of any EU Member State. The number of the required allowances would be calculated based on the data on transport work in tonne-miles travelled by all the EU-destined cargo, fuel type and index of fuel used per tonne-mile specific for the ship.

---

[33]   Alternatively, contiguous zone or continental shelf option could be considered, which would allow to extend the geographical scope of the policy, subject to legal feasibility.

[34]   'All cargo' as opposed to 'EU cargo' i.e. the cargo with destination to any EU country.

9.6.2   Assessment of the options

The assessment of the options will focus on the following elements:

- Environmental effectiveness. The environmental effectiveness of a policy is determined, among other factors, by the amount of emissions under the scheme. The larger this amount, the larger the environmental effect can be, other things being equal. Hence, we use the amount of emissions within the geographical scope as a measure for it's environmental effectiveness.
- Possibilities for avoidance. Annex H analyses the potential for avoidance of a certain geographical scope based on the assumption that a scheme will be avoided if the benefits of doing so outweigh the costs. We use the findings of this annex to evaluate the possibilities for avoidance.
- Legal feasibility. This aspect relates to the risk of a successful legal action against the scheme.
- Administrative complexity. This feature is related mostly to the need of collecting and reporting data on CO_2 emissions.

Environmental effectiveness

The basis for the assessment of the environmental effectiveness is the results of the model calculations of emissions presented in Chapter 2.

1   Territorial sea option. Territorial waters extend only up to 12 nautical miles i.e. about 20 km from the coast line so for most voyages this distance would account for a small percentage of the distance travelled. Hence, the environmental effectiveness of this option as compared to most other options is very limited as ships emit most outside territorial waters. We cannot estimate exactly how large the emissions are. Table 21 in section 2.6 of this report shows that according to Entec (2005), CO_2 emissions in territorial waters of the EMEP region amounted to approximately 38 Mt. However the territorial waters are only a fraction of the EMEP region and this estimate was not considered to be reliable for reasons explained in section 2.6. If we assume that ships sailing on intra-EU voyages emit 25% of the CO_2 generated on these voyages in territorial waters and ships sailing intercontinental voyages do so for 5% of their emissions, the emissions can be estimated at 16% of emissions on routes to EU ports (33 Mt CO_2) and 12% of emissions on routes to and from EU ports (38 Mt CO_2).
2   Only intra-EU shipping. As shown in chapter 2, emissions on intra-EU voyages accounted for 112 Mt CO_2 in 2006, being 36% of emissions on voyages to and from EU ports and for 54 % of emissions on voyages to EU ports.
3   All distance to the EU, all cargo option.
4   Including emissions only from the last port call to the EU port. The scope of emissions covered by the policy can be estimated to be at the level of approximately 208 Mt CO_2 per year, based on the modelling described in chapter 2.
5   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. The emissions in this scope are hard to assess, as they depend on the length of the period. If this period is short, e.g. days or weeks, the scope will be in the order of 208 Mt or less. If the scope is longer, e.g. one year, most likely many emissions on voyages between two non-EU ports will be included in the scope, so the amount of emissions would be considerably higher.
6   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships

with multiple bills of lading. The scope of emissions covered by the policy can be estimated to be at the level of approximately 208 Mt CO_2 per year, based on the modelling described in chapter 2.

7   All distance to the EU, EU-bound cargo only option. The scope of emissions covered by the policy can be estimated to be below 208 Mt per year (the estimated general scope for the option 3), however the percentage of cargo not destined to the EU for ships arriving at the EU ports would not expected to be high thus the scope would not be expected to be much different from the scope of option 3.

Possibilities for avoidance

Annex H analyses the potential for avoidance of a certain geographical scope based on the assumption that a scheme will be avoided if the benefits of doing so outweigh the costs. Analysing the costs and benefits for a number of ship types and routes, it concludes that:

−   If a voyage is defined so that no transshipment of cargo is necessary, the potential for avoidance is quite high, as the costs savings related to lower CO_2 fees are not counterbalanced with substantial costs related to such an additional port call.
−   In options where a voyage is defined so that transshipment is necessary to start a new voyage, the potential for avoidance from an economic point of view would be very limited. However, based on the analyzed examples, some risk of avoidance can be observed in a situation of low freight rates and high CO_2 costs.

For some cargoes, a voyage can be defined so that avoidance can be reduced. For most bulk cargoes, there is a single port of loading and a single port of discharge, and the bill of lading identifies both (see box on bill of lading). For break bulk and containerized cargo, there is often not a single port of loading and there may be numerous bills of lading associated with the ship movement, many of which would have different ports. So for these voyages, a definition cannot be based on the port of lading and the port of discharge.

A definition of voyage that requires transshipment for starting a new voyage is the route from the port of loading to the port of discharge for ships with a single bill of lading and from the last port call for ships with multiple bills of lading or ships in ballast. For non-cargo ships, such as passenger ships, the port of last embarkation may be considered and for other ships, such as offshore support vessels, distance from last operation and transit to EU waters and then the time on station (as such vessels may loiter for long periods of time).

We can apply these findings to the options under consideration in the following way:

1   Territorial sea option. The possibilities for avoidance in this option would be small, as ships sailing to EU ports would have to pass through territorial waters.
2   Only intra-EU shipping. Avoidance can take several forms, depending on the definition of a 'port call'. If port calls without transhipment would mark the beginning of a new voyage, it would result in avoidance in areas where non-EU ports are not too far away from the intra-EU route. Routes in the Mediterranean, from the Mediterranean to other ports vice versa, in and to the Baltic are susceptible for avoidance. If, on the other hand, port calls are defined so that transshipment is necessary for bulk cargoes, avoidance would be possible in the same regions, but just for containerized and break bulk cargoes. We assume that avoidance would not be attractive for passenger ferries because of the associated

additional time of the voyage (see, however, section 13.3 on cruise ships). Assuming that avoidance occurs for container ships, general cargo ships, and RoRo ships, and assuming that they could reduce their emissions under an intra-EU scheme to zero for half of their voyages, we estimate that the maximal potential for avoidance would be 22 Mt of emissions (19% of intra-EU emissions).

3   All distance to the EU, all cargo option.
4   Including emissions only from the last port call to the EU port. This is likely to cause avoidance by inducing ship operators to make additional port calls in non-EU country. If we assume that all ships sailing from non-EU ports could reduce their emissions under the scope by 75% by making an additional call at a non-EU port near the EU and half of the ships sailing on intra-EU routes could reduce their emissions by 50%, the scope for avoidance can be estimated at 73 Mt in 2006 (35% of emissions on voyages to EU ports).
5   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. This scope can be avoided by transhipping cargo, both in bulk and in break bulk. Even for break bulk cargoes, this option would require them to offload all of their cargo and loading it on another ship that is dedicated to transport within the EU. This would be costly and hence we conclude that avoidance of this option is probably small.
6   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. This is likely to cause avoidance by inducing operators with break bulk cargoes to make additional port calls in non-EU country. If we assume that all container ships, general cargo ships, and RoRo ships sailing from non-EU ports could reduce their emissions under the scope by 75% by making an additional call at a non-EU port near the EU and half of these ship types on intra-EU voyages could reduce their emissions by 50%, the scope for avoidance can be estimated at 32 Mt in 2006 (16% of emissions on voyages to EU ports).
7   All distance to the EU, EU-bound cargo only option. This scheme can only be avoided by offloading cargo in a non-EU port and transporting it overland to the EU. As Table 60 suggests, the major European ports, with the possible exception of Algeciras, are far away from non-EU ports. Therefore we conclude that avoidance will be very small under this scheme.

Table 60   Major EU ports, 2007

| Total cargo volume | | Container traffic | |
1,000 tonnes		TEUs	
Rotterdam	401,181	Rotterdam	10,790,604
Antwerp	182,897	Hamburg	9,917,180
Hamburg	140,923	Antwerp	8,175,951
Marseilles	96,282	Bremen/ Bremerhaven	4,892,056
Amsterdam Ports	87,840	Gioia Tauro	3,445,337
Le Havre	78,885	Algeciras-La Linea	3,414,345
Bremen/ Bremerhaven	69,095	Felixstowe	3,341,787
Grimsby and Immingham	66,279	Valencia	3,042,665
Genoa	57,189	Le Havre	2,638,000
Dunkirk	57,091	Barcelona	2,610,099

Source: American Association of Port Authorities.

> Bills of lading
>
> When a ship is loaded with cargo, the master of the ship, or the charterer of the ship (or their agents) is required to sign a bill of lading. The bill is often prepared by the shipper of the goods. Such document acts as evidence of receipt of the cargo, as a transferable document of title to the cargo and evidence of the contract of carriage between the holder of the bill and the ship owner or charterer (the carrier).
>
> The bill is a private commercial document - it does not serve a regulatory function although it is often required by customs authorities to calculate import dues and so on. In commercial law, it is often vital, for contractual reasons, that the bill of lading reflects accurately the amount of cargo on board and the date and place the cargo was shipped. For instance, with respect to an oil cargo, the date of shipment will determine the price to be paid by the buyer to the seller. A bill issued for a single container of furniture to be shipped by liner container service will reflect the date and place of loading but such information is unlikely to be so important
>
> In a usual transaction the bill will be prepared by the shipper (usually the seller of goods) issued by the master or charterer and physically transferred (directly by the shipper or more usually through a banking chain) to the buyer of the cargo in return for payment. Possession of the bill allows the receiver to demand delivery of the goods at the discharge port. If international letters of credit are involved, then the bill will pass between banks in the country of export and the country of import. If the cargo is traded whilst en route, such as an oil cargo, then the bill will pass down a chain from buyer to buyer (or more usually, their banks). This often takes longer than the voyage so the cargo arrives at the discharge port before the bill. In such case, the ship owner usually will discharge the cargo to the receiver in the absence of a bill but in return for a letter of indemnity from the receiver holding the ship owner harmless in case the person receiving the cargo turns out not to be the person to whom the cargo should have been delivered.
>
> Whilst the bill of lading is good, reliable evidence of the date and place of shipment of the goods, and therefore a reliable indicator of the voyage undertaken, the delay in the bill arriving at the load port after the ship has discharged and sailed might make practical problems for their use in the scheme. That said, customs authorities always obtain copies of the bill for import duty purposes and would be able to provide this evidence to any emissions authority who would, in turn, be able to check the details of the voyage against those provided by the ship's master, agent, or emissions allowance accounting agent.
>
> It would be wrong to say that there is no instance of bills of lading being forged but such instances are, as far as the writer is aware, rare. The bill is an important document due to the three functions it performs and therefore more than one party would have to be involved in the fraud. This risk may decrease as the industry moves away from paper bills to electronic bills over the next few years.

Legal feasibility

This section assesses the legal enforceability of a scheme and the risk of a successful legal action against the scheme.

In general, with regard to enforcement, a route based scheme would appear to be a more attractive option. In particular it will be relatively easy for the port state authority to assess the level of emissions from a ship during its journey from its load port to the discharge port in the EU according to the records held onboard the ship and the ability to assess emissions and the carbon efficiency of the vessel during the voyage. Formal notices can be provided to the ship regarding the emissions. Accounts for each ship can be held and maintained in the EU so that balancing payments can be made in relation to the ship at the end of the accounting period.

1   Territorial sea option. Inclusion of emissions of CO_2 within territorial waters for ships loading/unloading cargo in the EU ports does not seem to be challenging from a legal point of view. However the ships in innocent passage would need to be excluded from the scheme.

2   Only intra-EU shipping. From a legal point of view, the EU has no right to impose extraterritorial rules where it has no sovereignty or jurisdiction and a legal challenge is likely may be made. In response, the EU could argue that it was not attempting to exercise jurisdiction over waters outside its territorial sea. The scheme would simply apply as a condition of entry into EU ports. Both UNCLOS and GATT allow regional measures to be put into place to preserve and protect the environment. However the introduction of any such scheme is likely to be challenged by non-EU states on jurisdiction grounds and there are no provisions in UNCLOS or any other IMO conventions which could fully protect the EU from such challenges to the extraterritorial effect of the regulations.

3   All distance to the EU, all cargo option.

4   Including emissions only from the last port call to the EU port. The legal feasibility of this option is the same as for option 2.

5   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. Depending on the length of the period, there may be more extraterritorial emissions under the scope of the scheme which could aggravate the issue raised under option 2.
    A further issue, which will have trade and economic consequences, is that charterers or operators will not want to take on a vessel for a single journey to an EU port if upon entry to that port it is going to become liable for that ship's emissions for the specific allocated period of time prior to entry. These might have been incurred by previous operators and charterers; in such circumstances it is highly unlikely that the previous operator/charterer would agree to be liable for the allowances required to be made and as such a time based scheme would likely result in a distortion of competition. It would also be very unpopular as the lack of transparency would mean that passing such costs onto cargo and sub-charters would be problematic. Further, in terms of the integrity of an EU ETS, it would appear that the operation of such a scheme should at least be based on a link between emissions in the EU and the ship's entry into EU waters. In circumstances where operators could be held liable not only for emissions incurred outside EU waters but further as in respect of journeys which were in no way connected with or destined for the EU, it is highly unlikely that the operation of such a scheme would be met with a warm reception by the international industry.

6   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. The legal feasibility of this option is the same as for option 2.

7   All distance to the EU, EU-bound cargo only option. The legal feasibility of this option is the same as for option 2.

Administrative complexity

This section assesses the need to monitor and report data on CO_2 emissions. As a measure of administrative complexity directly associated with the choice of the geographical scope.

1   Territorial sea option. This option would require ships to monitor their fuel use from the point of entry of territorial waters to the point of exit. For ships that rely on tank soundings (see section 6.10), this may require additional tank soundings which, if taken at rough seas, would not always be very accurate. Moreover, it could be challenging to verify whether

these measurements were indeed made at the right location. Note that a ship sailing at 12 knots passes through the territorial waters in one hour, so taking the measurement 5 or 10 minutes too early or too late could have a large impact on the emissions.

2   Only intra-EU shipping. This option would require ships to monitor their fuel use and emissions on every voyage between two EU ports. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions.

3   All distance to the EU, all cargo option.

4   Including emissions only from the last port call to the EU port. This option would require ships to monitor their fuel use and emissions on every voyage to an EU port. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions.

5   Including CO_2 emissions based on fuel use during a certain period of time preceding the port call at the EU. This option would require ships to monitor their fuel use and emissions on a period prior to calling at an EU port. If this period is sufficiently long so that the ship operator may not yet know whether he will sail to an EU port in this period, he may have to monitor fuel use on a daily basis. This is actually the current practice for most ships who send noon reports including data on fuel use to the ship owner and/or operator. Whether the quality of these noon reports is sufficient for an ETS remains to be established.

6   Including emissions from the port of loading to port of discharge for ships with a single bill of lading and emissions from the last port call for ships with multiple bills of lading. This option would require ships to monitor their fuel use and emissions on every voyage to an EU port. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions. In addition, ships would have to monitor whether or not a new bill of lading was issued at a port.

7   All distance to the EU, EU-bound cargo only option. This option would require ships to monitor their fuel use and emissions on every voyage to an EU port. For ships that sail predominantly or exclusively on intra-EU voyages, the administrative complexity could be reduced by allowing an annual inventory of emissions. Moreover, they would have to monitor the share of cargo destined for the EU. This option would be administratively complex for ships carrying break bulk cargo or containers, where there may be multiple bills of lading. Ship owners would have to allocate emissions on every leg of every voyage to the various items of cargo on board.

Discussion

The assessments in this section are summarised in Table 61.

Table 61   Assessment of geographical scope options for emissions trading

		1: territorial waters	2: intra-EU	3a: last port of call to EU port	3b: period before entry in EU port	3c: port of laden to EU port	4: EU-bound cargo only
Environmental effect	Emissions under the scope (2006)	33-38 Mt CO_2	112 Mt CO_2	208 Mt CO_2	More or less than 208 Mt, depending on length of period	208 Mt CO_2	Less than 208 Mt CO_2
	Possibilities for avoidance	Small	22 Mt CO_2	73 Mt CO_2	Small	32 Mt CO_2	Small
Legal feasibility		Best	Second best	Second best	Third best	Second best	Second best
Administrative complexity		Less complex than 4, more complex than 2, 3a, and 3c	Less complex than 4, more complex than 3b	Less complex than 4, more complex than 3b	Least complex	Less complex than 4, more complex than 2 and 3a	Most complex

Option 3c has the largest amount of emissions under its scope, even when accounting for avoidance. Note, however, that the estimate of emissions that could be subject to avoidance depends on assumptions that have been hard to substantiate. Option 3c has a slightly higher administrative complexity than option 3a. The choice between 3a and 3c is one between environmental effectiveness and administrative complexity.

9.6.3   Conclusion

Among the identified options, option 3c, distance from the port of loading for ships with a single bill of lading and distance from the last port call for ships with multiple bills of lading or non-cargo ships, is the most recommended because:
–   It has a large environmental effectiveness.
–   It offers relatively little scope for avoidance.
–   It does not have a large chance of successful legal action.

9.7   Scope – ship size

The baseline-and-credit trading scheme can in principle be applied to all ships for which an efficiency indicator can be determined. According to section 8.4, this can be done for ships of all sizes. Because many small ships are currently exempted from regulation, and because their contribution to total emissions is low, we propose to set a threshold for the smallest ships, e.g. at 400 GT which

is the threshold for MARPOL or 500 GT which is the threshold for SOLAS. As these thresholds are already common in shipping, these size thresholds would not introduce additional market distortions in the shipping sector.

9.8 Scope – ship types

As stated above, the baseline-and-credit trading scheme can in principle be applied to all ships for which an efficiency indicator can be determined. According to section 8.5, this can not be done for dredgers, offshore supply vessels, fishing vessels and tugs. In absence of a specific index formula for these vessels, they would have to be excluded from a baseline-and-credit scheme. As these ship types perform very specific tasks, there would be little risk of distorting markets in the shipping sector.

9.9 Administrative set-up

In order for the baseline-and-credit system to be effective, ship owners would have to report their EEDI and capacity-miles for each of their ships within the geographical scope. This would need to be done in a verified report submitted to the competent authority.

On the basis of this report, the competent authority would issue credits or inform the ship owner that he would need to a certain amount of surrender credits. Moreover, the competent authority would need to retire surrendered credits.

As the tasks for the competent authority are very similar to the tasks the authority would have in a cap-and-trade scheme, the same conclusions can be drawn on the administrative set-up as in section 6.11.

In order to limit the administrative burden on the ships, reporting and surrendering allowances should be annual.

Whether ships should report to Member States or to a central authority needs to be assessed further.

9.10 Can differentiated harbour dues have the same results as a baseline-and-credit scheme?

In principle, harbor dues could be differentiated in order to provide incentives to reduce CO_2 emissions. The incentive could either be targeted at increasing the fuel efficiency of a vessel through improved performance or though implementing technical measures. In all cases, the differentiation of harbor dues would increase the return on the investment in fuel-efficiency measures.

The main advantage of using differentiated harbor dues as a policy instrument would be that the institutional arrangements for the payment of harbor dues and enforcement are already in place.

Differentiated harbor dues have proven to be an effective policy measure in Sweden to reduce NO_x emissions of ships (NERA, 2005). An immediate extension to CO_2 emissions is not straightforward, however. Whereas NO_x emissions may be reduced by end-of-pipe technologies that can be easily

monitored, this is not possible for the technical and operational measures to reduce CO_2 emissions.

A disadvantage of a differentiation of harbor dues is that it could distort the competitive market of ports. There are indications that the price elasticity of demand varies greatly between ports (Atenco, 2001). Differentiated tariffs could have a larger impact on some ports than on others.

The level of the differentiation could either be relative or absolute. A relative differentiation would have the effect that in some ports the financial incentive would be much smaller than in other ports. This could incentivise ship operators to send the most efficient ships to the harbors with the highest rebate, and thus maximise profits by a simple rerouting of vessels without taking measures that would reduce greenhouse gas emissions. Table 62 shows that a charge that is differentiated by a percentage of the harbor dues will provide a different incentive in different ports. The incentive will be much smaller in London and Hamburg than in Rotterdam and Le Havre.

Table 62   Harbor dues in selected EU ports

Port	Charge basis	Dues for an Aframax oil tanker (80,000 GT (47,000 m^3)) discharging 80,000 tonnes of crude (2006)
Rotterdam	Gross tonnage and cargo loaded and discharged	€ 93,280
Hamburg	Gross tonnage	€ 33,600
London	Vessel volume and cargo loaded and discharged	£ 28,936 (Approximately € 41,995)
Le Havre	Vessel volume and cargo loaded and discharged	€ 80,129
Marseille	Gross tonnage and cargo loaded and discharged	€ 68,779

Source: CE et al., 2006.

An absolute differentiation (e.g. a reduction of € 1,000 for the cleanest ships within a certain type/size class) would have the advantage that the financial incentive for ship owners and operators to improve their efficiency would not differ from port to port. Since many ships do not sail regular routes, their operators do not know in advance how many times they will visit a certain port in the near future. They may, however, make a more reliable calculation with regard to how often their vessels will visit EU ports. This would allow them to make a more accurate business case for an investment in fuel efficient technology.

Harbors have a large autonomy in establishing their dues, and as a result dues differ both in structure and levels. An advantage of using differentiated dues as a policy instrument is that the institutional arrangements for payment and enforcement are already in place.

Harbors use their dues to cover their costs. If a port is predominantly visited by fuel-efficient ships, it would receive fewer dues after the implementation of this policy. To balance its cash-flow, such a port would have to increase the nominal level of its dues at the risk of losing price-sensitive high emitting

customers to competing ports. If this happens the fuel-efficient ships would end up paying almost as much as they did before the differentiation was introduced (Kågeson, 2007).

Another obstacle is that real dues may as a result of commercial negotiations in individual cases differ greatly from the nominated rates (Kågeson, 2007). Large customers often enjoy special rates. Therefore, other ports or ship owners would not know to what extent the absolute differentiation of the dues prescribed by the EU had actually affected the deal. To force the market to publish all commercial agreements would, on the other hand, be a very far-reaching interference in business practices.

In summary, we think a differentiation of harbor dues would not be a good instrument to improve the fleet's design efficiency. The main objection to such a policy is that it could undermine the current purpose of harbor dues, i.e. to cover for the costs of harbors. In doing so, it could significantly change the division of cargo over harbors in Europe, which would have welfare costs.

9.11 A baseline-and-credit scheme and the policy objectives

Section 4.6 states two policy objectives.

The first policy objective is to limit or reduce maritime GHG emissions.

The secondary policy objective is to remove barriers and market failures that prevent measures to improve fuel efficiency from being implemented, so that the first objective can be met in the most cost-effective way.

A baseline-and-credit scheme for maritime transport can in principle increase the design efficiency of the fleet and thus to some extent emissions. However, emissions can continue to rise if demand growth outpaces efficiency improvement rate, as is likely (see section 4.1.2).

As for the market barriers and market failures, the baseline-and-credit scheme would induce innovations in design of both new ships and existing ships. It would not induce ship owners or operators to take operational measures to reduce emissions. However, a baseline-and-credit scheme does little to reduce the market failures and barriers that were considered to remain the most important, i.e. the split incentive in parts of the shipping market, transaction costs and the time lag.

9.12 Conclusion

In conclusion, a baseline-and-credit scheme would have the following design:
- The traded unit would be based on the Energy Efficiency Design Index, which is currently being developed by IMOs MEPC. Credits would be generated or surrendered in proportion to the difference of a ship's EEDI with the baseline value for that ship and in proportion to the miles sailed from the last port of loading to an EU port.
- The baseline would depend on ship type and ship size, in conformity with the current discussion in MEPC. The value of the baseline would gradually be reduced in order to improve the design efficiency of the fleet. The rate at which the baseline would be reduced would need to be assessed in a separate study.

- All ship types for which a baseline can be established can be included in the scheme. This includes all cargo ships. A size threshold could be set to exempt the smallest ships and thus reduce the administrative burden. In order not to distort markets, the threshold should be set in conformity with thresholds currently being used in maritime law, viz. at 400 GT or 500 GT.

10 Design of voluntary action

10.1 Type of voluntary action

Voluntary action can take many forms, ranging from a formal agreement to reach a certain goal or deliver a specified input to an encouragement to disseminate information.

As voluntary action has been extensively discussed at the IMOs MEPC, with active engagement of EU Member States, it is logical to build on the outcomes of this.

The IMOs MEPC is discussing a Ship Energy Efficiency Management Plan (SEEMP) for new and existing ships, which incorporates best practices for the fuel efficient operation of ships. The plan incorporates an Energy Efficiency Operational Indicator (EEOI) for new and existing ships, which enables operators to measure the fuel efficiency of a ship in operation.

MEPC59 strives to agree on a SEEMP to be used and tested in trials in July 2009.

10.1.1 Options

In a comprehensive study on voluntary environmental policies, the OECD identified four different policy types (OECD 2003):
1   Unilateral commitments made by polluters; the role of the regulator is limited to monitoring and dispute resolution.
2   Private agreements between polluters and polutees; again, the role of the regulator is limited to monitoring and dispute resolution.
3   Environmental agreements negotiated between industry and public authorities.
4   Voluntary programs developed by public authorities, to which individual firms are invited to participate.

These four types of policies will be assessed in the next section.

10.1.2 Assessment of the options

In 2005, CE Delft contacted various stakeholders in the maritime sector with the question whether they were willing and capable of entering into a voluntary agreement with a public authority to reduce GHG emissions (CE et al., 2006). At that time, no organization was found. During this project, several stakeholders were approached but again there seemed to be little appetite to enter into a formal agreement. Neither has an organization come forward with unilateral commitments. Therefore, we conclude that the first and the third option are not feasible by lack of a counterparty.

The second option would impossible to implement as it is hard to identify who the polutees are of GHG emissions.

So the fourth option is the only feasible option: to have a voluntary programs developed by public authorities, to which individual firms are invited to participate.

The voluntary program would take the form of the SEEMP, and the EU and/or its Member States could promote the use of the SEEMP. Promotion could take the form of e.g.:
− Disseminating information on the SEEMP.
− Publishing results of the SEEMP.
− Offer incentives to ships using an SEMP, such as a fiscal incentive on ships flying EU flags.

The promotional activities could be aimed at flying Member States flags, owned by companies registered in Member State, visiting Member State ports, but also to ships owned by companies registered in developing countries.

10.1.3   Conclusion

Voluntary action policy consists of the EU and/or its Member States promoting the use of a Ship Energy Efficiency Management Plan by ships.

10.2   Voluntary action and the policy objectives

Section 4.6 states two policy objectives.

The first policy objective is to limit or reduce maritime GHG emissions.

The secondary policy objective is to remove barriers and market failures that prevent measures to improve fuel efficiency from being implemented, so that the first objective can be met in the most cost-effective way.

Voluntary action would in itself not reduce emissions (see also section 12.2). There may be a limited additional fuel savings beyond business as usual because of the attention generated by governments, but this is unlikely to result in a reduction of emissions (see section 4.1.2).

As for the market barriers and market failures, while the SEEMP might draw attention of ship owners implementing it to cost-effective options to reduce emissions, it is unlikely that voluntary action addresses the market failures and barriers that were considered to remain the most important, i.e. the split incentive in parts of the shipping market, transaction costs and the time lag.

11 Research, development and innovation

11.1 Introduction

Reducing the emissions from maritime transport requires innovations in the shipping sector (see chapter 3, section 12.2 and annex A). The form of the MACC derived in chapter 3 suggests that innovation will become very expensive beyond a level that is cost-effective at expected fuel prices in 2030. Hence, a further reduction of per vessel emissions would require an increased supply of cost-effective technologies. As these technologies may have long lead times, it may be considered important to step up the current R&D effort in order to increase the chances of technologies becoming available.

Some of the instruments discussed in previous chapters raise revenue. Some of this revenue could be fed back to the sector (see section 6.9). One of the potential uses for such revenues is to invest in research of technologies that would provide real reductions in greenhouse gas emissions from ships.

This chapter aims to give an outline of the current and in the pipeline innovations and their potential for reducing GHG emissions, discuss some of the drivers, barriers and bottlenecks for conducting maritime related research and innovation (R&I) and the implementation of these innovations.

This chapter also aims to provide an outline of the possible policies and instruments the European Commission (EC) could pursue in relation to the use of revenue raised in R&I for reducing GHG emissions from shipping.

11.2 Current Research and Innovation

The maritime industry suffers from fragmentation, with no market leaders (20-25% share) with the size of financial strength to fund research and development (House of Commons, 2009). In general, fragmented industries have less innovation than more concentrated industries (Aghion et al., 2005). In the shipping sector, this leads to many stakeholders pursuing differing initiatives not always with a clear direction for technologies to be implemented successfully across the industry.

In the following sections we shall discuss some of the current and in the pipeline initiatives that have been developed and might be available for future use to assist in reducing CO_2 emissions from shipping. The principal ways for reducing CO_2 emissions have been divided into the following three categories:
- Improving the quality of marine fuels or switching to alternative sources of energy.
- Improvements in energy efficiency by introducing technical changes and operational improvements.
- Reducing emissions at the end-of-pipe by CO_2 capture and storage.

11.2.1 Marine Fuels and Alternative Sources of Energy

In the short to medium term there are no viable options to completely replace petroleum based fuels with alternatives across the shipping industry or a technical solution to eliminate CO_2 emissions from a conventionally powered ship. Research into potential primary and auxiliary power sources are at varying development stages, some of which are outlined in sections 2.1.1 and 2.1.2.

Primary Propulsion

Reducing CO_2 emissions from shipping is achieved by either burning less fuel or using fuels with lower or no carbon content. The possibilities for each of these options are wide ranging and at different stages of maturity. Further emphasis might be placed on alternative fuels with the decision by IMO (2008), to reduce the sulphur content of air emissions, which may potentially result in an almost complete phase out of residual fuels (Heavy Fuel Oil) by 2020-2025.

A switch to lighter fuels allows combustion engines to run more efficiently. The use of fuels with little or no sulphur content will also enable waste heat recovery plants to operate with lower temperatures in the exhaust and thereby generate more energy for auxiliary systems.

Natural Gas

Of the alternative energy sources, natural gas is presently the most feasible option in the medium to long term and has the potential to offer an alternative to conventional residual or diesel oil fuels as the distribution infrastructure becomes available.

The main advantage to using natural gas is its high energy content and potential to reduce CO_2 emissions by 20-25% and the use of Liquefied Natural Gas (LNG), will become more attractive as the price of HFO increases, but there are significant challenges with retrofitting existing vessels. Hence this option is likely to be limited to new buildings and may be developed in conjunction with technology to enable a move away from conventional engines.

The use of natural gas is well established with ferries, supply ships and tankers already in operation fuelled by LNG and ferries fuelled with Compressed Natural Gas (CNG).

Biofuels

Research into the use of biofuels has been quite wide with the main barrier to it becoming widespread in commercial shipping primarily economic (Hobson et al., 2007). However other concerns were raised in relation to EU biofuel targets for transportation by Friends of the Earth (2008), which highlighted other risks including: deforestation, biodiversity loss, climate change and rising food prices.

These considerations aside, at a biodiesel symposium in Vancouver in 2008, Wärtsilä revealed they had accumulated over 100,000 hours of research into the effects of biofuels and that they reduce CO_2 emissions by 25-30% (Bruckner-Menchelli, 2008).

Hydrogen
Marine applications of hydrogen as fuel is potentially today's emerging technology. However, with slow the pace of development it is unlikely to displace conventional engines in the foreseeable future.

Fuel Cells
Hobson et al., (2007) report that hydrogen fuel cell technology is developing at a slower rate that anticipated, with the current power outputs being well below what would be required for transport applications. Other potential technical barriers to the use of fuel cell technology includes the volume of storage for fuel required, reliability and resistance to flooding, fire and collisions, work is needed to assess fuel cells operating on diesel and the lack of an existing infrastructure for the distribution of alternative fuels.

FellowSHIP, is a joint industry research project including DNV, Eidesvik AS, Wärtsilä, Vik-Sandvik AS and MTU Onsite Energy GmbH, initiated in 2003, with the objective of developing a 320kW fuel cell power pack (running on LNG) for use on merchant vessels, initially as a potential replacement for auxiliary engines.
Fuel cell technology of this power has not been utilized on merchant vessels, and it is hoped that following successful trials fuel cells will become an economically viable option for reducing CO_2 emissions from shipping, particularly in port.

In this regard it is estimated that the fuel cell technology will reduce auxiliary engine CO_2 emissions by up to 50%, improve energy efficiency by up to 20% and emit zero SO_x, NO_x and particulate matter.

This has successfully been installed on the OSV Viking Lady in September. The third phase of the project aims to test, qualify and demonstrate a main fuel cell electric system, delivering between 1 MW and 4 MW of power.

Nuclear Power
Research into the use of nuclear power in commercial vessels might have been limited due to the perceived technical, economic, social and legislative barriers, however with the shipping industry facing increasing environmental legislation, the feasibility of a vessel being constructed with a nuclear reactor onboard is being looked at by class societies, engineering academies and other institutions (Eason & Ryan, 2009). This possibility was also supported by the General Manager of the Ocean Policy Research Foundation Akira Ishihara, who stated that '*Nuclear powered ships would be an option in the long run*' (Fairplay, 2009).

11.2.2 Auxiliary Power
Wind and solar energy are not likely to provide primary propulsion, but may contribute to a reduction of emissions by contributing to propulsion and power requirements, thereby reducing the power required from combusting carbon based fuels. Several sail and kite prototypes have been developed to harness wind energy and tested on merchant vessels to complement conventional propulsion. The research and development of these technologies is expected to continue, however, wind and solar energy contributions for larger vessels will remain low for some years to come.

Wind Energy

SkySails offers a towing kite propulsion system for vessels, which is claimed to be applicable to retrofit or outfit onto virtually all existing and new build cargo vessels and for fishing trawlers and super yachts over 30 meters in length. SkySails state that the system has the potential to reduce a ships annual fuel costs by 10 to 35% and under optimal wind conditions but 50% temporarily (SkySails, 2009). New more powerful versions of this technology are in development.

As one of the initiatives Greenwave they are promoting are looking to harness the wind to assist with propulsion using a system called Wind Assisted Ship Propulsion (WASP). This system uses spinning vertical cylinders that exploits the Magnus effect generating lift and therefore thrust similar to the way a sail would. Wind tunnel and tow tank tests are said to demonstrate at least a 13% of the required thrust necessary for propulsion (Greenwave, 2009).

The use of traditional sails in shipping have a number of barriers that means further research into their applicability is unlikely. Some of the key barriers include taking up space on deck and problems with cargo loading and unloading, the potential in unfavourable winds to create drag and cause ships to heel and height limitations for example in the Panama Canal (Hobson et al., 2007).

Solar Energy

Efficiencies and low power output from units converting solar energy to electrical pose technical problems to their widespread use in the maritime industry and will be limited to providing auxiliary power on larger commercial vessels (Hobson et al., 2007). Current research on marine applications of solar power is extremely limited, however there are applications of this technology in smaller ferries and a trial on the Auriga Leader, a 60,213 GT pure car truck carrier, developed jointly by NYK and Nippon Oil Corporation is equipped with 328 solar panels and has been used to test propulsion systems in part run on solar power. The solar power accounted for 0.05% of the ship's propulsion power and 1% of the everyday power requirements such as the galley and cabin lighting (NYK, 2009).

Wind and Solar

In 2008 a Memorandum of Understanding (MoU) was signed between Solar Sailor and COSCO to launch COSCO Solar Sails research program. This would attempt to adapt the technology of fold down aerofoil wing shaped sails fitted with solar panels, already used in smaller ferries to a commercial shipping scale (Solar Sailor, 2009).

11.2.3   Summary

Sustainable biofuel and hydrogen are potentially the only current fuels that could allow the industry to dramatically reduce its CO_2 emissions. Biofuel usage is likely to be prioritised in land-based applications before shipping and is unlikely to feature significantly in marine fuels within a 20 year horizon.

In the period from 2030 to 2050, alternative, radically new fuels and technologies may mature to play an important role for the maritime industry. A much stronger R&D focus would be needed to accelerate the development and phasing in of new technologies.

The primary focus areas in the short term may potentially include the development of natural gas as a primary fuel, while in the long run the development of non-petroleum energy sources and technological solutions would take priority.

11.2.4 Improvements in Energy Efficiency

The development of new technologies and improvements of current technologies are wide ranging and beyond the scope of this paper. Discussed later is the impact fuel costs have as a driver of R&I, mainly for increasing efficiencies/reducing fuel consumption and therefore indirectly reducing CO_2 emissions. This results in a continuing improvement in the design and operation of equipment, ships and development of more efficient solutions to ensure fuel costs are minimised. Examples include:

− Main and auxiliary engines.
− Propulsion.
− Hull form.
− Machinery.
− Waste heat recovery systems.
− Antifouling systems.
− Operational.

One of the innovations currently in development is the Air Cavity System (ACS), which aims to reduce the frictional resistance of the hull. This is achieved by integrating an air cavity into the flat bottom of the vessel to minimise the hull/water contact. Air is injected into the cavity through compressors and valves and has been predicted to equate to up to a 15% saving on fuel for low speed vessels (*Winkler*), which if demonstrated to be accurate would offer a substantial reduction in fuel and CO_2 emissions from one technology.

11.2.5 Carbon Capture and Storage

Carbon capture and storage (CCS) technologies exist but currently the only application is on land applied to large-scale point source emissions. CCS will only be a viable option when shipboard technologies and storage facilities are developed commercially and even then the technical challenges and economical advantages of this option are yet to be clearly defined.

11.2.6 Future Concepts/Designs

To meet potential future environmental requirements a number of concept ships have been designed over the years, that have tried to demonstrate potential designs and technologies with resulting increases in fuel efficiencies and emission reductions, that may become a template for ships in the long term, if current vessel design and technologies cannot meet the challenges of reducing CO_2 emissions.

The Momentum Project, conducted by DNV, is one example of concept ships that aimed to prove that a reduction of 50% in ship emissions could be achieved by 2030 by utilizing current technology and shipbuilding practices with the main objectives to:

− Test ideas and technology in practice, assessing their impact on emissions, energy consumption and commercial performance. And,
− Demonstrate an example of how targeted emission reductions can be achieved and realised.

A RoRo vessel was chosen due to having the highest emissions per tonne/mile in shipping (MEPC 59/INF.10). Reduced emissions would be achieved through an innovative combination of hull and machinery technologies including:

− New Panamax dimensions.
− Pure LNG engines.
− Ballast-free ship.
− Lightweight, modular construction.
− Auxiliary conventional sail power.
− Minimum treatment plants.
− No foils, flaps or rotors.

The reduction in CO_2 emissions were primarily achieved due to the tri-maran hull allowing low resistance, the trapeze-shaped midship waving the need for ballast and twin, contra-rotating, overlapping large diameter propellers with high propeller efficiency. The addition of the sails provides a CO_2 emission reduction of 5-6% in favourable conditions.

While DNV is not a ship designer the attempt was to demonstrate the potential reductions using current available technologies. While the target of 50% reduction in ship emissions by 2030 might be considered ambitious, this can be considered in line with comments made by Maersk's environmental chief, Stig Neilsen, reported by the *Harrabin* (2009), to have said to believe that in time innovations in shipping might enable the industry to cut its emissions in half.

Comparing the above predictions to a modern vessel, the Emma Maersk, which has installed a number of fuel reduction technologies on board including:

− Waste heat used to drive two turbines, converting extra power to the propeller.
− Electronically controlled engines.
− Silicon paint.
− Refrigerated containers partly cooled by water as well as electricity.
− Automatic lighting controls.
− Bulbous bow.
− Trim adjustments.
− Course optimization.
− Reducing speed to 10 knots where feasible.

Which has resulted in a reported approximate 25% reduction in fuel consumption and emissions against a comparable vessel, however the majority of this is attributed to slow steaming, which is unlikely to be maintained once the economy picks up. This shows that while there is significant improvements taking place, there is still potentially a large gap between current vessels and those that potentially might be required in the near future.

In a response to a predicted increase of 70% in number of ships in the four main sectors (tankers, LNG, bulkers and containers), with CO_2 emissions quadrupling by 2050 (Fairplay, 2009), OPRF General Manager, Akira Ishihara called for the accelerated development of ultra-low-emission vessels and prompt development of 'zero emissions' vessels. There is clearly a need in the long term to develop radically new designs and alternative marine fuels and power sources to meet any required CO_2 reductions.

11.3 Drivers for Research and Innovation

The industry is driven by a number of requirements in their business from the basic needs to run a compliant profitable business while maintaining long term competiveness by meeting stakeholder requirements, maintaining customer satisfaction and ensuring attractiveness to charterers. For certain companies in the industry maintaining a green image and therefore reducing CO_2 emissions are becoming important, but this is still of relatively low importance for most in the industry as a driver.

Most initiatives in the industry in relation to GHG emissions are linked to the reduction of fuel consumption and energy efficiency of the vessel, as there are few initiatives or requirements currently established in relation to CO_2 emissions and the costs of these emissions are not internalised.

Some of the drivers in the industry for R&I into technologies and options for reducing GHG from shipping are described in the following sections.

11.3.1 Fuel Costs

Operational costs are dominated by manning and fuel. Especially during times of high fuel prices, the cost of purchasing fuel either by the owner or charterer can be considered to be the primary driver for reducing CO_2 emissions, be it indirectly, reducing fuel consumption by implementing operational and technical solutions or pursuing further research into potential areas of improvement.

11.3.2 International Legislation and National Policy

The shipping industry is facing increasing regulation and the process of developing rules and regulations via the IMO requires R&I to develop new technology or other appropriate mechanisms such as the Energy Efficiency Design Index (EEDI), currently being discussed by MEPC. While currently not a major driver, as people wait and see what happens to regulate CO_2 from shipping, legislation potentially will become the major driver for R&I into reducing CO_2 emissions, especially considering reducing fuel costs is not currently directly linked as a driver for reducing CO_2.

Government policies have the potential to drive R&I into carbon reducing technologies, but potentially more importantly in providing the right support mechanisms and environment to allow R&I in low-carbon marine technologies to be conducted by ensuring budgets, funding and grants are available and that industry co-operation between owners, equipment suppliers, universities, research organizations, etc. is maintained with the aim of ensuring viable solutions are developed and implemented across the industry.

The Norwegian NO_x tax demonstrates how Government action is ensuring funds raised from an environmental tax are ploughed back into industry by subsidising cost effective projects to ensure Governmental reduction targets are met, with an estimated 80% of the reduction coming from maritime projects onboard vessels.

11.3.3 Going Green/Marketability

Shipping companies have been setting CO_2 reduction targets for themselves for a number of years now. Reasons might be varied, be it for fuel consumption reasons, a consequence of reducing other air emissions, or a genuine interest in reducing the environmental impact of their ships, this is proving to be one of the major drivers for developing solutions to reduce CO_2 emissions in the industry.

For some of the larger companies, they can potentially pursue some of the initiatives alone, however the industry is seeing a number of active partners in consortiums working with shipping companies in R&I to develop new and improved technologies. This is likely to be the type of framework and co-operation required for future R&I as the fragmented state of the industry and numerous different components and suppliers for ships does not lend itself to one company going it alone.

An example of such a consortium is the Green Ship of the Future (2009), which recently won the 'Green Shipping Initiative of the Year' at the Sustainable Shipping awards in July 2009. Members of this group aim to demonstrate and develop new technologies to reduce CO_2 emissions by 30% and NO_x and SO_x, by focusing on machinery, propulsion, operation and logistics.

11.3.4 Charterer/Cargo Owner

The uptake and maturity levels of environmental initiatives for land based industries means many charterers and cargo owners frequently will place requirements on the ships they will charter or use to transport their goods. While this will reward those companies and ships that meet these requirements with the contracts in the immediate term, this will not be a major driver for R&I in the longer term as establishing requirements that cannot be met would mean cargo would not get shipped.

The Oil Companies Marine Forum (OCIMF) has developed 'Energy Efficiency and Fuel Management guidance', which while not an example of R&I, it is an example of how certain initiatives in the industry and particularly the tanker market are achieved. This guidance utilizes the standard framework of the Tanker Management Self Assessment (TMSA), with the potential to be included within the TMSA requirements at a future date.

The guidance is aimed at operators offering their vessels for charter to OCIMF members with the aim of developing:

"A proactive approach to Energy Efficiency and Fuel Management that includes improvement of vessel and voyage efficiencies aimed at reducing the CO_2 emitted from vessels" (OCIMF, 2008).

and that:

"The efficient use of energy should be a fundamental requirement for operators offering their vessels for charter to OCIMF members" (OCIMF, 2008).

In general the guidance requires:
- An Energy Management Policy that addresses vessel operation.
- An Energy Management Plan that:
  - Demonstrates effective onboard implementation of the company energy policy.
  - Addresses voyage management and includes appropriate measurement and reporting requirements.
- The efficient use of energy and vessel optimisation and includes appropriate measurement and reporting requirements.
- Pocedures are in place for the measurement and monitoring of overall fuel consumption.
- All fuel is purchased against a defined specification.

11.3.5 Ports

Environmental initiatives in ports affecting shipping in the past have largely revolved around waste port facilities and improving local air quality. The use of shore side electricity in ports such as Göteborg, Helsingborg, Stockholm and Zeebrugge does offer an alternative for ships to reduce CO_2 while at berth, however this power supply still needs to be generated elsewhere.

There is potential for ports to differentiate between vessels environmental performance via port dues, and initiatives such as the Environmental Ship Index (ESI) proposed by the ports of Le Havre, Antwerp, Rotterdam, Bremen and Hamburg that would rate ships based on their emissions. However, the cost benefit in reduced port fees would need to be significant to encourage owners to invest in R&I to improve their rating.

11.3.6 Media and Environmental Groups

Shipping is generally only in the news when an accident occurs and other issues such as environmental performance, negative or positive is rarely covered so this is currently not considered a big driver for R&I into CO_2 reductions from shipping. While attention has increased on the industry from the media and environmental groups over CO_2 reduction targets with the Copenhagen climate conference approaching, outside of shipping media, this is minimal when compared to coverage of other GHG emitters.

11.3.7 Equipment Suppliers

Equipment suppliers have a vested interest in continually developing their products to ensure competeveness and with fuel costs driving improvements that reduce fuel consumption this ensures products are developed and refined to improve efficiency and therefore indirectly helping reduce CO_2 emissions.

11.4 Barriers and Bottlenecks

This identifies some of the barriers and bottlenecks to research and innovation.

11.4.1 Value of Environmental Performance in the Market

Companies with the in-house expertise, technical know-how and budgets and size of fleet to drive forward their own R&I development is limited to some of the larger owners and operators. For the bulk of the industry this is not really feasible, either due to lack of funding available, technical capacity or just not having a large enough fleet to justify the investment.

The nature of the shipping industry is changing over time moving from traditional run family businesses to consortiums or public limited companies. Environmental performance is generally not reflected in the asset (the ship) price, which is used to conduct business with cargo owners and investors, so until the value and attractiveness of energy efficient and environmentally friendly ships to the market is established, the business case for large investments to develop a low carbon fleet outside of reducing fuel costs is hard to justify.

11.4.2 Resistance from Ship Yards

In recent years, when new building orders reached its peak slipway space was at a premium. Even now during the economic crisis spare capacity is rare. Therefore yards might be reluctant to build ships of more complexity and unusual designs, with new technology the yard is unfamiliar with, due to loss of profit margin and increase time utilising a slipway.

Many yards prefer standard designs that are quick to build and avoid any complex designs that might result in delays, claims and a reduction in the number of ships delivered per year. When considering a new design the first vessel of a series can potentially take anything from one to two years or more depending on complexity and yard experience. Time to build later vessels in the series will be significantly reduced as the yard becomes familiar and competent in building that design. Yards will ask for higher premiums for building new novel designs and technology.

It does not therefore generally make financial sense for yards to get involved in building new novel designs that will likely result in a massive increase in delivery time, but to stick to building ships as quickly as possible.

Certain yards also produce their own generic designs and even those designed outside the yards will be designed with ease of building in consideration as increased time in the yard will increase the costs

11.5 Design of R&D support

11.5.1 Options

Innovation support policy can take many forms. One way to categorize policy instruments is (COWI, 2009):
- Aimed at increasing the supply of innovations, e.g.:
  - Grants for industrial R&D.
  - Investment in infrastructure (e.g. through the educational system or government financed research laboratories).
  - Support for education and training.
  - Support for public sector research.
  - Corporate tax reduction.
  - Intellectual property rights.
  - …, etc.
- Aimed at increasing the demand for innovations:
  - The use of regulation and standard setting.
  - Support of private demand (e.g. through subsidies and tax incentives).
  - Systemic policies (e.g. cluster policies or supply chain policies). And
  - Public procurement (R&D procurement, public procurement of innovative goods).

11.5.2 Assessment of the options

Apart from regulation or policies that internalise the costs of CO_2, there is little the EU can do to improve the demand for innovations and indirectly the demand for R&D. The EU does not own or operate ships and can therefore not use public procurement as a tool to increase demand. In contrast, Member States' navies can act as an innovative buyer and many in fact do, mainly driven by the desire to operate a ship without needing to refuel often.

Supply-side policies are more common. In general, private investment in the supply of innovations, such as R&D, is often less that the social optimal level because of the existence of knowledge-spillovers. In other words, because firms can only appropriate some of the knowledge they develop through lead times, patents and secrecy, and because some of the knowledge firms develop ends up with competing firms, firms spend less on R&D than if they could reap all the benefits of the knowledge they develop. As a result, a welfare optimizing policy subsidises R&D.

At the EU level, the main instrument for funding research are the Framework Programmes (European Communities, 2007)[35]. The Framework Programmes for Research have two main strategic objectives:
- To strengthen the scientific and technological base of European industry.
- To encourage its international competitiveness, while promoting research that supports EU policies.

Apart from these rather general policies, analysis within this project shows that it could be worthwhile to improve the maritime communications infrastructure in order to reduce congestion of ports. This could perhaps reduce emissions by a few percent by making speed optimization possible.

Moreover, in contacts with stakeholders several examples have been mentioned of possible violations of intellectual property rights. It is beyond the scope of this project to propose improvements of the system of intellectual property rights, but if the system is indeed weak in the shipping sector, this could be a reason for an underinvestment in private R&D.

11.6 Conclusions

Reducing the emissions from maritime transport requires innovations in the shipping sector. The form of the MACC derived in chapter 3 suggests that innovation will become very expensive beyond a level that is cost-effective at expected fuel prices in 2030. Hence, a further reduction of per vessel emissions would require an increased supply of cost-effective technologies. As these technologies may have long lead times, it may be considered important to step up the current R&D effort in order to increase the chances of technologies becoming available.

An essential element of an R&D policy would be the adoption of climate instruments. Without them, the level of technology development required will remain uncertain, thus reducing the incentive to invest in R&D.

This chapter outlines a number of options to reduce emissions that require more study and may merit funding. In the short to medium term, per vessel emission reductions can be expected to result from research into and

---

[35] FP7 in Brief: How to get involved in the EU 7th Framework Programme for Research.

innovations of alternative sources of energy and ship efficiency improvements. In the longer term, more radical improvements will be needed that take into account the ship concept and design.

12 Impacts on the shipping sector

12.1 Introduction

This chapter assesses the impacts of the selected policies on the shipping sector.

Section 12.2 analyses the behavioural responses in the shipping sector to a financial incentive to reduce CO_2 emissions. Section 12.3 assesses the impacts on the cost structure of the maritime transport sector. Section 12.4 assesses the impacts on modal split.

12.2 Behavioural responses to financial incentives to reduce CO_2 emissions

Inclusion of shipping in the EU ETS and an emission tax both result in CO_2 emissions becoming costly. Ship owners and operators acting rationally will take measures to reduce emissions up to the point where the cost-effectiveness of these measures is equal to either the allowance price or the tax rate.

This section first addresses the assumption of rational behaviour and the impact of policies on this in section 12.2.1. The next section, 12.2.2 evaluates the impact of policies on technical efficiency and section 12.2.4 assesses the impact on operational efficiency. Section 12.2.6 discusses incentives for innovation. The impact on demand for shipping is assessed in section 12.2.8. Section 12.2.9 extrapolates the conclusions of the previous sections to the fleet. Section 12.2.10 summarises and concludes.

12.2.1 Impact of policies on the implementation of cost-effective measures

In practice, not all cost-effective measures may be taken by ship owners and operators. Section 4.2.1 analyses six possible causes for not implementing cost-effective measures:
1   Low priority.
2   Depreciation period or risk premium.
3   Split incentives.
4   Transaction costs.
5   Fuel price.
6   Time lag.

Of these, the fourth and six were considered to be the most important in the coming years. Here, we assess how different policy options affect each of these factors.

Section 4.2.1 concludes that the shipping sector has given increasing priority to fuel-efficiency and will likely continue to do so if fuel prices stay at their current levels or increase further. Policies that increase the costs of emissions, like emissions trading and emissions taxes, are likely to reinforce this development. The same can be said for policies that reward efficiency improvements, like a baseline-and-credit scheme. In contract, voluntary action is not likely to increase the awareness of fuel consumption and

emissions over and above the business as usual level, which is determined by the current and forecasted fuel price.

The risk premium for operational and technical measures is not considered to be of major importance, but there may be a significant risk premium in new ship designs. While any policy that increases the costs of emitting CO_2 will change the balance between risk and reward and thus increase the implementation of risky measures, the impact on new buildings is probably most direct in policies that target the design efficiency of ships directly. These could be either global limit values for design efficiency or regional schemes rewarding ships with a better than average efficiency.

While charter markets appear to be working efficiently, there seem to be institutions that ensure that in some charter markets, incentives are not always well alligned. This could lead to split incentives. The size of this problem is hard to assess, as it depends on the type of charter party and on factors such as whether or not a ship is destined for a congested port or not. Policies that increase the costs of emissions are likely to increase the weight of fuel efficiency in the large number of factors that determine a ship's charter rate and thus reward ship owners that have invested in fuel efficient ships.

And although considerable uncertainties remain in fuel price forecasts, it is likely that ship owners will currently use higher forecasts in evaluating measures than a few years ago. Again, policies that increase the costs of emissions are likely to reinforce this development as ship owners and operators will take both the price fuel and the costs of the associated emissions into account.

Section 4.2.1 concludes that for the coming years, the most important factors that could contribute to a continuation of the apparently cost-effective measures to improve the fuel efficiency – apart from the obvious differences between the MACC model and reality – may be the transaction costs and the time lag. Both can only be indirectly addressed by policies, in the way that policies that increase the costs of emitting CO_2 and/or reward efficiency are likely to increase the transaction costs that are acceptable and reduce the time lag for the implementation of measures.

In summary, policies that increase the costs of emitting CO_2 and/or reward efficiency are likely to increase the implementation of cost-effective measures. Since chapters 8 and 9 conclude that policies aimed at improving the efficiency can only target the design efficiency, such policies only incentivise the implementation of cost-effective measures in a ship's design. Since there are both technical and operational cost-effective measures, policies that increase the costs of emitting CO_2 will have a larger impact in the implementation of cost-effective measures. Since we considered it to be impossible to quantify the reduction in the amount of cost-effective measures, we will also refrain from a quantification of the impact of the policy options considered here.

12.2.2 Technical measures to reduce emissions

Ship owners can take measures to reduce CO_2 emissions in response to policies that internalize the external costs of CO_2, such as emissions trading or an emissions tax.

This section assesses the extent to which ship owners are likely to take technical measures. The basis for the assessment is the marginal abatement cost curve for shipping in 2030 (see chapter 3), but only incorporating the following, technical, measures:

− Propeller/propulsion system upgrade.
− Hull retrofit.
− Air lubrication.
− Wind energy.
− Main engine retrofit.
− Auxiliary systems.
− Solar energy.
− Propeller/propulsion system upgrade.

See annex A for more details.

One important technical measure is not included in the MACC: building larger ships or ships with a different hull form. The impact of policies on this measure is discussed separately in section 12.2.3.

Figure 39   Cost-effectiveness of technical measures to reduce maritime CO_2 emissions, 2030
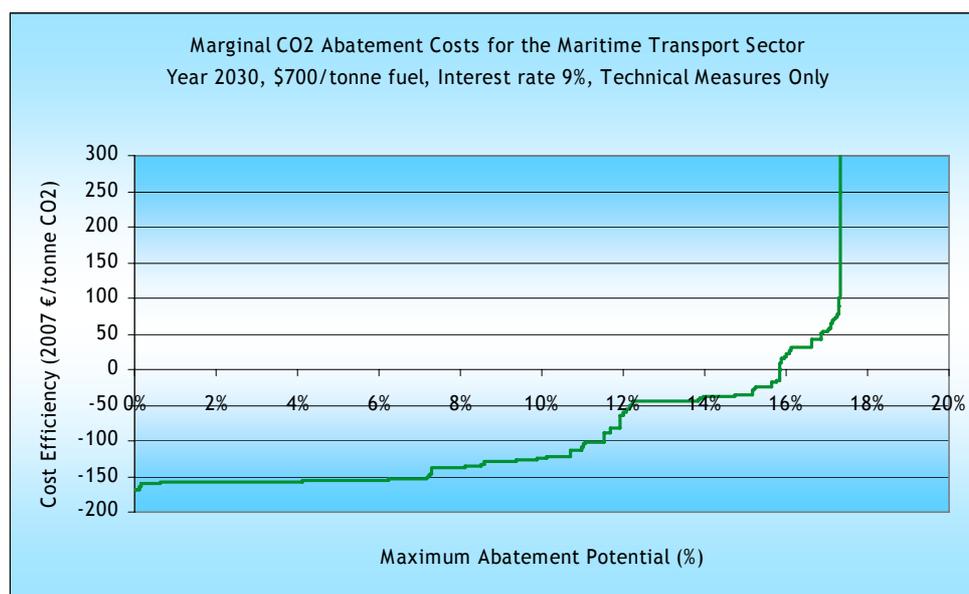
Source: This report.

The cost curve for technical measures shows a considerable cost-effective abatement potential at forecasted fuel prices. To some extent, these measures will be taken regardless of the incentive provided by the policy instrument (see section 12.2.1 for a more detailed discussion).

For the measures with positive marginal costs, it is important to note that the MACCs in this report show the marginal abatement costs of reducing a tonne of CO_2, regardless of where it is emitted. In a regional policy, some ships may have an incentive to reduce emissions when they are in the geographical scope of a scheme, but none when they are outside of its scope. Hence, for these ships the actual incentive that they experience will only be a share of the incentive within the scheme. To give one example, if a ship sails from the Gulf to Europe and back, and the allowance price in the ETS is € 55, this ship, if rational, will take measures op to a marginal abatement cost of € 27.5.

The additional effect of the internalization of the external costs of CO_2 would be small, since the curve is almost vertical from the point where it crosses the X-axis. It should be noted, however, that this curve does not comprise measures relating to improved hull design, as these are impossible to assess across a large number of ship types and sizes (see chapter 3). Moreover, the MACC only reflects technologies for which a price and an abatement potential can be currently assessed. Emerging technologies that are currently being developed could be commercially available in 2030.

Table 63 assesses the Impact of ETS or emissions tax on the implementation of technical emission reduction measures. It distinguishes between the impact on ships that sail predominantly intra-EU voyages and therefore have the incentive to reduce emissions up to the level of the allowance price or the tax, and ships that sail predominantly intercontinental voyages. For the latter, we assume that their incentive is at half of the allowance price or tax level.

Table 63   Impact of ETS or emissions tax on the implementation of technical emission reduction measures, 2030

	€ 22	€ 55	€ 100
Impact of having a policy	Not quantified		
Impact on emissions of ships sailing predominantly intra-EU voyages	0.2%	1.2%	1.5%
Impact on emissions of ships sailing predominantly intercontinental voyages	0.1%	0.3%	1.0%

Source: This report.

Note that the results presented in Table 63 assume a fuel price of US$ 700 per tonne of fuel. At some lower fuel prices, the impacts of the policy would be larger because the MACC crosses the X-axis as a larger angle. Conversely, at most higher fuel prices, the impacts of the policy would be smaller.

A baseline-and-credit system to improve the design efficiency of ships would also incentivise ship owners to implement technical measures. The extent to which this happens depends on the baseline and the target, both of which can vary for different ship types (see section 9.5). This makes it impossible to evaluate the costs of such a policy. On a fleet-average basis, the cost-effectiveness of the policy can be evaluated using the MACC of Figure 39. Over and above the impact of having a policy, an additional reduction of CO_2 emissions of 1% could be achieved at a marginal cost-effectiveness of € 41 per tonne of CO_2, an additional reduction of 1.5% at a marginal cost-effectiveness of € 108 per tonne of CO_2, while an additional improvement of more than 1.6% would require technologies not evaluated in this report.

12.2.3   Impact on ship size and shape

Impact on ship size
Adding cost like CO_2 tax or allowance to the shipping sector could in many cases effect the transportation cost. If the transportation cost per unit shipped increases, the charterer might look at possibilities to increase the total quantity of unites so it can be shipped on a bigger ship reducing the transportation cost per unit, economy of scale.

One of the essential questions is why there are different sizes on vessels and how is their size determined. Economy of scale is very much valid in shipping, bigger is cheaper, in the sense that a bigger ship can transport a unit cheaper than a smaller vessel. Also a bigger vessel is cheaper to build and to buy if we consider the price compared to the cargo carrying capacity. A VLCC on 300,000 dwt is today estimated to cost mUS$ 100, where as an Aframax on 110,000 dwt is today estimated to cost mUS$ 52. The VLCC carries lifts 3 times the cargo as the Aframax, but the cost is only twice. There are however differences in for segments in the shipping sector, bulk ships (dry and wet) are built to minimizing transportation cost per unit, while the container business has historically been more concerned about speed, reliability and quality of service. What are the parameters that force behind the decision for owners when they order new ships? We have listed some:
–   Economy of scale.
–   Trading flexibility.
–   Market norms.
–   Shipyards design.
–   Port restrictions/limitation.
–   Port infrastructural limitations.
–   Size of stem or parcel.
–   Owners knowledge to market(s).
–   Building costs.
–   Operation cost.
–   Trade route limitation.

Economy of scale is the major driver to use as big as ship possible, however there are certain other constraints that controls the size of a vessel. That is of course the natural topography (landmasses) and bathometry (depth) of harbours and trading lanes. Draught restriction is one of the or maybe The key factor in designing a vessel. Getting physically stuck on the harbour bottom, while being loaded, or running a ground is a situation that is avoided by all means necessary, so there are strict draft restrictions in harbours and on challenging trading lanes. With one of the main dimensions for a vessel set, the draught, it is limitation to what the other main dimensions could be according to ship design. For a harbour to do something with its draught restriction it would need to do dredging or even blow away bedrock and rocks, and this is an extremely costly operation. Beam or length restriction could also be a design limitation but they are more determined by manoeuvrability and quay outline. Also trading flexibility for a vessel is important, meaning that it could trade to and from as many ports as possible.

Some of the vessels sizes, main dimensions are directly linked to sail fully laden through canals. For the tankers there are the Suezmaxes which are built with the purpose to sail through the Suez Canal fully laden. For the dry bulk and also container segment there is the Panamax size, which is built to sail through the locks in the Panama Canal. Recently we have seen a new size

description, which is 'Post-Panamax', this design is made to fit the Panama Canal after it is expanded in 2014.

One other important factor or essential factor for the need of transportation is the flow of commodities either as import or export. Form an export view it is the surplus of a commodity in a country that creates the need for this to be sold and shipped. However it is the size of this surplus and the daily production rate (from for example an oil well, mine or factory) that in a logistical perspective sets the limit for the ports infrastructure as storage capacity, berth size, building costs and also the port restriction is included to determined what ships that are used to export the product(s). In the international commodity trading market there are certain sizes the products are sold in called stems or parcels. Building bigger or expanding storage facilities and infrastructure cost money, and if there is not any outlook for an increase in the current production rate it would be economical unwise to spend money on expansions.

Based on the above explanations the shipping market has set some market norms on ship sizes and their main dimensions. However the market norms have changed based on expansions of harbours and also new trades coming into the market. A Panamax dry bulk vessel today is considerable bigger than back in the 1980s. Shipyard's standard designs are based on these norms, so are the ship owners' preferences. Building an odd sized vessel compared to the market norms could or most likely cost more money to build and also it might be harder to trade. This has been the experience for some vessels that were purpose built for a specific project and when the project was cancelled, these vessels have faced big difficulties trading in the normal market. For an owner to order a vessel he will consider the investment cost, but also the operation cost. It is important that a vessel at least performs as good as the vessels already existing and in many cases better. This is to get the owner an upper hand on the other owners by offering freight to reduced levels and still make bigger profit.

One example on that economy of scale does not always have a positive impact in the market are the Ultra Large Crude Carriers, these are the biggest tankers or ships ever built. They range from 320,000 dwt up to the biggest ship ever built on 564,650 DWT, currently known as Knock Nevis. These large vessels was built to transport crude oil in large quantities from the Middle East Gulf to the US and Europe. The ULCC fleet peaked in 1982 and 1983 counting 116 ships, and a small comeback in the 1990s. But today there are only 2 ships left of these massive giants in the commercial tanker market. The reason for the ULCC 'failure' are mainly due to an change in the oil trading market in the 80s, where more oil traders came in to the market and both cargo and freight became tradable. A ULCC could load between 3-5 million barrels of oil, and it was the size that 'killed' them since with high or volatile oil price the value of the cargo would be so high that no one wanted to take the risk. This is a trend we see in today's market as well when the oil price is volatile the traders tend to prefer Suezmaxes instead of VLCCs, as this limits the losses if the price of the oil would fall.

Based on the above argumentation there could be a possibility that a CO_2 tax or CO_2 allowance could have an impact on ship sizes, however the limitations in draught etc. would mean that the economy of scale cannot run the show alone. Therefore it would probably not affect the sizes more than the normal evolution in the shipping market.

Impact on ship shape

There is a difference between ship's shape and a ship's size, the shape describes more the physical forming of a ship's hull. The hull shape is mainly influenced by three factors, the cargo carrying capacity and the hydrodynamic futures, which determents the resistance of the hull and then the engine size and speed, and last but not least the building cost. Other parameters are sea worthiness, stability, and manoeuvrability. Hull shape varies with the ship type and what kind of cargo the vessels is designed to carry.

For maximum cargo carrying capacity a rectangular hull form would be the best. A rectangular hull would utilize as much as possible of the available volume inside the hull for cargo, which is desirable for a bulk vessel. However a rectangular shape is not very ideal for high speeds. The flat front and stern together with the sharp edges creates extra resistance. A ship constructed for maximum carrying capacity would be more 'bulky' going towards the rectangular shape, so almost no volume on the inside of the hull is not used for other than cargo.

If the ship is to be built for high speed there are different criteria. It should be long and narrow and shallow, the bow should be pointy and stern round. This is to minimize the resistance by cutting the water, letting the water run smoothly down the hull, and then letting it easily go. A comparison can be drawn to the hull shape of sailing vessels. However this hull shape does not allow much cargo onboard since the internal volume available would be very small.

The last factor we will consider here is the building cost. A ships steel plate normally comes in XX m long, YY m wide, and is flat. It is when a plate needs to be rolled/fabricated into a form it becomes more costly. A speedy or curvy vessel compared to a more bulky straight cargo optimized is more expensive to build as more plates needs to be curved to get a smoother shape. For bigger ships more flat plates are used which reduces a cost compare to a smaller ship.

If we then look at today's vessels shape we will see the distinct difference in the shape depending on the purpose a vessel is designed for. Bulk vessels are built to reduce cost per unit transported, this means these vessels are very bulky. Container vessels on the other hand are the opposite, where speed is a key factor in the design which results in a very curvy and slim ship. We can look at two examples, the Emma Maersk, one of the worlds' biggest container vessels and some miscellaneous Frontline modern VLCCs. These vessels have some similarity in their main dimensions, but also distinct differences.

Emma Maersk

- Length: 398 m.
- Beam: 56 m.
- Draught: 13 m.
- DWT: 156,907.
- TEU: 13,500.
- Service speed: 24.5 knots.
- Installed power, MCR: 80,080 kW.

Miscellaneous Frontline VLCCs

Front Queen
- Length: 330 m.
- Beam: 60 m.
- Draught: 21 m.
- DWT: 300,000.
- Service speed: 15 knots.
- Installed power, MCR: 25,480kW.

These two vessels have distinct hull shape features. The VLCCs are as rectangular as possible, whereas the container vessel is going towards a slim smooth ship. It is not likely that a climate policy instrument will alter a ship's shape considerably in the coming decades, unless the incentive to do so would become very large.

12.2.4 Operational measures to reduce emissions

Ship owners can take measures to reduce CO_2 emissions in response to policies that internalize the external costs of CO_2, such as emissions trading or an emissions tax.

This section assesses the extent to which ship owners are likely to take operational measures. The basis for the assessment is the marginal abatement cost curve for shipping in 2030 (see chapter 3), but only incorporating the following, operational, measures:
- Speed reductions.
- Propeller maintenance.
- Hull coating and maintenance.
- Weather routing.
- Autopilot upgrade.
- Performance monitoring.

Two important operational measure is not included in the MACC: improved logistics and port operations. The impact of policies on this measure is discussed separately in section 12.2.5.

Figure 40   Cost-effectiveness of operational measures to reduce maritime CO_2 emissions, 2030
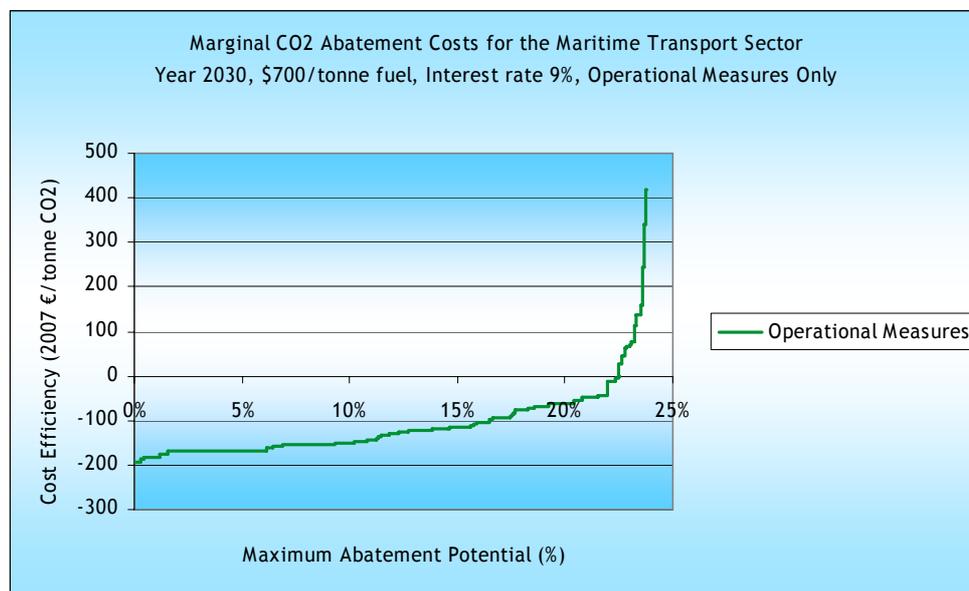
Marginal CO2 Abatement Costs for the Maritime Transport Sector
Year 2030, $700/tonne fuel, Interest rate 9%, Operational Measures Only

Source: This report.

The cost curve for technical measures shows a considerable cost-effective abatement potential at forecasted fuel prices. To some extent, these measures will be taken regardless of the incentive provided by the policy instrument (see section 12.2.1 for a more detailed discussion). Measures with positive costs may be induced by the policy.

As these policies have minimal investments, they will be taken up to the point where the costs-effectiveness would equal the incentives within the scope of the scheme. However, when sailing outside the scope of the scheme, these measures would not be implemented. In other words, there would not be a knock-on effect in other regions.

Table 64 assesses the Impact of ETS or emissions tax on the implementation of operational emission reduction measures. It distinguishes between the impact on ships that sail predominantly intra-EU voyages and therefore have the incentive to reduce emissions up to the level of the allowance price or the tax, and ships that sail predominantly intercontinental voyages. For the latter, we assume that their incentive is at half of the allowance price or tax level.

Table 64   Impact of ETS or emissions tax on the implementation of operational emission reduction measures, 2030

	€ 22	€ 55	€ 100
Impact of having a policy		Not quantified	
Impact on emissions of ships sailing predominantly intra-EU voyages	0.0%	0.3%	0.7%
Impact on emissions of ships sailing predominantly intercontinental voyages	0.0%	0.0%	0.2%

Note that the results presented in Table 64 assume a fuel price of US$ 700 per tonne of fuel. At some lower fuel prices, the impacts of the policy would be larger because the MACC crosses the X-axis as a larger angle. Conversely, at most higher fuel prices, the impacts of the policy would be smaller.

The baseline-and-credit scheme as designed in chapter 9 would not have an impact on operational measures as it would not incentivise them.

12.2.5 Improved logistics and port operations

There are opportunities to reduce emissions by improving logistic planning and port operations. This section assesses the scope for reducing emissions of both, and addresses the question whether these emission reductions are likely to be induced by policies designed in this report or whether additional policies are needed.

Improved logistics

The suggestion of an operational measure presented as 'just-in-time' principle is a good suggestion, and can be utilized very effective for the smaller vessels engaged in coastal and short sea shipping, and shipping with set contracts (COAs).

The principle is to get a better information flow between port or charter and the vessel on when the cargo is ready and the berth is free of other vessels. This means that the vessel can adapt its speed to a proposed ETA, reducing waiting (congestion) and also by reducing speed the vessel will emit less CO_2.

For continental, deep sea shipping, this 'just-in-time' principle is not so easily implemented. For the liner business (containers) the whole trade is based on set time schedules, so they are basically following the 'just-in-time' principle. However the recent development with crashing freight rates and transportation demand, the time schedules has been changed due to more slow steaming from the operators. Currently the speed have been so much reduced that there is a general concern that the goods indented for the Christmas season might not make it for the Christmas season, but arrive too late. For spot market or the tramp market the 'just-in-time' principle is harder to implement, as fixing the vessels on a contract is normally market dependent. If the freight market is falling and the owner believe it will continue to fall owners will try and fix the vessels for the next voyage maybe as much as 40-50 days before the cargo is ready for shipment. However if the freight market is going up the owner will wait fixing the vessels to try and get a better freight rate. However it is in the interest for the owner to get as few days idle when waiting for loading to keep the vessel utilized as much as possible. The problem for the owner is if the dates of laycan[36] are missed, he will then most likely lose his contract with the charter (this is subject to discussion and market situation). Normally for the VLCC segment the vessels trading from Middle Eastern Gulf are fixed 2-3 weeks before laycan and for West Africa liftings a month in advance. This means that for a West Africa to China trade the owner will try to fix the vessels in an early stage of the ballast leg back to West Africa. However for the owner to be certain that he will be able to reach the laycan, against weather, sea margin, delays, etc. he will add additional days to his ETA. If it is smooth sailing the vessel would of course arrive earlier than the agreed laycan and it would have to wait until the cargo is ready for loading. This is not just the case for VLCC but also other long haul

---

[36]   The owner stipulates in the charter party the amount of time allowed for loading and unloading the cargo. This allowance is known as 'lay days', 'laytime' or 'laycan'.

trades, where nature and other aspects might play an important role on the estimated ETA.

As for this matter the reduction of CO_2 by operational matters it is believed to be limited to short sea and coastal shipping whereas continental deep sea shipping does not have the same possibilities to use the 'just-in-time' principal.

Improved port operations

We have assessed the impact of port congestion on emissions of Greenhouse Gasses (GHG) from International Shipping. A full analysis can be found in annex G. A summary of the analysis is presented here.

Port congestion has two impacts on CO_2 emissions and fuel use. First, while waiting to enter a congested port, a ship must keep auxiliary engines running to provide power for hotelling and other functions, and depending on the ship and cargo type, fuel may be used to heat or cool the cargo. Second, a ship that is waiting to enter a port could theoretically have sailed slower if it had been informed about port congestion in advance, thus saving fuel.

Port congestion statistics are not readily available, making an estimate of its contribution to GHG emissions from International shipping at this stage difficult. No relevant studies were identified during the research phase of this report and therefore to gain an in depth insight into the effect of port congestion, European wide port co-operation would be required. However within the scope of this report a number of conclusions can be made.

Amongst the ship categories included in this study, container ships and LNG vessels have the potential to produce the most GHG emission, if forced to wait at anchor due to port congestion, due to their high average installed auxiliary power. However, relatively low numbers of LNG vessels means container ships and particularly liner services would be expected to contribute the most GHG emissions, due to more frequent port calls by a large number of vessels and their reported unreliability of arriving on time, as well as the high installed power.

Port utilisation was increasing year on year prior to the economic downturn with ports in Scandinavia, the East Baltic and North East Continent predicted to be congested again by 2015 (> 80% utilisation). While the global economic downturn has provided a period of grace, potentially delaying this predicted date, the problems of port congestion are expected to return.

The diverse European port system offers, both advantages and disadvantages in mitigating port congestion. The competitive nature ensures ports operate efficiently, as alternative ports and logistic chains offer shippers numerous alternatives to shift freight to avoid congestion or a faster route to market. However, further co-operation between ports would be required to ensure spare capacity in European ports is utilised once demand is high in the key larger ports resulting in high utilisation levels.

We estimate that that for ships sailing to congested ports, emissions can increase by more than 10% if the delays extend over several days. However, although data is scarce, we have the impression that in most European ports, if there is congestion, it causes a delay of a couple of days at most for most of the time. If our impression is correct, this would imply that the emissions associated with congestion are less than 5% of total shipping emissions. While this may not be much, it could still be worthwhile to reduce congestion.

12.2.6 Differences between emissions trading, taxes and baseline-and-credit trading

A fundamental difference between the baseline-and-credit scheme as designed in chapter 9 on the one hand and the emissions trading scheme or the emissions tax as designed in chapters 6 and 7 on the other is that the former only incentivises technical measures to reduce emissions while the latter two also incentivise operational measures. This has a significant impact on the abatement potential under the policy and on its cost. This is shown in Figure 41. In total, technical measures account for less than half of the total abatement potential with operational measures accounting for the rest.

Figure 41   MACC curves for all measures and for technical measures only, 2030, 9% interest rate and fuel price of US$ 700 per tonne
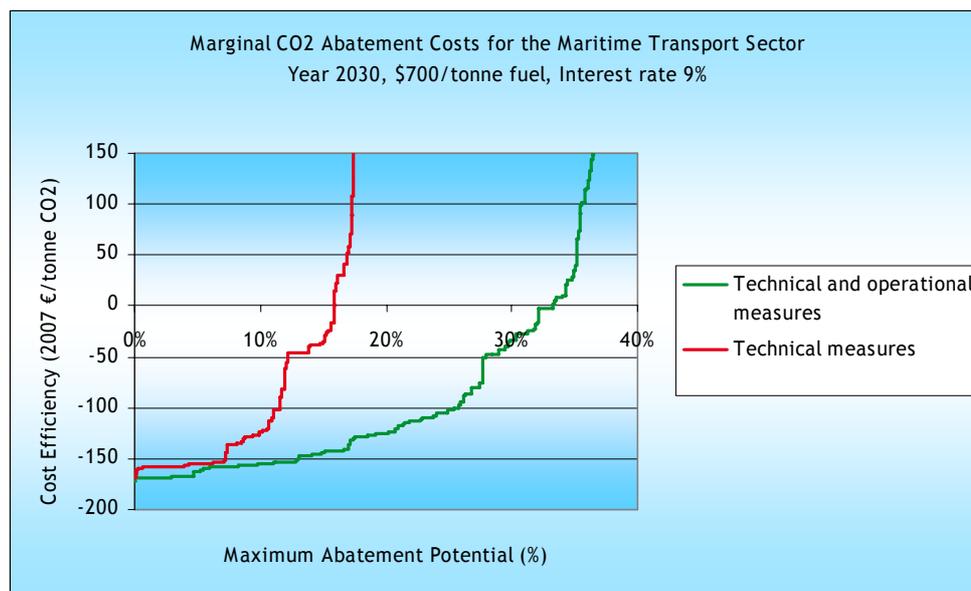
12.2.7 Impact on innovation

In general, policies that increase the costs of a factor trigger innovation to limit this cost increase. This is known as induced innovation (Hicks,1932). In climate policies, the induced innovation takes two forms. It creates the demand for emissions-reducing technologies and it guides the supply of innovation towards reducing emissions and/or lowering the price of emissions reducing technologies (Popp, 2002).

This section discusses the impact of the policies considers in this report on innovation in the shipping sector.

Of the policies discussed in this report, emissions trading and emissions taxes increase the costs of emitting carbon. They are likely to drive innovation by making it more attractive for ship owners to install equipment and/or adopt practices that reduce emissions. Such innovation may be hampered, however, by the existence of market barriers and market failures. As section 4.2.1 argues, the market failure of split incentives may limit the impact of innovation in time-charter markets to an extent.

A mandatory EEDI standard would increase the demand for technical innovations, if it does not result in avoidance by redeployment of fuel-inefficient ships outside the scope of the policy. A baseline-and-credit system would have the same result.

Some innovations are not directly market driven, as they require a change in institutions. Examples from this report include improved communication systems between ports and ships to reduce port congestion and allow ships to sail at an optimal speed to ports (see section 12.2.5) and changed charter contracts in order to allow all parties to reap the benefits of slow steaming (see section 4.2.1). While policies that increase the costs of CO_2 emissions may increase pressure on the actors involved, institutional changes are needed to make these innovations possible.

12.2.8 Reduction of demand

Internalising the external costs of CO_2 increases marginal costs of transport and therefore reduces demand. However, since demand for shipping is rather inelastic (this report uses an elasticity range 0.2–0.3), the impact is likely to be small.

For a number of different ship types, we estimate the costs to increase by 10 to 17%, depending on ship type and size (see section 12.3.3). These estimates are based on central estimates for CO_2 price and fuel price (CO_2 allowance price of € 55 per tonne and fuel price of US$ 700 per tonne). Higher prices for CO_2 push the cost increase up. Higher fuel prices push the cost increase down. Also taking different allowance and fuel prices into account, cost increase estimates range from 3 to 51%.

The central estimates suggest that a reduction in demand of 2 to 5% can be expected in the period up to 2030, relative to a baseline that grows more than 2 to 3% per annum.

12.2.9 Extrapolation to fleet

In the coming decades, the maritime fleet is able reduce its emissions by some 30% relative to a frozen technology scenario by implementing cost-effective technologies and operational practices. Note that efficiency improvements of this magnitude are included in our emission baselines.

The inclusion of maritime transport in the EU ETS or the taxation of emissions of maritime transport would result in very small additional efficiency improvements in the shipping sector, in the order of a few percent, according to our MACC estimate. The reason is that there are few technical operational measures that have cost-effectiveness estimates up to € 100 per tonne of CO_2, which is the upper value for either allowance prices or an emission tax that this report uses.

In reality, efficiency improvements could turn out to be larger due to new technologies being developed and currently available technologies being improved. It is also possible, however, that due to market barriers and market failures, actual emission reductions will be lower.

12.2.10 Conclusion

Policies that increase the costs of emitting CO_2 and/or reward efficiency are likely to increase the implementation of measures that are cost-effective under these policies. Since chapters 8 and 9 conclude that policies aimed at improving the efficiency can only target the design efficiency, such policies only incentivise the implementation of cost-effective measures in a ship's design. Since there are both technical and operational cost-effective measures, policies that increase the costs of emitting CO_2 will have a larger impact in the implementation of cost-effective measures.

The amount of abatement in policies that reward both operational and technical measures is approximately twice as large as the amount of abatement in policies that only reward technical options. Hence, the environmental effectiveness of an emissions trading scheme or an emissions tax can be larger than the effectiveness of a mandatory EEDI value or a baseline-and-credit trading scheme.

In 2030, unless new technologies become available, there seems to be little additional impact on emissions from the shipping sector from any of the policies discussed here, as long as the assumptions used in this impact assessment on fuel price and allowance price or tax level become a reality. The impact these policies could have on emissions in the shipping sector would be in reducing some of the market barriers and market failures that currently prevent the implementation of some cost-effective measures. This, however, cannot be quantified. Hence, the impact that these policies have on emissions would have to result from either the cap or the use of the tax revenues.

The central estimates suggest that a reduction in demand of 2 to 5% can be expected in the period up to 2030, relative to a baseline that grows more than 2 to 3% per annum.

The policies will have a positive impact on the rate of innovation. However, some innovations are not directly market driven, as they require a change in institutions. Examples from this report include improved communication systems between ports and ships to reduce port congestion and allow ships to sail at an optimal speed to ports and changed charter contracts in order to allow all parties to reap the benefits of slow steaming. While policies that increase the costs of CO_2 emissions may increase pressure on the actors involved, institutional changes are needed to make these innovations possible.

12.3 Impact on the cost structure of the maritime sector

In this section, we will focus on cost increase due to the obligation to pay for the CO_2 emissions according to the planned policy scheme (emissions trading or an emissions tax). The overall costs of such a scheme can be divided in two main categories:
− Increase in voyage costs leading to increase in consumer prices and/or in profit margins of ship operators.
− Transaction costs including:
  • Costs for the participants of the market (including monitoring and enforcement).
  • Costs of enforcement for public authorities.

These categories of costs will be described in separate sections below. We will assume that increase in voyage costs and cost pass-through will be the same for the emissions trading scheme and for the emissions GHG tax of equivalent value to the price of allowances in the emissions trading scheme. Administrative costs and costs of enforcement will be described separately for each of the policy schemes.

For assessing the impact of increase in voyage and administrative costs, we will try to answer the following questions: (1) what is the expected impact in quantitative terms?; (2) who will be most likely to bear these costs and in what proportions? (in other words, to what extent cost pass-through can be expected?).

12.3.1 Increase in voyage costs

Our estimates of increase in voyage costs are based on six examples for different segments of the market and different types of vessels, as presented in Faber et al. (2009). First, however, we will discuss types of costs relevant for shipping and place the climate policy costs among them.

12.3.2 Shipping cost structure

The cost structure for running a ship is the cost either the ships' owner or operator will bear. Below, in Figure 42, we present the cost structure for running a ship based on Stopford (2009). The general cost categories are indicated in the dark blue and individual cost items are listed below. The costs of climate policy have been placed in the scheme under voyage costs.

Figure 42   Cost structure for running a ship
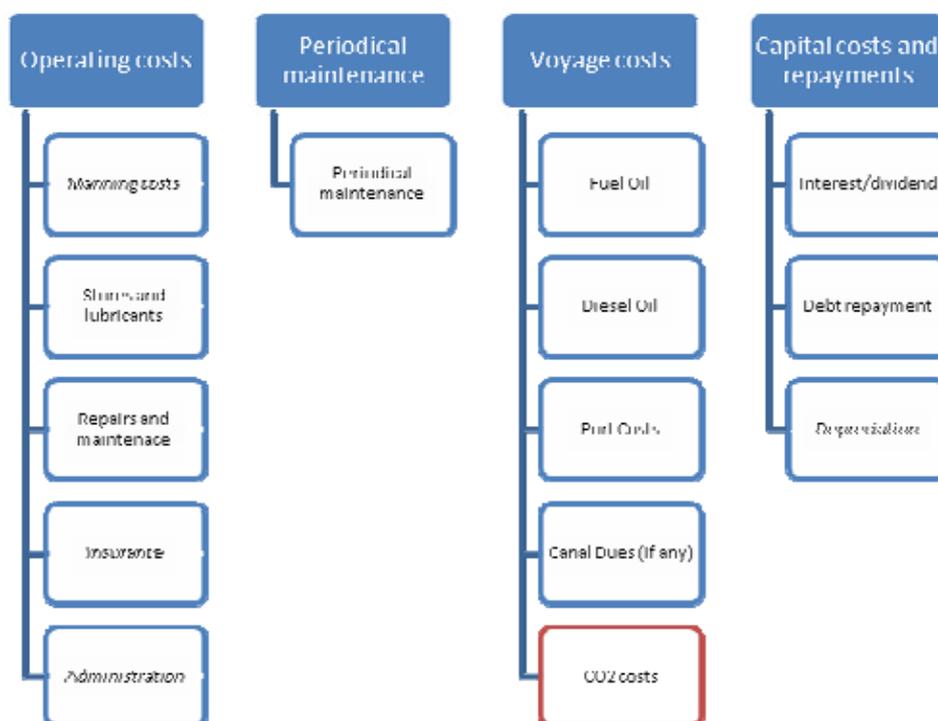
The magnitude of individual costs will vary across segments and the size of the vessels and also over time as variables in the individual cost items undergo changes e.g. fuel costs. To give a very crude impression on the magnitude of costs: operating and maintenance costs are typically in the order of millions of

dollars per year (see next section). Fuel costs depend on fuel price, of course, but are also most of the time in a range of millions of dollars[37]. New built ships typically cost several tens of millions of dollars (UNCTAD, 2009), so at an interest rate of 10% and a lifetime of 25 years, the annual interest payment and depreciation is also in the order of millions of dollars. In other words, annual operational costs and maintenance, annual voyage costs and annual capital costs are of the same order of magnitude.

A baseline-and-credit scheme also impacts the voyage costs, albeit in a slightly different way than emissions trading or an emissions tax. Such a scheme *lowers* the voyage costs for efficient ships and *increases* the costs for inefficient ships.

A mandatory EEDI standard will induce ship owners and operators to increase the efficiency of their ships, if it cannot be met completely by shifting ships to different markets (see section 8.3.2). Since the EEDI only rewards technical measures, meeting a standard will require capital investments (see section 8.2.3). Hence, the capital costs of a ship will increase. Insofar as the capital costs are not recouped by lower voyage costs, the total costs of operating a ship will increase.

12.3.3 Estimates of cost increase

Below, we will present 6 examples of increase in costs for different segments and vessels sizes to show an estimated cost for the CO_2 emitted compared to today's costs. The examples are taken from Faber et al. (2009). The operation costs are based on Moore Stephens' OpCost 2008 report, where samples from a selection of vessels that are used to give an average cost overview for the operational costs for different segment and sizes. The examples refer to the following vessel types:
- Handysize Bulker.
- Capesize Bulker.
- Handysize Product Tanker.
- VLCC Tanker.
- Container Main Liner.
- RoRo vessel.

A detailed analysis for these vessel types is given in Faber et al. (2009). Table 65 gives a summary of the results for the costs of compliance with CO_2 policies at the level of € 22, € 55 and 100 € per tonne CO_2, according to the assumptions adopted for the IA for the year 2030. Total and operational costs are based on the estimates for the year 2007 and we assume that these costs will remain constant. In Table 65, we give detailed estimates of cost increase for a Handysize Bulker. The estimates in Table 65 refer to the scenario with bunker fuel prices of US$ 350, US$ 700 and US$ 1,050 per tonne (which, recalculated into Euro according to the exchange rate of 2007 would be equal to € 255, € 511 and € 766, respectively). The analysis is made in prices of 2007. For the analysis in the year 2030 we assume increase in fuel efficiency of 33% for all types of ships as compared to the current level assumed in Faber et al. (2009), according to the assumptions used for constructing the MACC curve. In each cell, three values are given: the uppermost refers to the lowest price of fuel, the middle – to the middle level, and the lowest – to the highest assumed price of fuel.

---

[37] Buhaug et al. (2009) estimate total fuel consumption of international shipping in 2007 at 277 million tonnes. For a fleet of approximately 36,000 vessels (UNCTAD, 2008), the average consumption per vessel is about 8000 tonnes. The fuel price has ranged from USD 250 per tonne to USD 600 per tonne over the past years.

Table 65   Estimated increase in total and operational costs for Handysize Bulker according to different allowance prices and fuel prices, estimates for the year 2030

Ship type	Increase in total costs			Increase in operational costs*		
	Price of allowances (tax rate) per tonne CO_2, US$					
	22	55	100	22	55	100
Handysize Bulker	4%	9%	17%	7%	18%	34%
(20,000-40,000 DWT)	3%	8%	15%	6%	14%	26%
	3%	7%	13%	5%	12%	22%

Operational costs stand for O&M plus bunker costs.

Source: Own calculations based on Faber et al., 2009.

Table 66 below shows the figures for other types of ships but only with the assumption of central estimate of allowance and fuel prices (i.e. CO_2 allowance price of € 55 per tonne and fuel price of US$ 700 per tonne).

Table 66   Increase in total and operational costs for maritime shipping due to climate policies according to different ship types at allowance price (tax rate) of € 55 per tonne of CO_2 and US$ 700 per tonne of fuel for the year 2030

Ship type	Increase in total costs	Increase in operational costs*
Capesize Bulker (over 80,000 DWT)	11%	20%
Handysize Product Tanker (30 000-50 000 dwt)	8%	14%
VLCC Tanker (250,000–320,000 DWT)	10%	20%
Container Main Liner (2,000-6,000 TEU)	18%	26%
RoRo (5,000-30,000)	7%	16%

Operational costs stand for O&M plus bunker costs.

Source: Own calculations based on Faber et al., 2009.

As we can see from the table, at the price of CO_2 at the level of € 55, the range of increase is between 7 and 18%, with the lowest estimated increase for a RoRo vessel and the highest estimated increase for a Container Main Liner. Increase in operational costs is always a few percentage points higher.

Changing the assumption about the price of fuel would of course have an impact on the percentage increase of voyage costs. Assuming that the bunker fuel price in 2030 stays more or less on the same level as today (the assumption of about US$ 350 per tonne, i.e. half of the middle price assumption), the percentage increase in costs would go up (for the price of CO_2 equal to € 55 the range of increase would be equal to 8-24% depending on the type of the ship). The highest assumed price of fuel (US$ 1,050 per tonne) would bring the increase in costs down (to the range of 6-14% for the central estimate of price CO_2 price).

The same analysis has been performed for the year 2010, with the following assumptions: CO_2 price at the level of € 7, € 25 and € 45 per tonne, fuel price equal to 200, 400 and 600 US$ per tonne. The results are given in Table 67. In analogy to the approach adopted for the year 2030, first we give more detailed estimates for a Handysize Bulker (Table 67). In each cell, three values are given: the uppermost refers to the lowest price of fuel, the middle – to the middle level, and the lowest – to the highest assumed price of fuel. In the next

table (Table 68) we summarize the results for other types of ships, with central assumptions regarding price of CO_2 allowances and price of fuel (i.e. € 25 and US\$ 400, respectively).

Table 67   Estimated increase in total and operational costs for Handysize Bulker according to different allowance prices and fuel prices, estimates for the year 2010

Ship type	Increase in total costs			Increase in operational costs*		
	Price of allowances (tax rate) per tonne CO_2, US\$					
	7	25	45	7	25	45
Handysize Bulker	3%	12%	21%	6%	21%	38%
(20,000-40,000 DWT)	3%	10%	17%	4%	15%	27%
	2%	8%	15%	3%	12%	21%

Operational costs stand for O&M plus bunker costs.

Source: Own calculations based on Faber et al., 2009.

Table 68   Increase in total and operational costs for maritime shipping due to climate policies according to different ship types at allowance price (tax rate) of € 25 per tonne of CO_2 and 400 per tonne of fuel for the year 2010

Ship type	Increase in total costs	Increase in operational costs*
Capesize Bulker (over 80,000 DWT)	12%	19%
Handysize Product Tanker (30,000-50,000 DWT)	10%	15%
VLCC Tanker (250,000-320,000 DWT)	11%	19%
Container Main Liner (2,000-6,000 TEU)	17%	23%
RoRo (5,000-30,000)	8%	16%

Operational costs stand for O&M plus bunker costs.

Source: Own calculations based on Faber et al., 2009.

As we can see from the table, at the price of CO_2 at the level of € 25 the range of increase is between 8 and 17%, with the lowest estimate for a RoRo vessel and the highest estimate for a Container Main Liner. Increase in operational costs is always a few percentage points higher.

Changing the assumption about the price of fuel would of course have an impact on the percentage increase of voyage costs. Assuming that the bunker fuel price is lower than today (the assumption of about US\$ 200 per tonne, i.e. half of the middle price assumption), the percentage increase in costs would significantly go up (for the middle price of CO_2 the range of increase would be equal to 10-26% depending on the type of the ship). The highest assumed price of fuel (US\$ 600 per tonne) would bring the increase in costs down (to the range of 7-13% for the middle price of CO_2).

In a baseline-and-credit scheme, the average costs will increase as ships on average have to meet the baseline. Since the indicator is the EEDI and only reflects design efficiency, changes to the design will be needed to meet the baseline. This means that the capital costs will increase. In order to achieve the same environmental effect as the cap-and-trade scheme, total costs would increase by a higher percentage because a policy based on a design index excludes operational measures, many of which would be more cost-effective.

In a mandatory EEDI limit value, the capital costs will increase. The amount by which depends on the limit value, which is not specified in this report. An analysis in Buhaug et al. (2009) indicates that for a fleet-wide implementation of most measures that are awarded in the EEDI, the marginal costs are negative. This means that although the capital costs increase, the annual capital costs are less than the fuel savings.

Figure 43   Marginal abatement cost curves for 2020, with fuel at US$ 500 per tonne
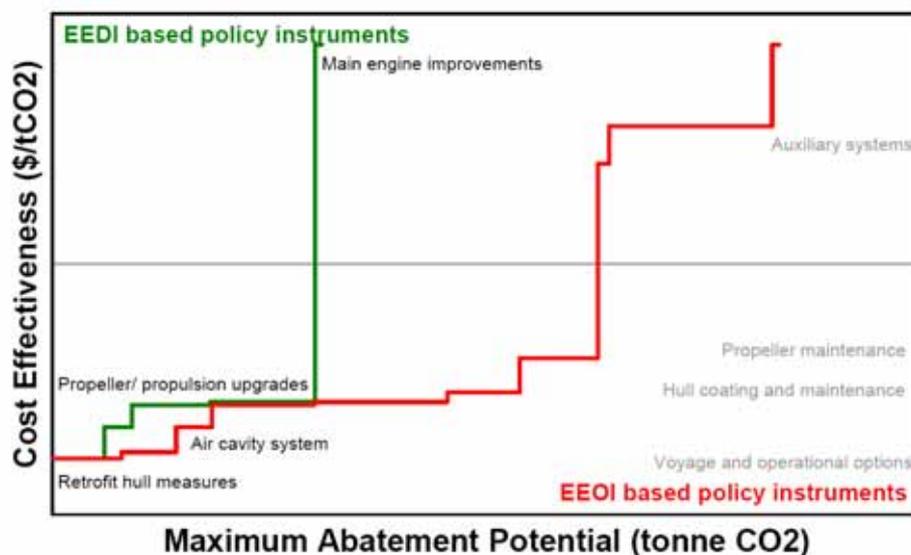
This report has broken down the above curves into a multitude of ship type and size categories. The result is presented in Figure 41. In this graph, separate measures are not distinguished. We note, however, that in this case most measures are cost-effective as well. So a mandatory EEDI value would increase the capital costs for ships not meeting the value, but would lower the fuel consumption and hence the operating costs.

12.3.4   Division of costs among different market players

In both the ETS (chapter 6) and the emission tax (chapter 7), the proposed responsible entity is the ship owner. It should be noted that the actor who takes responsibility for surrendering allowances is not necessarily the actor who bears the costs: a ship owner can, in principle, pass on the costs to the shipper who, in turn, can pass on the costs to the consumer. Theoretically, when supply of ships and demand for transport services are in equilibrium and there are no market failures, prices are determined by marginal costs and all the costs are borne ultimately by the consumer. In practice the shipping market is very volatile and hardly ever in equilibrium because supply of ships is inelastic – it takes a long time to build a ship and when there is a high demand for ships yards' order books may last several years.

In order to assess which actor bears the costs, it is therefore necessary to consider two situations:
1   The demand for shipping is higher than the supply of ships.
2   The demand for shipping is lower than the supply of ships.

In the first case, freight rates are not determined by marginal costs but rather by the marginal benefits, in other words by the shippers' willingness to pay for transport. In these cases, shipping companies will be able to reap scarcity rents (sell their services above costs). The introduction of a new cost item, CO_2 costs, higher costs will in general not affect rates in this case. (If shipping companies would be able to pass on costs under very good market circumstances, so raise their rates and increase their profit margins even more, the question is why they had not increased their rates without the additional costs). However, existing market institutions such as charter contracts in which the charterer pays for the voyage costs may occasionally or temporarily allow shipping companies to pass on some of the additional costs (like currently Bunker Adjustment Factors sometimes allow shipping companies to pass on higher bunker costs even in times of high freight rates (Cariou and Wolff, 2006)). The new cost item will, however, reduce the scarcity rents.

In the second case, freight rates are set by marginal costs, the costs of operating the ship (or more precisely, at the costs of operating the ship minus the costs of laying her up – after all, if it costs more to operate a ship than it does not to operate it, a shipping company would decide to lay her up). Investment costs, which are sunk costs, will typically not be recovered under these circumstances. Since voyage costs are typically costs of operating a ship, and since allowance costs are part of the voyage costs, ship owners will be able to pass them on to shippers (see also Stopford, 2009).

In summary, the costs of climate policy are not always borne by the actor that is responsible for surrendering allowances or paying a tax. When demand for shipping is high, costs are borne by the shipping companies, leading to lower scarcity rents and thus lower profit margins. Conversely, when demand for shipping is low, the costs will be passed on to the shipper and ultimately to the consumer. However, not all consumers will be equally affected, as the least price sensitive consumers – typically consumers in developed countries, are likely to pay a higher share of the costs.

In a baseline-and-credit scheme, in circumstances where costs are passed through, the marginal costs are set by the least efficient ship in the relevant market. In many cases, this will be a ship above the baseline, so the costs of acquiring credits will be passed through. Hence, the profit margin for efficient ships increases. So in addition to the allowances that efficient ships generate, they have the additional margin from higher freight rates.

In case a mandatory efficiency limit value is set, the capital costs will increase. Because investments in a ship's efficiency will generally reduce its fuel consumption, the marginal costs will decrease. Consequently, freight rates will decrease in times when they are set by marginal costs.

In summary, the costs of climate policy are not always borne by the actor that is responsible for surrendering allowances or paying a tax. When demand for shipping is high, costs are borne by the shipping companies, leading to lower scarcity rents and thus lower profit margins. Conversely, when demand for shipping is low, the costs will be passed on to the shipper and ultimately to the consumer.

Because currently the situation on the market is such that demand is lower than supply, we will assume that at least at the beginning of implementation of the scheme the costs will be passed through from ship owners to charterers and further to the shippers and consumers. We argue that this is the only interesting case for this Impact Assessment because if the costs are not passed

through, it means that the ship owners are able to absorb these costs. Hence, the ship owners' profits would marginally go down, which only means that their scarcity rents would decrease. This is not a very interesting case for IA since such a situation does not mean that an average shipping company will go out of business. We will not investigate this case further in our report also for another reason – simply because information on ship owners' profits is not available.

The next section focuses on impact on consumer prices due to costs pass through. We will assume that full costs are passed through, which will allow assessing the maximum possible impact.

12.3.5 Impact on the value of imports and consumer prices

In case the costs of climate policy are positive and transferred fully to the consumers, we have to investigate the possible impact on the value of imports and on consumer prices. How much of the increased costs of shipping would have to be borne by the final consumers of traded goods, and finally, what a percentage rise in prices of consumer goods could be expected depends on several factors, including:

- Elasticity of demand: the lower the elasticity of demand for maritime shipping, the higher the share of the additional costs related to climate policy that will have to be borne by the maritime shipping customers[38].
- Design of the policy – specifically, in ETS, if allowances will be allocated using auctioning or (partly) distributed for free.
- Share of maritime shipping costs in final consumer price of a given good.

In order to investigate the potential impact of climate policy in maritime shipping on consumer prices, we will analyze a few typical examples of goods transported by maritime ships. We will adopt assumptions which allow assessing the worst-case scenario, i.e. the scenario inducing maximum possible estimates of impact (i.e. so that the risk of underestimating the impact of climate policy on consumer prices would be very low). Thus, we assume that (1) the elasticity of demand for maritime shipping of these goods is equal to zero, meaning that the increase in costs due to the emissions reduction policy will be fully transferred on to the consumers[39] and (2) that in case of emissions trading all allowances will be allocated using auctioning, i.e. the ship operators will have to pay for every unit of CO_2 emitted and in case of a tax that full amount of tax per tonne of CO_2 will have to be paid by the responsible party. Another important factor, as described in more detail in section 12.3.4, is that we make the analysis for the case where the demand for maritime shipping is lower than the supply of ships ready to carry the freight, so that we implicitly assume that the supply curve of maritime shipping services is horizontal (thus it is characterised with infinite elasticity).

---

[38] It should be noted that elasticity of demand plays the same role at every step of the production-consumption chain, so that not only elasticity of demand for maritime shipping but also elasticity of demand for intermediate and final product count. Elasticity of demand for maritime shipping related to a given product depends on elasticity of demand for the product traded on the market. Luxury goods tend to have higher price elasticity of demand than goods which satisfy basic needs, so in general it can be expected that higher freight rates will impact the demand for luxury goods more than they will impact the demand for other goods.

[39] Elasticity of demand for maritime shipping transport is reported to be indeed quite low, in the range of 0.2-0.4, which would mean that ship operators would have to bear most of the additional costs but probably not the whole amount. For simplicity we assume also that all other relevant elasticities of demand along the production-consumption chain are close to zero, so that full costs of ETS allowances would be transferred on to the final consumer. This is not a very plausible assumption but conforms with our cautious approach.

We also make a general assumption that the markets for the specific goods are perfectly competitive and that the changes in freight costs are reflected in price changes.

Table 69 shows the expected increase of the value of imports given the above assumptions. The costs of maritime transport per tonne of specific categories of goods as well as percentage ad valorem are based on Korinek and Sourdin (2009). On the basis of the assumed type of ship used for transport for a given commodity, we have applied the relevant percentage increase in transport costs based on data from the Table 66. Under the assumption that all increase in costs of transport is passed through to the consumer, increase in absolute value of the commodities has been calculated on the basis of the data on value/tonne (i.e. price per tonne). We make a simplifying assumption here that price per tonne of commodities and the percentage share of maritime shipping costs in 2030 will stay the same as in 2007, which is not so strange if we calculate all values in constant prices (we assume the level of prices of 2007). The last column shows an estimate of percentage increase in the value of imports resulting from increase in shipping costs due to the policy instrument with the rate of € 22, € 55 and € 100 per tonne of CO_2. For calculating these percentages we have used the estimates of increase in costs of shipping for the relevant categories of ships as calculated earlier.

Table 69   Estimated percentage increase in value of imports for different types of commodities for the year 2030 and fuel price US$ 700 per tonne

Type of commodity	Ship type*	Costs ad valorem (%)	Value of goods (US$/tonne)	Percentage increase in value of goods		
				CO$_2$ price		
				22	55	100
Agriculture	HB	10.89	740.50	0.33%	0.87%	1.63%
Raw materials	CB	24.16	134.89	0.97%	2.66%	4.83%
Crude oil	VLCC	4.03	448.88	0.16%	0.40%	0.73%
Manufactures	C	5.11	3403.91	0.36%	0.92%	1.64%

* CB – Capesize bulker.
* HB – Handy Size Bulker.
* VLLC – Very Large Crude Carrier.
* C – Container Vessel.

From these numbers we can draw a conclusion that the expected increase in the value of imports due to CO_2 policy in maritime shipping is relatively small and for the middle price of CO_2 ranges from 0.4 to 2.66%. The highest increase in value is expected for raw materials (because a relatively high share of the value of these goods can be attributed to maritime transport costs), and the lowest – for crude oil.

Ideally, we would like to know the increase in consumer prices rather than the increase in the value of imports. Percentage increase in consumer prices can on average be expected to be lower than the increase in value of imports of the specific types of goods because consumer prices are as a general rule higher per unit (because of value added in the importing country). Therefore, we can treat the percentage price increase estimated for the value of imports as a higher bound estimate for consumer prices. The difference between the expected percentage increase between import prices and consumer prices will be the highest for manufactures, as these goods are most likely to be

subjected to several transactions resulting in price mark-up before they reach the consumer.

Increase of the price of fuel to US$ 1,050 per tonne would bring the percentage increase in the value of imports down in the following way:

Table 70   Estimated percentage increase in value of imports for different types of commodities for the year 2030 and fuel price US$ 1,050 per tonne, CO_2 price of € 55 per tonne

Type of commodity	Percentage increase in the value of goods
Agriculture	0.76%
Raw materials	2.42%
Crude oil	0.36%
Manufactures	0.72%

The lowest assumed price of fuel, at the level of US$ 350 per tonne would lead to higher rates of increase in consumer prices than in both scenarios above (Table 70).

Table 71   Estimated percentage increase in value of imports for different types of commodities for the year 2030 and fuel price US$ 350 per tonne, CO_2 price of € 55 per tonne

Type of commodity	Percentage increase in the value of goods
Agriculture	0.98%
Raw materials	3.14%
Crude oil	0.48%
Manufactures	1.23%

The same analysis of increase in the value of imports due to a climate policy for maritime shipping has been performed using the assumptions for the year 2010, i.e. with CO_2 prices of € 7, € 25 and € 45 per tonne and fuel prices of US$ 200, US$ 400 and US$ 600 per tonne. The base case scenario is for fuel price of US$ 400 per tonne; the percentages of increase are given in Table 72 below.

Table 72   Estimated percentage increase in value of imports for different types of commodities for the year 2010 and fuel price US$ 600 per tonne

Type of commodity	Ship type*	Costs ad valorem (%)	Value of goods (US$/tonne)	Percentage increase in value of goods CO_2 price		
				7	25	45
Agriculture	HB	10.89	740.50	0.33%	1.09%	1.85%
Raw materials	CB	24.16	134.89	0.72%	2.90%	5.32%
Crude oil	VLCC	4.03	448.88	0.12%	0.44%	0.81%
Manufactures	C	5.11	3403.91	0.26%	0.87%	1.58%

* CB – Capesize bulker.
* HB – Handy Size Bulker.
* VLLC – Very Large Crude Carrier.
* C – Container Vessel.

From these numbers we can draw a conclusion that the expected increase in consumer prices due to CO_2 policy in maritime shipping is relatively small and for the middle price of CO_2 of € 25 per tonne ranges from 0.44 to 2.9%. The highest increase in prices is expected for raw materials (because a relatively high share of the value of these goods can be attributed to maritime transport costs), and the lowest – for crude oil.

Increase of the price of fuel to US$ 600 per tonne would bring the percentage increase in consumer prices down in the following way.

Table 73   Estimated percentage increase in value of imports for different types of commodities for the year 2010 and fuel price US$ 600 per tonne, price of CO_2 of € 25 per tonne

Type of commodity	Percentage increase in the value of goods
Agriculture	0.87%
Raw materials	2.42%
Crude oil	0.32%
Manufactures	0.66%

The lowest assumed price of fuel, at the level of US$ 200 per tonne would lead to higher rates of increase in value of imports than in both scenarios above (Table 73).

Table 74   Estimated percentage increase in value of imports for different types of commodities for the year 2010 and fuel price US$ 200 per tonne, price of CO_2 of € 25 per tonne

Type of commodity	Percentage increase in the value of goods
Agriculture	1.31%
Raw materials	3.87%
Crude oil	0.56%
Manufactures	1.33%

Thus, with the lowest assumed price of fuel, the increase in value of imports can be expected to be in the range of 0.5-4%, depending on a type of commodity.

A general conclusion regarding the estimated increase of the value of imports and consumer prices is such that the expected increase in prices is not high and with central assumptions regarding allowance price levels and price of fuel the prices are not expected to rise more than 3%.

12.3.6   Transaction costs

According to a broad definition, transaction costs include all costs other than the costs of abatement (related to technical or operational measures), which are borne by the project proponent and the units responsible for implementing the scheme (Betz, 2007). Transaction costs can be divided in two categories:
−   Costs for the market participants to comply with the scheme rules.
−   Costs of administration of the scheme.

These two categories of costs will be discussed separately in the subsequent sections. Quantitative assessment of transaction costs for the maritime shipping policies is very difficult because no such system exists so far. Betz (2007) reports that the total annual transaction costs of EU ETS in Germany are at the level of approximately € 0.35/t CO_2 reduced. This number is, however, only indicative.

12.3.7 Transaction costs for the market participants

Transaction costs for the regulated sector can be divided into two categories:

– Costs related to search for most cost-effective solutions to deal with emission reduction policies. These costs are the lowest for inflexible, command-and-control instruments such as standards because there is no need to look for solutions minimizing the costs of compliance. Economic instruments like emissions trading and taxes, on the other hand, by allowing flexibility, impose relatively high transaction costs on companies which get involved in active search for cost-minimizing techniques to reduce pollution. For example Hein and Blok (1994) report that search and information costs of energy-efficiency measures are between 3 and 8% of total investment costs. Emissions trading would probably result in the highest transaction costs of all policy measures. Flexibility in choosing the reduction measure would be the same as in case of taxes but the process of trading allowances would require more intellectual effort (i.e. also higher costs) both on the side of the ship operators and on the side of administration. Transaction costs of emissions trading for the market participants include the costs of researching the market, finding buyers or sellers, negotiating and enforcing contracts for permit transfers, completing all the regulatory paperwork, and making the payments. For small companies, costs of looking for options that would be cheaper than the price of allowances are relatively high, so that these companies can be expected to play a passive role and create additional demand for allowances even if cheap abatement options are available. Such a behaviour increases the equilibrium price of allowances and reduces the efficiency of the system. Implementing *'de minimis* threshold' may thus have an effect of improving efficiency of the scheme (Betz, 2007).

– Costs of monitoring. We assume that these costs will have to be borne by the ship owners. Monitoring of emissions in the context of CO_2 will be carried out by applying an emission factor to the fuel consumption. Therefore, in estimating costs for monitoring and reporting of CO_2 emissions, we can consider fuel consumption. Monitoring and reporting of fuel consumption is normal practice in the maritime industry. While not a legal requirement, the use of tank soundings or flow meters are utilized due to fuel bunkering, charterer party agreements or voyage management practices. This means that while the accuracy of this data might be in question the mechanisms for monitoring and reporting of emissions from an individual ship are already established and any costs associated with this would be limited to man power to establish practices to meet the requirements and increase accuracy of fuel consumption reporting. For more detailed assessment of monitoring options see section 6.10.

– Costs of enforcement. Enforcement of any EU action to reduce CO_2 emissions from International Shipping as would be flag neutral and enforced through port based state control for foreign flagged vessels and the Flag State Authority for vessels falling under national jurisdiction. These are already established systems across the EU and compliance and enforcement would become just another requirement under their inspection regimes. Therefore, as long as there are no major non-compliance issues, any increase in cost by the addition of another requirement can be considered minimal. Any potential significant costs

that could arise would be in relation to any detentions and legal challenges, which at this stage can not be quantified.

12.3.8 Implementation costs for public authorities

Administrative costs of various policy instruments for public authorities are triggered among others by such activities as the need to train the staff, hold public hearings on proposals, monitor emissions, and develop and implement strategies for managing non-compliance. For emissions trading there is also a need to establish the basis for the initial allocation, design the rules for trading and set-up the registry system.

Implementing and operating an *emissions trading scheme* requires an administration capable of issuing permits, operating registries, allocating allowances and managing new entrant reserves. Within the EU ETS, Member States have chosen different paths to finance their administrations. Most Member States recover at least some of the administrative costs of the trading scheme through fees and charges to operators, for services such as issuing allowances or the use of the registry. Fees and charges for the same service differ substantially between Member States. This is due to different approaches to cost recovery (EEA, 2008).

Fees for issuing and updating GHG emission permits are charged in ten MS while fifteen countries decided not to do so. In some countries, like the UK and Finland, the fees depend on the type/size of installation. In other countries, like Poland, operators have to pay a nominal fee (€ 20) for the issuance of the permits. The use of the registry is free of charge only in four countries (Cyprus, Estonia, Italy and Luxembourg). Twenty-two MS charge fees, often differentiated between operators and individuals. In some countries, the maintenance fee for operators depends on the allocation received by an installation.

Administrative costs of issuing permits and establishing/maintaining the registry in Germany are estimated at € 43.5 million for three years and it is expected that during the first trading period, approximately the same amount will be raised through the charges. Approximately 60% of the revenues is used for staff, 25% for the use of the software and the registry in the EU ETS, and 15% for material expenses. In the UK, in 2007, a total income of approximately € 3.5 million was generated from operators and registry account holders by the Environment Agency. The income was used to fund staff working on permits, monitoring plans, annual emission reports, registry administration, management and development of tools and procedures necessary for operation of the scheme.

For maritime shipping, it seems fair to device the same rules and to establish the same administrative fees for issuing and registry of allowances regardless of the flag of the ship or country of origin of the operator. However, the fees could be differentiated depending on a type and/or size of the ship, to give advantage to smaller ships for which such fees would constitute a relatively higher burden. For consistency and efficiency, one central institution would be recommended for administration and management of the scheme although this institution could have branches in several (port) states. A big share of administrative costs could be covered through charges and/or revenues from auctioning allowances.

In a *credit-based scheme*, reductions have to be verified/certified before credits can be traded. A separate institution has to be created in order to process registration, issue guidance documents, validate the credits and

establish a registry of projects. To give just an idea of the range of such costs, according to Marbek Resource Consultants (2004), one-time administrative costs of setting up a greenhouse gas offset programme in Canada were in the range of € 1.3-3.6 million Euro, and ongoing annual costs are in the range of € 0.7-1.2 million.

Another example of a programme which in its principles is similar to a credit-based mechanism is Clean Development Mechanism (CDM). In assessments of CDM, total transaction costs (thus including both the administrative costs and costs for the companies) are found to be in the range of € 0.3-0.7/t CO_2 for large projects and € 0.4-1.1/t CO_2 for small projects (Betz, 2007). The difference can be traced back to the economies of scale and the high proportion of fixed costs. It appears that transaction costs of baseline and credit schemes can be reduced by pooling small projects together. Also setting a threshold on size of transport work or emissions can help to avoid the situation where transaction costs exceed the welfare benefits of pollution reduction.

According to Tietenberg (2006), credit-based programmes seem to be characterised by higher transaction costs and administrative costs than cap-and-trade programmes. Credit-based programmes typically involve a considerable amount of regulatory oversight at each step of the process (such as certification of credits and approving each trade). In contrast, cap-and-trade systems rarely require either of the steps, instead using a system that compares actual and authorised emissions at the end of each year.

In case of the scheme based on technical standards (EEDI), verification of compliance would be relatively straightforward and the costs of verification would be low (type of technology used is described in documentation which every ship operator is obliged to keep).

In case of operational standards the costs of verification would be higher than for technical standards – both reporting data related to the operational index and verifying compliance would have to take place more often than for the technical standards, and the risk of unverified non-compliance would be higher. However verification costs could be imposed partly or fully on ship operators which would mean that these costs would not constitute a part of costs for public administration.

Administrative costs of imposing *a tax on CO_2 emissions* can be expected to be lower that the costs of an emissions trading system. Enforcement potentially can be through national tax regimes or local tax bodies such as customs, and additional costs of collecting CO_2 emissions taxes would be very low. In this case, probably no new institutions would have to be created and no new skills required from the personnel.

Environmental subsidies involve financial support by the government of environmentally desirable activities. The support can come in the form of grants, low-interest loans and other financial assistance for products with desirable environmental characteristics.

One way to provide subsidies would be to incorporate environmental criteria into current support programmes, notably subsidies for ship-building. Several such programmes operate within the EU. Making some of these subsidies contingent on environmental performance (such as a given emissions rate for ships built which may be expressed with an index value) could provide an effective incentive for emissions reductions without creating substantial

administrative costs. Other potential programmes that could be used for subsidies include EU-wide initiatives such as the 'Marco Polo' programme to relieve congestion on European motorways (the second phase runs in the period 2007-2013 with a budget of € 450 million). Such an option would require almost no additional administrative costs (only negligible costs related to introducing new criteria).

Another way to use the subsidy option is to make it additional to the primary instrument such as emissions trading or a tax (if it is not revenue-neutral). The revenues collected through such an instrument could be used (partly or fully) to provide support for all ships or only for the selected types/sizes of ships and to finance administration of such a programme.

12.3.9 Conclusion

An emissions trading scheme or an emissions tax adds to the voyage costs of a ship. The impact depends on the other cost items, of which fuel is probably the most important. These items vary for various ship types and sizes. Under the assumptions of fuel prices, allowance prices and tax rates used throughout this impact assessment, we find that for six different ship types, total costs increase by 8-17% and operational costs by 16-23%.

It depends on the market circumstances whether these costs can be passed through. When demand for shipping is high, freight rates are well above operating costs as they are determined by marginal demand. Since demand will not change when shipping is included in an emissions trading scheme or an emissions tax is levied, freight rates will not change. Hence, in these circumstances costs are borne by the shipping companies, leading to lower scarcity rents and thus lower profit margins. Conversely, when demand for shipping is low, freight rates are set by marginal costs. These change when the policies are implemented. So in such a situation, the costs will be passed on to the shipper and ultimately to the consumer.

In circumstances where costs are passed through, we estimate import values to increase by 0.4 to 2.66% under the assumptions used throughout this impact assessment. The highest increase in value is expected for raw materials (because a relatively high share of the value of these goods can be attributed to maritime transport costs), and the lowest for crude oil. Impacts on consumer prices are smaller because of value added in the importing country, which is not affected by a climate policy for maritime transport.

The administrative burden on ship owners of the emissions trading scheme, the emissions tax and the baseline-and-credit scheme all mainly stem from the requirement to verify data that is already routinely monitored. It is hard to calculate an accurate cost figure. However, comparing with current CO_2 certification practices the costs would be expected to be less than US$ 10,000 (approximately € 6,700) per ship.

12.4 Impacts on modal split

12.4.1 Introduction

The objective of this section is to investigate the potential shift away from short-sea shipping in Europe that might result from addressing CO_2 emissions from maritime transport. The analysis departs from the assumption that maritime shipping will be included in the EU ETS or subject to an emissions tax. It is also assumed that the resulting cap and trade scheme or the tax will cover emissions from journeys between European ports, including ports in EEA

countries and countries that candidate for EU membership. Whether the scheme will also cover emissions from transoceanic shipping is disregarded in this section as it would have little impact on short-sea shipping.

The four main questions that this section will attempt to answer are:
1 What are the factors currently affecting mode choice?
2 Which routes and market segments in shipping are most susceptible to modal shift?
3 What are the factors driving and limiting modal shift?
4 How can climate policies for shipping or other transport policies be used to reduce the risk of modal shift?

It should be recognised that access to price information is often limited as freight contracts and other relevant figures are generally not in the public domain. As a result, part of the assessment is more qualitative than quantitative.

12.4.2 Trends in European shipping

The demand for goods transport by land-based modes in the EU-27 was 2,595 billion tonne-kilometres in 2006. Road accounted for 72.7%, rail for 16.7%, inland waterways for 5.3% and oil pipelines for the remaining 5.2%. When intra-EU maritime and air transport are added to the land modes, then the share of road reduces to 45.6%, rail accounts for 10.5%, inland waterways and oil pipelines contribute respectively 3.3 and 3.2%. Maritime transport then accounts for 37.3% and aviation for 0.1% of the total.

Intra-EU transport by ships is estimated to have produced around 1,545 billion tonne-kilometres in 2006, an increase of close to 400 billion tonne-kilometres since 1995. While the overall growth of freight transport was 35.3% between 1995 and 2006, shipping grew by 34.3%. This corresponds to a minor loss of market share (down from 37.6 to 37.3%). This, however, may not reflect any long-term trend. Between 1995 and 2005, the share of shipping rose from 37.6 to 38.1% with a peak in 2001 (38.8%). The average annual growth was 2.7% for shipping compared to 2.8% across all modes.

The volume of freight transport by road and air rose significantly faster, by respectively 3.5 and 3.8% per year, while the annual growth of goods transport by rail and inland waterways was respectively 1.1 and 1.2%. The market shares of latter thereby fell to 10.5 and 3.3% (down from 12.6 and 3.9% in 1995).

The share of shipping in intra-EU passenger traffic is small. In 2006, ships accounted for 0.6% of the passenger market, measured as passenger kilometres (down from 0.8% in 1995).

The view on what should be regarded as short-sea shipping varies among experts (Paixão and Marlow, 2002). Some prefer to use ship sizes for drawing a line between the various types of shipping. However, for the purpose of this section it appears rational to consider any ship used for intra-European sea transport as contributing to short-sea shipping and regardless of whether it operates in the pure intra-European market, in feeder traffic or is used for cabotage.

Figure 44 shows the most important short sea shipping routes in the EU. The most important routes in terms of cargo mass are domestic routes in the UK, Italy and Spain. Domestic traffic in Greece, France, Denmark and Sweden is also large. Routes to and from the UK are also among the major routes in terms of cargo mass.

Figure 44   Main routes in intra-EU maritime transport 2005

RANKING	country of loading port	country of un-loading port	mio tonnes trans-ported
1	UK	UK	96.1
2	IT	IT	78.3
3	ES	ES	50.4
4	UK	NL	36.6
5	EL	EL	32.4
6	UK	FR	26.1
7	FR	UK	25.6
8	NL	UK	23.7
9	FR	FR	20.0
10	SE	DE	17.5
11	UK	DE	16.3
12	UK	BE	15.4
13	DK	DK	14.5
14	BE	UK	13.0
15	UK	IE	12.9
16	IT	ES	12.9
17	DK	SE	12.7
18	SE	SE	12.7
19	DE	SE	11.9
20	FI	DE	11.5

Source: EU ENERGY AND TRANSPORT IN FIGURES.
STATISTICAL POCKETBOOK 2007/2008, Brussels: DG TREN.

Cargo transported in short sea shipping is very diverse and varies from country to country. Consider for example the UK and Sweden in Table 75. In the UK, 38% of maritime imports in its main ports was from EEA countries in 2007. 53% of exports from the UK were destined for EEA countries. In Sweden, the figures were 76% of imports and 81% of exports. In both countries, liquid bulk

and RoRo imports dominate in short sea shipping. Especially RoRo can be considered to be sensitive to modal shift, as this cargo is already often on trucks or trailers.

Table 75   Importance of short sea shipping for imports of various commodities, UK and Sweden, 2007

UK (2007)		Sweden (2007)	
Import category	Quantity (1,000 tons) (share of imports in this category from EEA countries)	Import category	Quantity (1,000 tons) (share of imports in this category from EEA countries)
Liquid bulk -- Crude oil	40,181 (12%)	RoRo, mobile self-propelled units	15,291 (100%)
Liquid bulk -- Refined oil products	30,716 (41%)	Liquid bulk -- Refined oil products	14,005 (81%)
RoRo, mobile non-self-propelled units	30,478 (78%)	Liquid bulk -- Crude oil	10,266 (48%)
RoRo, mobile self-propelled units	30,060 (82%)	RoRo, mobile non-self-propelled units	7,879 (88%)
Dry bulk -- Other dry bulk goods	27,999 (32%)	Dry bulk -- Other dry bulk goods	6,177 (88%)

Source: Eurostat: Maritime transport - Goods - Quarterly data - Main ports - Detailed data for United Kingdom; Maritime transport - Goods - Quarterly data - Main ports - Detailed data for Sweden.

Intra-EU shipping accounted for 112 Mt of CO_2 emissions in 2006. This is 36% of CO_2 emissions from ships sailing to and from EU harbours.

12.4.3   Short sea shipping compared to other modes

In general, shipping is more energy-efficient than road transport. However, this is not necessarily true for all types of short sea shipping. Smaller vessels and vessels operating at high speeds (e.g. ferries) may have an energy consumption that is equivalent to trucks and trailers. So in some cases, the additional greenhouse gas emissions due to a modal shift may be small or even zero.

Figure 45 shows an example of emission estimates for the Netherlands (CE, 2008). The figures for both bulk and containerised traffic show that small ships are less efficient than trains and that their CO_2 emissions are in the same order of magnitude as trucks with trailers. The efficiency of ships increases with their size.

Figure 45   CO$_2$ emissions of different transport modes
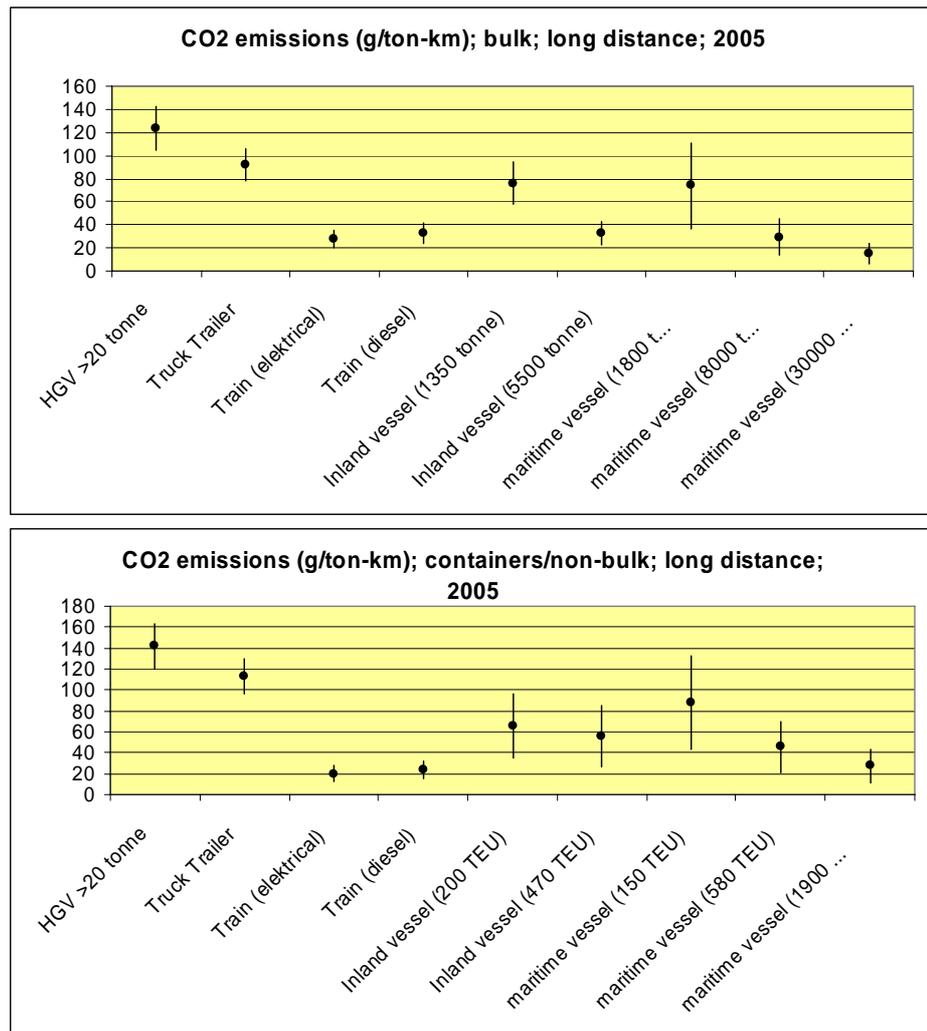
Source: CE, 2008.

12.4.4   Factors affecting mode choice

Europe, being a peninsula on the Euro-Asian mainland, is in a good position to use ships for freight transport. It has long coastlines along the Mediterranean Sea and the North-East Atlantic as well as coasts along the Baltic Sea and the Black Sea. Nearly a hundred million of its inhabitants live on islands, and most of its industrial centres and major cities are located within 100 to 200 km of the coast.

Short-sea shipping has the advantage over land based transport of requiring less investment in infrastructure. It is also a way of avoiding or reducing congestion.

Many factors affect the customers' choice of freight transport mode. Baumol and Vinod (1970) consider four to be of prime importance: shipping cost per unit, mean shipping time, variance of shipping time and carrying cost per unit of time while in transit. In more elaborate models other factors are also significant, and anecdotal evidence suggests that in some cases factors such as rest times for truck drivers affect the choice for the inclusion of a sea leg.

In general, trucks have an advantage over competing modes of providing high flexibility, door-to-door services and often good predictability and little risk of cargo being lost or damaged. Road transport also provides for the frequent departures/deliveries on a regular basis required for time-based logistics strategies. The back-side of the coin is cost, which explains why trains, barges and ships mainly attract high-volume and low value goods.

As an example, consider Spanish exports to North-West Europe. Garciá-Menédez et al. (2006) find that routes involving short sea shipping take twice as long but the costs per tonne kilometre are considerably lower. As a result, they find that low-value added products are often transported over sea, while high value-added products are often transported over land.

It is important to note here that of all the factors that affect mode choice, the inclusion of shipping in the EU ETS or an emissions tax only affect the costs of maritime transport (and hence its price).

12.4.5 Routes and market segments susceptible to modal shift
Evidence on price elasticities of demand can show which routes and market segments are most susceptible to modal shift.

A number of studies have found that demand for inland shipping is quite elastic. Beuthe et al. (2001) estimate the price elasticities for inland shipping in Belgium to be between −1.3 for longer distances and −2.6 for shorter distances. Oum et al. (1990) found that the demand for inland shipping of coal is inelastic, while demand for inland shipping of wheat and oil is much more elastic. Van den Bossche et al. (2005) find that in the Netherlands, demand for domestic general cargo and container traffic is elastic (-1.0 and -1.1 respectively) while demand for dry and wet bulk is inelastic (-0.5 and -0.7). International inland shipping is less elastic for general cargo and containerized cargo (-0.9 and -1.0) and more elastic for dry and wet bulk (-0.7 and -0.8).

These elasticity estimates are not cross-elasticities and can therefore not be taken as perfect indicators of modal shift. They do show clearly that bulk transport over water is much less price sensitive than containerized traffic. It is reasonable to assume that this is at least partly so because it is easier to shift a container from a ship to a truck than to do so with coal, ore or liquid bulk.

While these studies focused on inland shipping, the same may apply to short sea shipping. In Australia, the price elasticities of domestic shipping are estimated to be -0.8 on average, much higher than the price elasticity of international shipping (Bureau of Transport and Communications Economics, 1990).

In summary, these studies suggest that containerized traffic over short distances is most susceptible to mode shift, while bulk cargo transported over longer distances is less susceptible.

While there is scant evidence on cross-price-elasticities, it seems reasonable to assume that the higher price elasticities of containerized cargo are due to competition with other modes of transport, such as rail and road transport. Similarly, for short distance transport, more transport alternatives may be available than for long haul transport.
In some cases, e.g. transport to and from the UK, modal shift may not entail bypassing waterborne transport completely but reducing the distance of the

waterborne leg. CE Delft and Resource Analysis (2008) identify four possible routes from Brussels to Norwich with a maritime leg between 30 nautical miles (Calais-Dover) and 280 nautical miles (Zeebrugge-Immingham). Such routes may be even more susceptible to modal shift as they all comprise of a land-leg and a waterborne leg, so in terms of equipment demand and also travel times they are very similar.

Owing to the high volume and low value characteristics, the bulk market already fully exploits the possibilities of cost-effective sea transport (Becker et al., 2004). To substitute a medium-size sea carrier by road transport may require hundreds of trucks. Small changes in overall cost are therefore not likely to make bulk cargo-owners change to another mode.

RoRo shipping competes with road transport on short distances for reasons of physical geography and cost, while LoLo services make better sense over longer distances. Where RoRo is concerned, hauliers and cargo owners may have an opportunity to choose between several ports and are thus given a chance to influence how much of a journey that will be on the sea. Regulations on rest times and the need for drivers to sleep sometimes make a longer journey by RoRo ferry a winning concept, while on shorter trips where the voyage time is too short to cover a sufficient sleeping period, hauliers often choose non-accompanied trailers.

12.4.6 Factors driving or limiting a shift from shipping to land based modes

In order to understand the potential for a shift away from short-sea shipping it is essential to have a medium to long-term perspective. If maritime emissions of CO_2 become subject to a cap in 2013 it will take a while for the market to adjust to the new situation. A large immediate shift from one mode of transport to another is unlikely for several reasons, among them:

- The relative low cost of freight transport, and in particular of transport by sea.
- The influence of long-term contracts.
- Short-term capacity restraints involving rolling stock and crew and in some cases also infrastructure.
- The short-term opportunity for shipping companies of setting freight rates based primarily one variable costs thus disregarding sunk capital costs.

However, some freight customers may turn out to be more price-sensitive than others and some of them may react instantly and begin to prepare themselves for the day when the trading scheme will be launched. In calculating the potential price of future alternatives these customers will have to make assumptions on the development of a number of parameters that may influence total cost. One of them concerns the future price of emissions allowances, another the extent to which shipping companies will find ways of improving efficiency in order to be able to run vessels on less fuel. The cargo owners will also have to guess on the future prices of crude oil, bunker fuel and road fuels. As nothing of this is easy and the risk of miscalculating is large, most freight customers will probably wait and see before they take any decisions on changing habits due to the effect on freight prices of introducing a cap on CO_2 emissions from maritime shipping. It may thus take up to ten years before it is possible to fully assess the impact of emissions trading on modal split.

Of great importance in such a context is that during this period of time lots of other changes will occur, some of which may have as significant an impact on inter-modal competition as the requirement to participate in an effort to combat climate change. In this section, we focus on the relative prices of rail, road and water transport, as these are affected by the climate policy for shipping. We acknowledge that other developments, such as the implementation of the revised MARPOL Annex VI, or the extension of road tolls, may have a larger impact on the modal split, but these are not affected by the instrument choice in climate policy for shipping.

12.4.7 Factors related to climate change mitigation

Insofar as rail transport is electrified, it is already subject to climate change policies as the power sector is included in the EU ETS. The price of the electricity consumed by trains is affected by the cost to the trading sector of remaining within the cap. In a deregulated market, power generators try to pass on the marginal cost of production to all customers, and production in coal fired power stations is generally used to meet increased demand. The marginal cost does also affect costumers who purchase their electricity from hydro, wind or nuclear sources. An emission price of € 30/tonne CO_2 will raise the cost of electricity by up to €cents 2.4 per kWh compared to the situation before the cap was introduced.

Diesel trains and road transport are currently not included in the EU ETS. A main reason for not wanting to extend emissions trading to CO_2 emitted from road vehicles has been a fear that the inclusion of the transport sector in the EU ETS would make the price of emission allowances rise to a much higher level then would otherwise have been the case. A high price is feared to give energy-intensive European industries difficulties in competition with similar industries located to countries that do not implement similar climate policies.

Keeping road transport outside the EU ETS and launching an emission trading scheme for maritime transport that is openly linked to the EU ETS (or is a part of it) means by definition that the marginal cost of contributing to climate change mitigation will differ between the two modes. However, excluding road transport from the ETS does not mean that it will not have to contribute towards the climate change objectives of the Community. In fact, given the significant share of transport emissions in total emissions and the commitment to reduce emissions by at least 20% in 2020, it is likely that the EU and/or its Member States will implement climate policies for road transport. It is unavoidable that these policies will raise the costs of transport, thus potentially shifting transport to maritime.

12.4.8 Price increases induced by climate change policies

Due to their enormous loading capacity large ships have low costs for crew and capital compared to road and rail transport when counted per tonne-kilometre. The first table, taken from Kågeson (2008), illustrates the approximate cost of fuel and electricity in the various types of transport including current excise duties. The large variations within some modes of transport are the results of differences in capacity utilisation, costs of manning and capital, and choice of design speed. A passenger and car ferry, for example, has much higher capital and crew costs than a container ship of equal size, and in addition higher port dues. These figures, though, may differ somewhat between Member States due to variations in factor prices and taxation.

Table 76 The approximate share of fuel and electricity costs in various types of transport including current excise duties (excluding VAT)

Type of transport	Share of fuel and electricity costs (%)
40 ton long-distance truck (2007)	31
Delivery truck (2007)	12
Freight train (2007)	10
General cargo vessel, 3,000 DWT (2007)	7
Container ship, 9,300 DWT (2007)	25
Bus (2005)	15
Passenger train (2007)	5
Car and passenger ferry, 3,000 DWT (2007)	6
Traditional airline (medium-haul)	17
Budget airline (medium-haul)	20-30

Sources: The Swedish Association of Road Haulage Companies, the Swedish Taxi Association, the Swedish Bus and Coach Federation, SJ, Green Cargo, SAS, Ryanair, Easyjet, Air Berlin and Lloyd's Register Fairplay.

In Table 77, it is assumed for the sake of simplicity that all four modes are part of the EU ETS (or linked to it). It is also assumed that rail transport purchases electricity on a deregulated market where producers, at least in the long run, may shift the marginal costs of emission allowances on to their customers. The fact that road fuels are heavily taxed explains the limited additional effect from participating in the EU ETS.

Table 77 Approximate effect on fuel and electricity prices of the transport sector's participation in EU ETS when the market price is € 30 tonne CO_2

Type of transport	Percentage increase in fuel cost
Diesel-fuelled road vehicles*	7.5
Electrified rail transport	45.0
Container ship	22.3
Ferry	21.3
Aviation (traditional airline)	20.5

* Major customers, September 2007.

'Current cost' for rail transport estimated prior to the establishment of the ETS.

Table 78 shows the approximate effects of participating in the EU ETS on the average total cost of various transport alternatives.

Table 78	The approximate marginal effect of CO_2 emissions trading at €30 per tonne on the total costs of different types of freight and passenger transport

Type of transport	Percentage increase in total cost (%)
40 tonnes long-distance truck (2007)	2.3
Delivery truck (2007)	0.9
Freight train (2007)	4.5
Container ship, 9,300 DWT (2007)	5.6
Taxi (diesel) 2005	0.5
Bus (2005)	1.1
Passenger train (2007)	2.3
Car and passenger ferry, 3,000 DWT (2007)	1.3
Aviation (traditional airline, medium haul)	3.5

Source: Kågeson, 2008.

Under equal treatment (all modes under the same emissions cap) the percentage increase on overall costs would be greater for some types of shipping than for long-distance trucks. However, as discussed above, one of the reasons not to include road transport in ETS is that this would raise prices. So in order to achieve a reduction of emissions from road transport, higher tax raises would be needed than the equivalent of € 30 per tonne of CO_2.

The conclusion on costs related to climate change mitigation is, despite a considerable uncertainty concerning some key parameters, that the participation of short-sea shipping in a scheme for CO_2 emissions trading is not likely to cause any significant and maybe not even a noticeable shift to land-based modes. It should in this context also be kept in mind that the revenues from higher taxes on road fuels will not be recycled to the hauliers.

It may be relevant to study the impact on inter-modal competition under varying assumptions about the price on crude oil. Given the importance of petroleum products in the European energy mix, crude oil prices and the price of carbon to some extent act as communicating vessels. As a high price on oil depresses demand, the climate change objectives of the Community can be achieved at a lower price on CO_2 allowances compared to a situation when petroleum is relatively inexpensive. This means that the potentially negative effect on short-sea shipping from being part of an emissions trading scheme would be less pronounced compared to a situation of low oil prices. However, the cost of fuel, including the purchase of emission allowances, would be roughly the same. The difference lies in the fact that the governments of importing countries have little chance of influencing the world market price on crude oil.

Another aspect of a high crude oil price is that the chance that EU governments will manage to raise fuel excise duties enough to reach the reduction target for emissions from the non-trading sectors would be greater then in a case of low oil prices (when taxes would have to be raised a great deal more). The risk for a large gap in incremental abatement cost between the trading and the non-trading sectors may therefore be smaller at high crude oil prices than with low. If this is correct, it will be somewhat easier for the shipping sector to compete with road transport under high oil prices.

12.4.9 Conclusion: The impact of climate policy for shipping on modal shift

- Modal shift is confined to transport routes where alternatives via other modes exist. If it will occur, it will most likely occur in unitised short sea shipping, including RoRo and LoLo. For intercontinental shipping other modes of transport hardly exist, while elasticity estimates of short sea bulk transport suggest that these are not very sensitive to price, which this section interprets as being caused by little competition with other modes of transport. Model results estimate unitized (Container, RoRo and General cargo) intra-European shipping to account for 77.6 Mt of CO_2 in 2006 (39% of total emissions intra-European emissions and 21% of all emissions on voyages to and from Europe).
- Modal shift may result in higher emissions in some cases, yet this need not be true in every case. Small vessels (up to approximately 1,800 DWT) have emissions that are comparable to road transport and higher than emissions of rail transport. So modal shift only results in higher emissions on routes where relatively large ships compete with road transport.
- On routes where unitised cargo is transported and relatively large vessels compete with road transport, modal shift may occur if road and rail transport are not subjected to cost increasing climate policies or if the cost increase per unit of CO_2 emissions is the same as in maritime transport. If the cost increase in road and rail transport is higher than in maritime transport, modal shift in unlikely to occur, or may occur in a way that increases the share of maritime transport.

12.4.10 How can climate policies be designed to reduce the risk of modal shift?

If mode shift is considered to be a serious risk, it might be of interest to look at possible exemptions or thresholds in the climate policy for shipping for the operations most susceptible to modal shift. However, the idea behind economic policy instruments is to allow the market to take care of an environmental problem at the least possible cost. Any derogation therefore comes at the price of a higher overall abatement cost. It may thus be better to look at supplementary measures aimed at improving the competitive strength of short-sea shipping.

In two papers, Paixão and Marlow (2002 and 2005) discuss the weaknesses (and the strengths) of short-sea shipping. They find one problem to be that, with the exception of liquid and dry bulk cargoes that are often delivered to dedicated and private terminals, short-sea shipping cannot offer door-to-door transport services. Unlike channel distributors most short-sea operators have focused on port-to-port deliveries rather than door-to-door services. According to Paixão and Marlow, this has prevented them from exercising control over cargo flows, from gathering information about other modes, and from becoming freight integrators. They say that the shipping market is 'characterized by a low brand image derived from poor marketing management'.

Another problem is the amount of paper work required. A study by the European Commission (1998) demonstrated that the documentary procedures required for road transport are far less than the ones enforced on short sea shipping. The documentation compulsory for the latter can, according to Paixão and Marlow, be classified into five different groups; navigation control, cargo operations, reporting in and clearance outwards, checks on ship safety, and cargo declaration and clearance.

A problem in the context of short-sea shipping and hinterland distribution by barges is that there is a strong tendency in the port industry to lease or sell terminals to large companies that, for commercial reasons, give priority to large capacity users. This translates to delays in berthing for smaller vessels that may have to wait for hours. According to Comtois and Slack (2007), this is particularly problematic for container feeder services. This problem is also mentioned by the European Commission in a recent port policy consultation. High port dues are also causing problems for short-sea shipping.

To promote the use of short-sea shipping, the Port Authority of Antwerp has modified the port dues so that they no longer form a significant part of the total transport cost, with discounts for regular short-sea services. The proportion of freight carried by barge in the Port of Antwerp is growing rapidly, with container freight in the lead. Nearly one third of the container volume passing through Antwerp now travels by barge.

Noticeably the short-comings of short sea shipping fall into two categories, one that concerns marketing and business strategies, and another that has to do with infrastructure. While governments and the EU presumably can do little to assist the industry in the former case, they can make a difference when it comes to infrastructure and conditions in port. They may contribute towards more fair conditions for short sea shipping in ports and help create better and more efficient terminals that can cut hours at berth and reduce overall costs. Improved use of IT is also relevant for shortening delivery times and improving capacity utilisation. This would also be a way of compensating ships and ship owners that due to increasing costs for fuel may have to slow down and need to increase the round frequency by other means. Spending part of the revenues from auctioning CO_2 allowances to the shipping sector on such improvements may be a better strategy than offering exemptions from the cap and trade scheme.

13 Other impacts

13.1 Introduction

This chapter assesses the impacts of climate policies for maritime transport on islands, least developed countries and landlocked regions (section 13.2) and on tourism (section 13.3).

An assessment of the macro-economic impact of the policies or an assessment of the impact on trade flows was not possible within the scope of this project. In principle, such an assessment can be made by employing a general-equilibrium model or an econometric model. Steps were undertaken in this project to employ GEM-E3, but the calculations couldn't be concluded within the proper timeframe.

13.2 Impacts on islands, least developed countries and landlocked regions

13.2.1 Introduction

EU policies addressing emissions from maritime transport can affect third countries in different ways. On the one side transport costs are likely to rise slightly which might adversely affect national economies, especially in countries heavily dependent on maritime transport. On the other side reduced greenhouse gas emissions from shipping will reduce the negative impacts of climate change and might spur innovation and efficiency enhancements in the shipping sector. According to chapter 3.2 about 33% of the business-as-usual emissions in 2030 could be abated cost-effectively; EU legislation would likely raise awareness and knowledge of actors in the shipping sector and help utilising this potential. This would not only reduce emissions within the scope of any EU policies but reduce fuel consumption and associated costs worldwide due to the global nature of the sector. These positive effects are hard to quantify and will not be further assessed. Possible negative economic consequences will be assessed for the example of small island developing states, least developed countries and landlocked developing countries. These three country groups might be affected most due to their specific geographic locations as well as their sizes and economic potentials. The impacts will be assessed for exports of these countries to the EU-27, imports from the EU-27 as well as imports and exports under three different impact scenarios.

13.2.2 Impacts on trade with the EU-27

The United Nations identified small Island developing states (SIDSs), least developed countries (LDCs) and landlocked developing countries (LLDCs) as countries in need of special support from the international community (UN-OHRLLS, 2009):

- SIDS share similar sustainable development challenges, including small population, limited resources, remoteness, susceptibility to natural disasters, vulnerability to external shocks, and excessive dependence on international trade. Their growth and development is often further stymied by high transportation and communication costs.
- LDCs represent the poorest and weakest segment of the international community with extreme poverty, structural weaknesses of their economies and the lack of capacities related to growth.

– LLDCs countries are generally among the poorest of the developing countries, with the weakest growth rates, and are typically heavily dependent on a very limited number of commodities for their export earnings. Their sea borne trade unavoidably depends on transit through other countries.

The selection of these groups for the assessment of potential negative impacts of EU maritime policy on third countries ensures that the analysis is based on the most vulnerable countries. In addition, many of the countries in these groups have geographically remote locations. Impacts on other developing and developed countries are expected to be smaller.

The recommended scope of EU policy is emissions of ships travelling to EU ports between port of laden and arrival in the EU. From this follows that imports from the EU by third countries would only be affected indirectly if at all, e.g. if goods from a non-EU country would be shipped via an EU harbour. Despite this other scopes are discussed in this report and the analysis therefore assesses three different trade flows: imports from the EU-27, exports to the EU-27 and the sum of im- and exports. Table 79 gives an overview of the relevance of maritime trade with the EU for the three country groups as well as for all countries worldwide. It can be seen that for the three country groups maritime trade with the EU is about twice as important as for the global average.

Table 79   Overview of maritime exports between different country groups and the EU (average 2000-2008 values)

	GDP (billion €)	Maritime imports from EU-27		Maritime exports to EU-27		Maritime imports & exports	
		Billion €	% of GDP	Billion €	% of GDP	Billion €	% of GDP
SIDS	251.0	14.6	5.8%	8.0	3.2%	22.5	9.0%
LDC	383.3	13.7	3.6%	16.0	4.2%	29.7	7.7%
LLDC	304.9	4.0	1.3%	17.9	5.9%	21.9	7.2%
All countries	31 105.4	543.1	1.7%	727.1	2.3%	1 270.2	4.1%

Sources: Eurostat, 2009; IMF, 2009; own calculations.

Note: Due to data gaps the table only includes information from 31 out of the 51 SIDS, 45 out of the 49 LDCs and 28 out of the 31 LLDCs. 150 countries are included under 'all countries'.

For the assessment of potential economic impacts on third countries several assumptions have to be made for the year 2030:
– The fuel price.
– The carbon price, the level of a tax or a similar instrument which increases the costs of fuel use.
– Shipping efficiency improvements.
– Share of emissions within the scope of any EU policy.
– Fuel costs compared to the overall costs of operating a ship.
– Freight costs compared to the product value.
– The elasticity of demand.

As none of these parameters is known three different scenarios have been calculated representing a lower, upper and middle estimate of possible impacts (Table 80). All of these parameters have been chosen to reflect the

possible range and are set mainly independent of each other; especially the high impacts scenario is most likely a strong overestimation of potential effects (see below). A high impact scenario signifies that the effect of climate policy has a high impact on the sector, i.e. a low fuel price together with a high carbon price to mention two parameters.

Most of the assumptions (fuel prices, carbon prices, efficiency improvements and elasticity of demand) are the same as in other sections of this report. In addition the following assumptions have been made:

- Due to the small absolute quantity of exports there will be very limited direct shipping between EU ports and SIDSs, LDCs or LLDCs if at all; in most cases cargo will be transhipped at least once to larger vessels. Only emissions of the last ship which unloads the cargo in an EU harbour would be covered by a scheme; for an accurate calculation of economic impacts information on actual trade routes would be necessary which is not publicly available. In this calculation a range of 40 to 80% of total carbon emissions are assumed to be within the scope of EU policy.
- Transport costs compared to product value vary wildly; they have been taken from UNCTAD (UNCTAD, 2007; UNCTAD, 2008).

Table 80   Overview of the different impact scenarios

	Parameter	Unit	Impact scenario		
			Low	Medium	High
Input	Fuel price	(US$/t fuel)	1,050	700	350
	Carbon cost	(€/t CO_2)	22	55	100
	Shipping efficiency improvement	(%)	45%	33%	23%
	Share of emissions within the scope	(%)	40%	60%	80%
	Fuel cost compared to overall costs	(%)	50%	40%	30%
	Transport costs compared to product value	(%)	30%	8%	4%
	Elasticity of demand	(-)	-0.2	-0.3	-0.8
Calculation	Price increase of fuel combustion	(%)	3.6%	20.0%	97.1%
	Price increase of transport costs	(%)	1.0%	5.4%	22.4%
	Price increase of end user goods	(%)	0.3%	0.4%	0.9%
	Change of exports	(%)	-0.2%	-1.6%	-17.9%

Note: The low impact scenario signifies that the additional effect of policies addressing greenhouse gas emissions from shipping is small, i.e. in a world with high fuel prices and low carbon prices. Despite this, the sector would have lower total costs in the high impact scenario because the overall cost for fuel and carbon is lower than in the low impact scenario.

Source: Own calculations.

Using these values the impacts on national economies of SIDSs, LDCs and LLDCs can be estimated (Figure 46). In the low and medium impacts scenarios any adverse effects on GDP would be below 0.2% for these country groups. Only in the high impacts scenario potential reductions in maritime trade with the EU would exceed 0.2% of the GDP. Overall there is little difference between the country groups, especially if imports & exports are used for the assessment basis. Despite this it can be noticed that SIDSs have a negative maritime trade balance with EU Member States whereas LLDCs export more by shipping to the EU than they import.

All scenarios overestimate potential adverse effects:
— The assessment presented here assumes a static world and does not take any adaptation into account. In reality affected countries would adapt to rising transport costs, e.g. by restructuring their economies or increased exports to non-EU countries. General equilibrium models are one tool to examine such effects but are outside the scope of this assessment.
— The elasticity for ocean shipping used for this study is -0.1 to -0.3 for dry and liquid bulk carriers and 0.0 to -1.1 for general cargo and container transport. Using an elasticity of -0.8 assumes that a very large share of exports are done through the latter ship category.
— The elasticities given are for transport service demand and not for exports. Transport service could be reduced without reducing exports, e.g. through better logistics.
— UNCTAD calculated the freight price as percentage of value of transported cargo for eight different goods – routes combinations. Out of these, the percentage is six times below 7% and one time at 13%. Only for jute transported from Bangladesh to Europe the freight costs represent 44% of the value of the good. A national average share of 30% is very high and not realistic.

Due to practical questions the recommended scope of an EU regime is limited to trips to the EU (chapter 6.3), i.e. exports from the three country groups. Based on the considerations above the expected negative effects for most countries outside the EU would be below the medium scenario for exports, i.e. well below 0.1% of GDP. For all other regions in the world the impact would be even less: the higher developed a country the lower the share of transport costs compared to product value. The closer a region is to Europe the lower would be the additional carbon costs compared to the product value. Even for SIDSs, LDCs and LLDCs the average price increase for end-users in European countries is below 0.4% in the medium scenario. Such a small figure is not likely to influence trade patterns or investment decisions in these countries. For comparison, the impact compared to GDP for the medium impact scenario, exports to the EU, would be 0.0% for Australia and the United States and 0.1% for the People's Republic of China.

Figure 46   Impacts on GDP in LDCs, LLDCs and SIDS under three different scenarios
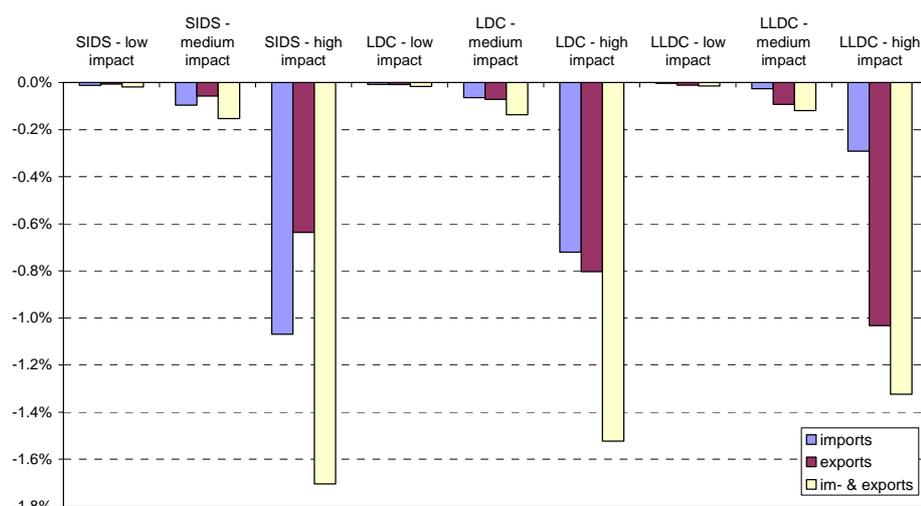
Source: Own calculations.

13.3   Impact on tourism

Tourism industry around cruise ships can be an important source of income for some island states, especially in the Caribbean. Increased prices for fuel use due to carbon costs could adversely affect such cruises. Typical cruise ships consume 300 to 500 g of fuel per passenger kilometre, i.e. emit about 900 to 1,500 g CO_2/pkm (Seum, 2009). During a typical 7-day cruise in the Caribbean costing between € 500 and € 5,000 the vessel covers about 1,400 km. Using the medium impact scenario for carbon price and fuel efficiency improvements the extra costs per passenger and cruise would be around € 50 to € 80. Despite this it is not likely that EU policies would affect cruise shipping to SIDSs and LDCs as there are very few cruises which would be within the scope of EU action. Most cruise ships do not cross Oceans on a regular basis but do shorter trips within a region where they operate.

For cruises which land at EU ports the picture is quite different; such trips would be within the scope of EU legislation. Cruise tourism in Europe causes about 7.2 Mt CO_2 per year (Policy Research Corporation, 2009). Cruises in the Mediterranean emit 71% of the total quantity, 13% in the Atlantic Ocean and 10% in the Baltic Sea (ibid.). The North Sea and the Black Sea only contribute with 5% and 0% respectively to total emissions. While there is limited possibility to evade EU waters and ports in the Baltic and the North Sea, cruises in the Mediterranean and the Atlantic Ocean could in principle change their itineraries to reduce operation within the scope of EU action.

To assess possible impacts the same assumptions as above have been made. A typical cruise in the Mediterranean lasts 8 days, covers 3,000 km and costs between € 950 and € 3,000 (Seum, 2009). EU maritime climate policy could increase cruise prices by € 100 to € 170 or 3 to 18% in 2030. Especially an 18% cost increase could in principle lead to strategic behaviour by operators to evade the scope of EU policy.

When considering changing cruise destinations, a cruise line would have to balance the price of the cruise to the attractiveness of the destinations. currently, cruise lines seem to visit ports of cities that are attractive tourist destinations (see examples below). Limiting the cruise to destinations outside the scope of an EU climate policy may be less attractive for tourists.

Source: Holland America Line.

Source: MSC cruises.

Source: Norwegian Cruise Line.

Whether or not cruise lines will change their destinations, the costs of cruises within the geographical scope of an EU policy would increase. If this cost increase were to be passed through in prices, it could lower demand. This would not be primarily due to the own price elasticity of demand, as most studies find tourism demand to be price inelastic (price elasticities of -0.4 to -0.8, although there are notable exceptions) (Crouch, 1994). More important is the choice tourists face: cross-elasticities in tourism demand seem to be high (Maloney and Montes Rojas, 2005), implying that demand shifts easily from one destination to another.

Hence, including cruises in an EU policy could change the choice to go on a cruise or spend a holiday at an alternative accommodation on land, the choice to take a cruise in the Mediterranean or in another region of the world, et cetera. It could marginally reduce the cruise activity relative to an increasing baseline and marginally increase tourism activity on land.

13.4 Conclusions

The assessment has shown that impacts for small island developing states, least developed countries and landlocked developing countries will be low to very low under realistic assumptions. Only under very specific circumstances could EU policy addressing emissions from international maritime transport affect these countries in a noticeable way. Despite this, the effect for individual countries with specific circumstances might be higher.
EU maritime climate policy is not expected to adversely affect cruise shipping in developing countries. Cruise activities in the Mediterranean could be affected, however, and the climate policy could induce a marginal shift from cruise tourism to land based tourism.

14 Measures to reduce the climate impact of refrigerant emissions

14.1   Introduction

This chapter analyses potential measures to reduce emissions of refrigerant gas emissions with a positive global warming potential. It first discusses the regulation of these gases, then analyses the technical options for using other gases with a lower GWP. The emission reduction potential of different refrigerant systems is discussed in section 14.4. Section 14.6 assesses the costs and the cost-effectiveness, and section 14.7 assesses the wider impacts. Section 14.9 concludes.

14.2   Regulation of refrigerants gases in maritime transport

Refrigerant gases and emissions are controlled by global, regional and national regulation. On a global scale, some refrigerants are being phased out by the Montreal Protocol. Others are regulated by MARPOL Annex VI. In the EU and its Member States, emissions are currently not covered by regulation, but this could be changed.

Regulation of refrigerant systems in ships is typically a Flag State right. Flag States have the obligation to ensure that ships in their register comply with MARPOL regulations and they can in principle require ships in their register to apply standards that go beyond the globally set standards. States cannot require ships that do not fly their flag to comply with standards on construction, design, equipment and manning that go beyond the generally accepted international rules and standards (see legal analysis in annex B). Therefore, this chapter focuses on regulation of the EU-flagged fleet.

Cooling gases (refrigerants) for air conditioning and refrigeration in EU registered merchant ships and fishing vessels have almost exclusively been fluorinated compounds in the past. Before 2002, the common refrigerants were HydroChloroFuoroCarbons (HCFCs, R-22) which deplete the ozone layer and contribute to global warming when released to the atmosphere. The ozone-depleting potential is the reason why HCFCs are regulated by the Montreal Protocol, by EU legislation, and by Reg. 12 in MARPOL Annex VI.

MARPOL Annex VI prohibits installations which contain ozone-depleting substances on all ships constructed on or after 19.05.2005. (In the case of ships constructed before 19 May 2005, which have a contractual delivery date of the equipment to the ship on or after 19 May 2005, or, in the absence of a contractual delivery date, the actual delivery of the equipment to the ship on or after 19 May 2005). Installations containing HCFCs are prohibited on ships constructed on or after 01.01.2020. On ships under reg 12 of Marpol Annex VI, a list of equipment containing ozone depleting substances needs to be maintained and if the ship has rechargeable systems containing ozone depleting substances a Ozone depleting Substances record book is to be maintained. HCFCs must no longer be used for new equipment from 2002 onwards, and are not allowed to be used for maintenance of existing equipment by 2015 at the latest.

Since 2002, chlorine-free HydroFluoroCarbons (HFCs) have been replacing HCFCs as refrigerants in new-built ships. HFCs do not damage the ozone layer but contribute to global warming. Therefore, HFCs are subject to the Kyoto Protocol. Their application as refrigerants in new-built vessels and as replacements for HCFCs in existing ships are the reason why their emissions are projected to rise sharply and to increase to approx. 2 million tons CO_2 equivalents, by 2020, if no political action is undertaken.

In sea going merchant ships, fishing vessels and ships for refrigerated cargo (reefer ships), the annual leakage rates of air conditioning and refrigeration systems are extremely high and amount to 20 to 40%. As a consequence, containment of operating emissions is the key abatement option for the EU policy.

According to regulation EC 2037/2000 producers and importers shall not place HCFCs on the market after 31 December 2009.

Regulation EC 842/2006 on certain fluorinated greenhouse gases (F-Gas Regulation) does not include emission reduction measures for ships. There are, however, provisions for a general review which could include the need to introduce measures in 'modes of transport other than motor vehicles in a cost effective and proportionate way'. Application of emission control measures as per Art 3 (containment) and 4 (recovery) is presently limited to land-based refrigeration and air conditioning systems. The extension to the maritime sector is currently being discussed by the EU Commission.

Relation to other studies

BIPRO (2008) analyses cost-effectiveness and environmental, economical and social impacts of a potential application of the F-Gas Regulation to the maritime sector in a study for the European Commission. The study comes to the conclusion that the emissions of HFCs in 2020, which are predicted to increase to 2 Mt CO_2 eq. in a 'no-political-action' scenario, can be reduced by 0.8 Mt CO_2 eq. (40%) by application of Art 3 and 4 to the EU registered merchant and fishery fleet, at abatement costs of € 22/tonne.

The present study does not repeat the detailed impact assessment but identifies emission reduction measures beyond the ones mentioned in BIPRO (2008). Natural refrigerants such as ammonia and hydrocarbons are not GHGs: some HCs are O3 precursors and have indirect GWP values but leakage rates compared with background/other sources make them negligible. Similarly, CO_2 can be used as a natural refrigerant and is a GHG but again, leakage rates are negligible when compared with combustion sources. These refrigerants are proved and tested in land based systems. We discuss whether they can serve as technically and economically feasible alternatives to HFCs in ship systems, and how much of the predicted 2020 global warming emissions could be saved by a comprehensive application of natural refrigerants in new and in existing ships.

14.3 Technical choices for natural refrigerants in ships

The forthcoming ban on the use of HFC-134a in mobile air conditioners of passenger cars has triggered the development of new fluorinated refrigerants with low Global Warming Potential (GWP) and thermodynamic properties similar to those of as HFC-134a. The most prominent new fluid is HFO-1234yf with a preliminary GWP estimate of 4 (see Forster at al. (2007) for a list of GWPs of HFCs). The use of 1234yf is considered for other mobile air

conditioning applications, as well as for stationary Air Conditioning. As this refrigerant has not been used commercially so far, no practical experience is available yet. Therefore, we focus on natural refrigerants with low GWP including hydrocarbons, CO_2 and ammonia.

Hydrocarbons[40]

The thermodynamic properties of hydrocarbons (propane, butane, etc.) are excellent and quite similar to those of R-22. The disadvantage of hydrocarbons is their high flammability. Direct refrigeration systems must be sealed hermetically, and the charges should be very small (< 2 kg; refrigerators, heat pumps). In commercial plants, hydrocarbons cannot be used in direct systems because of the high refrigerant charge (> 50 kg) but in indirect systems only, which include the chilling of a secondary liquid that transports the heat. The plant itself must be designed according to 'flameproof' regulations, and it should be enclosed in a separate and ventilated room outdoors. In case of leakage, a flammable gas mixture should not occur inside. Since these conditions cannot be found on ships, hydrocarbons have not been in use on board so far.

Carbon Dioxide

In low ambient temperature, CO_2 is in the sub critical state and features excellent thermodynamic qualities. It is mostly used in so-called cascade systems. The first refrigeration cycle of cascade refrigeration systems (high-temperature stage) works with HFCs or ammonia. It produces temperatures of about -35°C in the evaporator which serves as a condenser for the second stage medium, thus keeping it at a very low level. The second stage covers the temperature range of -10 to -50°C and is running on CO_2 which is energetically by far the best choice for these temperatures.

On land, sub critical CO_2 is widely used in the industry, e.g. for deep freezing of food. In fishing vessels and reefer ships, CO_2 was introduced in 2002 as low temperature refrigerant in the second stage for freezing of fish and deep-freezing of cargo, saving up to 25% energy consumption against one-stage R-22 systems. Ammonia is increasingly used as refrigerant in the primary cycle.
At positive temperatures as necessary for air conditioning, CO_2 often reaches its trans-critical state (> 31°C) and hence does not show thermodynamic advantages compared to other refrigerants. These disadvantages can be balanced by technical arrangements in some cases such as in passenger car air conditioners.

In refrigeration systems of large capacity, e.g. in supermarkets, trans-critical CO_2 can be used with energetic advantage over HFC refrigerants under moderate climate conditions only. Consequently trans-critical operation of CO_2 is not yet a reasonable option for air conditioning systems of ships, because sea-going ships are sailing in all climatic regions.

---

[40] The 2005 IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate System broadly discusses Non-HFC technologies like CO_2, ammonia, hydrocarbons in chapter 4.6 (Transport refrigeration), and in sub chapter 4.6.3 (Sea transport and fishing vessels). See pages 253-267.

Ammonia[41]

Ammonia (NH_3) has been used for more than a century in industrial refrigeration plants for large capacities. Energy efficiency is at least as good as for R-22, in many areas even better. There are, however, some negative aspects related to the use of ammonia, which usually require costly technical arrangements.

A major disadvantage is the corrosive action of ammonia on materials containing copper. Refrigerant lines, heat exchangers, and fittings must hence be made of steel; the compressor requires a more complex design. While the flammability of NH_3, which is moderate against to that of hydrocarbons, is manageable, its toxicity poses considerable challenges. NH_3 must be kept away from humans and goods, and extensive safety provisions must be made.

As a consequence, NH_3 is used in indirect and cascade systems only, as the primary refrigerant. The refrigeration plant including all refrigerant containing components and pipes must be located in a separate and gas-tight machine room, and safety measures must taken in case of accidents or leakage. Under these conditions, the positive aspects of the use of NH_3 related to capacity and energy efficiency can be shown to advantage.

For normal temperatures, the secondary cycle which is connected with the primary ammonia cycle, mostly consists of brine (often based on glycol), for low temperatures the secondary cycle is inorganic brine (mostly based on $CaCl_2$), for even lower temperatures sub critical CO_2 is used – either as a refrigerant with own compressors or as an evaporating fluid being circulated by pumps. In this study, all these combinations are considered 'natural'.

The toxicity of NH_3 was the main reason why its use was deemed impossible in ships for a long time. First from 2001, the application was gradually considered controllable, and NH_3 started to be used in large fishing vessels and in reefers. Meanwhile, classification bodies and authorities have widely ceased their reservation towards NH_3, in particular if exclusively professional personnel are on board, as on both fishing vessels and reefer ships. As for new-built fishing vessels and reefer ships, NH_3 is of higher importance than HFCs today.

14.4 Emission reduction potential by use of natural refrigerants

In 2020, HFC emissions from refrigeration in the maritime sector are projected to amount to about 2 Mt CO_2 eq. in a business as usual scenario which refers to the policy option 'no action' (BIPRO, 2008).

Current uses of refrigerants
− In new built fishing trawlers of > 70 m length, which use large scale refrigeration and freezing equipment, a trend to indirect systems with ammonia in the first, and brine or CO_2 in the second refrigeration circuit has been observed (SenterNovem, 2006; Grenco, 2007). HFCs are no longer the only refrigerant option. It must be noted that the vast majority (> 95%) of the ~400 fishing vessels of > 36 m, which are presently in service, still run their refrigeration plant with HCFC-22.

---

[41] Special information on the use of ammonia was given by Anders Lindborg 2009, Ammonia Partnership AB, Viken (Sweden), pers. comm. 29th July 2009.

- In the small sector of reefers, the only new-built vessel in EU registers after the ban of HCFCs (2002) is equipped with an indirect ammonia system. The remaining ships in the EU registered reefer fleet include ca. 100 vessels and still use HCFC-22 for refrigeration and freezing of cargo.
- Merchant ships for passenger and cargo include more than 9,000 units and represent the majority of EU registered sea going vessels with refrigerants on board. Here, refrigerants are used for air conditioning, both for passengers and for the crew. To date, not a single merchant ship is in service, which uses natural refrigerants. The refrigerant in ships built before 2001 is R-22; in new ships HFC-134a is used. The HFC-blends 407C and 404A are mostly used in the small number of ships that have already replaced R-22 in existing equipment.

HFC emissions under the business as usual scenario

We categorize projected HFC emissions in 2020 in the business as usual scenario into three age classes:
- HFC emissions from ships built in 2002-2010.
- HFC emissions from ships built in 2011-2020.
- HFC emissions from ships built before 2002 which have replaced R-22 in existing systems.

The first age class includes all new builts before the policy option is assumed to enter into force, and the second age class comprises all new builts of the period from 2011 onwards. The third category refers to the current legal framework which requires replacement of the HCFC-refrigerant R-22 by refrigerants which do not contribute to depletion of the ozone layer [42].

Table 81   Projected HFC emissions from refrigeration in EU maritime sector in kt CO_2 eq. by 2020 business-as-usual scenario

	No. of ships in 2020 in EU registers	New-built in 2002-2010	New-built in 2011-2020	Built before 2002
Merchant ships	9,400	420	445	244
Reefer ships	50	0	0	137
Fishing vessels	8,170	132	148	642
Total	17,620	552	593	1,023

Source: Update of Öko-Recherche/Ecofys 2007 and BIPRO 2008. The numbers of ships > 100 GT are obtained from Lloyd's Fairplay Register.

Table 81 shows the shares of emissions caused by each of the age classes of ships. While for merchant ships emissions from new builts (2002-2020) are higher than emissions from ships built before 2002, all emissions from reefer ships and most emissions from fishing vessels are caused by conversion of existing R-22 systems.

---

[42] Regulation EC No 2037/2000 does not explicitly prohibit the use of HCFCs in existing equipment from 1 January 2015, but the use 'in the maintenance and servicing', i.e. for topping up the systems. However, as a consequence of the high leakage rates it is not possible to operate the systems several years without refilling of refrigerants. Therefore, replacement of R-22 is very likely, and is assumed to take place.

Characteristics of the reduction scenario

In the reduction scenario, it is assumed that ships built in 2002-2010 are allowed to continue the use of HFCs as refrigerants. HFC-replacement in existing systems is not considered consistent with the EU policy. In new-built ships of the period 2011-2020, however, it is mandatory to use natural refrigerants if their application is possible. In ships of the period before 2002, it is also mandatory to use natural refrigerants for the replacement of systems with ozone-depleting refrigerants[43].

As outlined previously, all natural refrigerants applicable to ship-based systems are indirect NH_3 systems which differ from each other in the second stage only (CO_2, in-organic or organic brine). This limits their use in two ways:

1 Due to its toxicity, NH_3 cannot be used on ships which carry passengers but on ships with professional crew only. Cruise ships and passenger ships are hence not obliged to use natural refrigerants.

2 For energetic, safety and space reasons, indirect NH_3 systems are not appropriate for equipment with relatively low refrigeration capacity and refrigerant charge < 300 kg, as is common for cooling of cargo holds in fishing vessels < 36 m. On this type of ships the use of direct systems based on HFCs would continue.

Table 82 picks up on the previous table but includes additional information on the business-as-usual emissions in 2020 per type of ship. It shows that the potential for emission reductions by using natural refrigerants is limited to cargo ships, reefer ships and fishing vessels with HFC refrigerant charges above 300 kg.

Moreover, the table illustrates that these types of ships will cause 70% (1,104 kt CO_2 eq. of 1,562 kt CO_2 eq.) of the total emissions projected for 2020 of the two age classes subject to the reduction option.

Table 82   HFC emissions and HFC emission reduction potential in EU maritime sector in 2020, by ship types and age classes, in kt CO_2 eq.

	Number of ships in 2020 in EU registers		HFC emissions in 2020, ktCO_2 eq.		
	Total	with NH_3	New-built in 2002-2010	New-built in 2011-2020	Built before 2002
Cruiser Liners	100		57	64	60
Passenger Ships	1,800		80	89	98
Cargo Ships	7,500		283	292	85
Reefer Ships	60	10	0	0	137
Small Fishing Vessels < 36 m	7835	14	65	72	129
RSW Trawlers > 42 m	55	20	7	7	13
Medium Freezer Trawlers	140	30	37	41	143
Large Freezer Trawlers	110	46	24	29	358
Total	17,630	120	553	593	1023
- suited for natural refrigerants			0	368	736

Source: Update of Öko-Recherche/Ecofys 2007.

---

[43] It should be noted, however, that under the conditions of the business-as-usual scenario a large part of the fishing vessels and reefer ships built after 2002 also use natural refrigerants instead of HFCs.
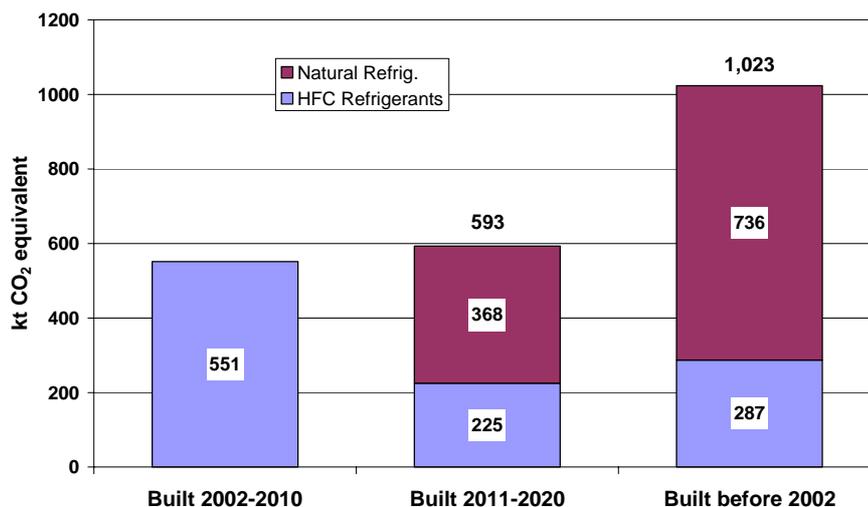
The emission reduction potential of the policy option 'natural refrigerants' is illustrated graphically above. The left bar represents the continuing HFC emissions from ships built in the 2002-2010 period. The central bar and the right bar show that the majority of emissions (purple) from ships built from 2011 onwards, and from converted refrigeration systems in existing ships built before 2002, are covered under the reduction option: 368 of 593 kt CO$_2$ eq., and 736 of 1,023 kt CO$_2$ eq., respectively.

14.5 Annual costs and emissions per standard ship systems

This chapter is the first step to estimate ship type by ship type growth in costs and savings in emissions by use of natural refrigerants instead of HFCs in refrigeration systems. Starting point of the estimations are technical data on the relevant ship types.

Technical data on refrigeration systems specific to types of ships

As a first step of the assessment of environmental, economical and social impacts of the policy option 'natural refrigerants', a refrigeration system for each of the five relevant types of ships (cargo ships, reefer ships, medium-sized and large freezer trawlers and Refrigerated Sea Water (RSW)[44] ships) is identified which reflects specific characteristics and average values. These reference systems (typical systems based on HFCs) are compared to indirect NH$_3$ systems of equal performance in two different options:

− Option 1: Natural refrigerant systems instead of HFCs systems in new ships to be built in 2011-2020.
− Option 2: Natural refrigerants instead of HFCs replacing R-22 in existing ships built before 2002.

---

[44] RSW ship means fishing vessel with tanks of Refrigerated Sea Water where the catch is cooled, however not frozen. The refrigeration equipment is large-scaled but of lower refrigeration capacity than that in freezing vessels such as trawlers or tuna seiners. (Teknotherm, 2007).

Option 2 includes replacement of R-22 both in direct systems and in indirect systems. The difference between the two operation modes as to costs and emission reduction is enormous so that we consider it appropriate to divide option 2 into sub option 2a and sub option 2b. Sub option 2a compares new indirect NH_3 systems with indirect HFC systems, replacing indirect R-22 systems and re-using the existing brine system. Sub option 2b compares indirect NH_3 based systems including new brine systems with direct HFC systems, replacing existing direct R-22 systems.

For each comparison, empirical data for at least one of the systems have been made available by experts of the leading equipment manufacturer, Johnson Controls Inc.[45]. The data on the equivalent ship system are virtual but are based on calculations and expertise of experts of the same company as well as on simulations of internal and publicly available software from Denmark (Pack Calculation II, version 2.10). The reliability of the data is thus considered to be quite high.

The technical data on the various ship refrigeration and air conditioning systems including the typical annual operating time are listed in Table 83. The table includes both the option 1 (comparison of systems in new built ships) and the sub option 2a and 2b (comparison of NH_3 system with converted R-22 system in existing ships).

Table 83   Technical data of reference systems and NH_3 systems in the relevant ship types, by options and sub options

1 Air Conditioning of Cargo Ship					
	Option 1		Sub option 2a	Sub option 2b	
	HFC-134a	NH_3/ brine		R-22 → R407C	NH_3/ brine
Refrigerating capacity kW	300		*not*	300	
Evaporation/Condensation	+2/+40°C		*existing*	+2/+40°C	
Operating time	3,000 h/y			3,000 h/y	
El. Power compressor kW	55.3 kW	46.9	*no*	60.8	46.9
El. Power brine pump kW	-	8	*indirect*	-	8
HFC refrigerant charge kg	150	50	*R-22*	150	50
Invest/Conversion cost k€	40	60	*systems*	20	60
Maintenance cost k€	8	9		10	9

---

[45]   Special thanks to Mr Alexander Cohr Pachai from Johnson Controls, Aarhus, Denmark, who provided almost all the data on the ships refrigeration and air conditioning systems.

2 Ship for Refrigerated Cargo (Reefer Ship)

	Option 1	Sub option 2a		Sub option 2b	
		R-22/brine→404A/brine	R-22/brine→NH₃/brine	R-22 DX R-404A DX	NH₃/brine
Refrigerating capacity kW	*not existing*	290		290	
Evaporation/Condensation		- 45/+40 °C		- 45/+40 °C	
Operating time		7,000 h/y		7,000 h/y	
El. Power compressor kW	*no new built with HFC until 2020*	221	216	221	216
El. Power brine pump kW		16	16		16
HFC refrigerant charge kg		500	400	3,000	400
Invest/Conversion cost k€		315	400	315	1,600
Maintenance cost k€		20	22	22	22

(Column headers for Sub option 2a use LaTeX: R-22/brine→404A/brine, R-22/brine→NH₃/brine. For Sub option 2b: R-22 DX, R-404A DX and NH₃/brine.)

3 Freezing and Refrigeration on LARGE Fishing Vessel (> 90m)

	Option 1		Sub option 2a		Sub option 2b	
	404A/CO₂	NH₃/CO₂	R-22/brine→404A/brine	R-22/brine→NH₃/brine	R-22 DX 404A DX	NH₃/brine
Operating time	5,000 h/y		5,000 h/y		5,000 h/y	
Freezing						
Refrigerating capacity kW	1,370	1,370	1,370	1,370	1,370	1,370
Evaporation/Condensation	-50/-12 - 16/40	-50/-16 - 20/40	-45/40	-45/40	-45/40	-45/40
El. Power compressor kW	919	890	1,046	1,022	1,046	1,022
El. Power brine pumps kW	incl.	incl.	20	20		20
Sea Water (RSW) Tanks						
Refrigerating capacity kW	1,600	1,600	1,600	1,600	1,600	1,600
Evaporation/Condensation	-5/40	-5/40	-5/40	-5/40	-5/40	-5/40
El. Power compressor kW	486	430	486	430	486	430
El. Power brine pumps kW	7	7	18	18		18
HFC refrigerant charge kg	3,000	2,250	3,000	2,250	6,000	2,250
Invest/Conversion cost k€	6,000	6,900	1,465	1,850	1,250	4,465
Maintenance cost k€	40	44	40	44	44	44

4 Freezing and Refrigeration on MEDIUM Fishing Vessel (42-70m)						
	Option 1		Sub option 2a		Sub option 2b	
	404A/CO$_2$	NH$_3$/CO$_2$	R-22/ brine→ 404A/brine	R-22/brine→ NH$_3$/brine	R-22DX 404A DX	NH$_3$/brine
Operating time	5,000 h/y		5,000 h/y		5,000 h/y	
Freezing						
Refrigerating capacity kW	457	457	457	457	457	457
Evaporation/Condensation	-50/-12 - 16/40	-50/-16 - 20/40	-45/40	-45/40	-45/40	-45/40
El. Power compressor kW	306	297	349	341	349	341
El. Power brine pumps kW	incl.	incl.	7	7		7
Sea Water (RSW) Tanks						
Refrigerating capacity kW	533	533	533	533	533	533
Evaporation/Condensation	-5/40	-5/40	-5/40	-5/40	-5/40	-5/40
El. Power compressor kW	162	143	162	143	162	143
El. Power brine pumps kW	6	6	6	6		6
HFC refrigerant charge kg	1,000	750	1,000	750	2,000	750
Invest/Conversion cost k€	2,000	2,300	489	617	417	1,488
Maintenance cost k€	20	22	20	22	22	22

5. RSW trawlers					
	Option 1		Sub option 2a		Sub option 2b
	R-404A	R-404A	R-22→ R404A	R-22 → NH$_3$	
Refrigerating capacity kW	1,200		1,200		
Evaporation/Condensation	-5/+40°C		-5/+40°C		
Operating time	5,000 h/y		5,000 h/y		*not existing*
El. Power compressor kW	365	365	365	323	
El. Power brine pump kW	-	-	-	-	*no indirect*
HFC refrigerant charge kg	500	500	500	400	*R-22 systems*
Invest/Conversion cost k€	1,200	1,200	614	700	
Maintenance cost k€	8	8	10	10	

Source: All data provided by Alexander Cohr Pachai, Johnson Controls, Aarhus, 2009.

Costs and emissions specific to types of ships

Technical data and annual operating hours specific to the types of ships listed in Table 83 serve as a basis for the calculation of annual global warming emissions and total annual costs for both, the reference systems and the systems with natural refrigerants. In order to carry out these calculations, the standard values shown in Table 84, which are the same for all systems, are applied to the ship-type specific technical data.

Table 84   Standard values for all systems

Price of 1 kWh (el)	€ 0.06[46]
CO_2 per kWh (el)	0.618 kg
Lifetime new system	20 years
Remaining life existing system	10 years
Discount rate	9%
Leakage rate	40%*
Price 1 kg HFC-134a	€ 10
Price 1 kg R-407C/R-404A/R-507	€ 15
Price 1 kg NH_3	€ 1
GWP values	IPCC 2007[47]

*   At the beginning of this chapter we mentioned that annual leakage rates of ships refrigerant
     systems amount to '20 to 40%'. The 20% value refers only to passenger ships with indirect air
     conditioning systems (chillers). Systems in cargo ships are direct, with leakage rates averaging
     40%. This value is also applied to fishing vessels and reefer ships, in this study.

As a result, the following information for each ship-type is obtained:
1   Total annual cost (energy, maintenance, and invest), in Euro.
2   Annual emissions of refrigerants and from fuel use, in t CO_2 or t CO_2 eq.
3   Difference in cost and emissions between NH_3 system and HFC based
    reference system.

These ship-type related values are calculated separately for option 1 (systems
in new builts) and the sub options 2a and 2b (conversion of existing systems).

The comparison of the additional annual costs of the NH_3 system and the
reduction in global warming emissions gained through the use of the NH_3
system, results in the specific abatement costs per tonne CO_2 eq. and per
standard ship system. This figure will further be used for the impact
assessment.

14.6   Natural refrigerants vs. HFCs. Paired comparisons of cost and emissions by individual ship types

This chapter estimates the ship-type specific absolute amounts and the
differences of cost and emissions between systems with natural and HFC
refrigerants. The calculations, which base on the technical data given in the
chapter before, are carried out consecutively under option 1, sub option 2a,
and sub option 2b. Explanation of the calculations is given below the Table 84.

---

[46]   Calculation basis: Price of 1 kg HFO (Heavy Fuel Oil): €0.30; HFO consumption per 1 kWh (el):
      0.200 g.

[47]   Based on Chapter 2, 212/213, of the contribution of Working Group I, AR4 to the IPCC 4th
      Assessment Report (2007) the GWPs are calculated: HFC-134a: 1,430; R-404A: 3,922; R-507:
      3,985; R-407C: 1,774.

Option 1: Natural refrigerants for new ships built 2011-2020

Table 85   Differences in annual costs and emissions between HFC and NH_3 operated systems in ships new-built 2011-2020, by four relevant ship types

	Annual Cost in Euro					Annual Emiss. t CO_2 (eq.)			Abatement
	Energy	Refrigerant	Invest	Maintenance	Additional cost of NH_3 system	Fuel	Refrigerant	Emission reduction of NH_3 system	Euro per t CO_2
1. Cargo Ship Air Conditioning									
HFC-134a	9,954	600	4,382	8,000	+2,532	102.5	85.8	- 87	29.23
NH_3/brine	9,875	20	6,573	9,000		101.7	0		
2. Medium Freezer Trawler									
404A/CO_2	140,579	6,000	219,093	20,000	+20,557	1,448	1,569	-1,657	12.40
NH_3/CO_2	131,972	300	251,957	22,000		1,359	0		
3. Large Factory Trawler									
404A/CO_2	423,836	18,000	657,279	40,000	+59,672	4,366	4,706	-4,9278	12.00
NH_3/CO_2	398,015	900	755,871	44,000		4,100	0		
4. RSW Trawler									
404A dx	109.422	3.000	131.456	8.000	+1,944	1.127	784	- 915	2.13

Source: All data provided by Alexander Cohr Pachal, Johnson Controls, Aarhus, 2009.
Explanation: DX means direct expansion (direct system).

1

A conventional air conditioner in cargo ships is a direct system and operates on HFC-134a. An indirect system based on NH_3 and glycol-brine represents a technically feasible alternative which relies on natural refrigerants. While energy consumption and energy costs are almost the same (lower energy consumption for the NH_3 compressor is balanced by the additional energy consumption for the brine pump), the investment cost of the NH_3 system is considerably higher than the one of the HFC system, resulting in additional total cost of € 2,532 per year. As the NH_3 system saves direct global warming emissions of 87 t CO_2 eq., the abatement costs amount to € 29.23/t CO_2 eq.

2

Freezer trawlers have been using CO_2 instead of brine in the second refrigeration stage, for several years. CO_2 allows significantly lower freezing temperatures than brine, and saves energy up to 25% compared to it. This effect is independent from the refrigerant in the first stage. R-404A or R-507 are the mostly used HFCs for the high temperature circuit, however NH_3 is increasingly used because it shows better cooling performance in this temperature range.

NH_3 causes lower annual costs for energy and refrigerant, but involves significantly higher annualised costs for investment and maintenance, compared with an R-404A system of the same refrigeration capacity, leading to surplus costs of € 20,500 per year. However, NH_3 saves HFC emissions of 1,569 t CO_2 eq. and generates lower (indirect) CO_2 emissions from combustion (-89 t) than the R-404A system. The abatement costs of one tonne CO_2 eq. amount to € 12.40.

3

Large freezer trawlers like factory ships of more than 70 meters of length require high refrigeration capacities at low temperatures for freezing equipment as well as high cooling capacities for refrigeration of seawater tanks and cargo holds. The refrigeration systems do not show significant qualitative differences to those of medium sized freezer trawlers as both of them use CO_2 for low temperature, and R-404A or NH_3 for high temperature. However, typical capacities and refrigerant charges are three times higher than in medium factory trawlers. As a consequence, the difference in annual costs between NH_3 and R-404A systems is three times higher than in medium sized trawlers, similarly to the difference in global warming emissions. Thus, the specific abatement costs are almost at the same level, with € 12.00 per t CO_2 eq.

4

In RSW fishing trawlers the catch is not frozen but kept cool in large tanks of refrigerated sea water (RSW). The water tank is cooled by a one-stage refrigeration system running on HFCs (404A; 507) or, increasingly, NH_3. A special secondary refrigerant or brine circuit is not required as the water tanks themselves are cooled indirect. The difference in investment costs between NH_3 and HFC systems in RSW trawlers is hence not as high as in cargo ships or freezer trawlers. In total, the annual costs of the NH_3 system are € 1,944 higher than the costs of the HFC system, and the emissions are 915 t CO_2 eq. lower. This results in abatement costs of
€ 2.13 per t CO_2 eq.

Option 2: Natural refrigerants for systems in existing ships

Standard refrigerant for ships built before 2002 was the HCFC R-22. Initially, the common mode of operation was direct, which required large quantities of refrigerant for given refrigerating capacities. In the 1990s, on new ships increasingly indirect systems were installed with $CaCl_2$ brine as heat transfer fluid. This particularly applies to major fishing vessels with freezing equipment, and to reefer ships. Air conditioning systems of cargo ships, which are relatively small systems, continued to operate directly.

The existence of two operational modes of existing R-22 systems makes the compulsory replacement by either HFCs or natural refrigerants diverse.

In existing systems, R-22 is normally and most economically replaced by HFC blends, whose thermodynamic properties are similar to those of R-22, such as R-404A, R-507, R-407C, or special service blends like R-417A, etc[48]. This applies to both direct and indirect systems. In direct systems the refrigeration and freezing equipment can be re-used after some technical adaptation measures like oil change, application of new valves, sealing, fittings, electric motor, etc. The most important component, the compressor, and the piping can mostly continue to be used after a thorough check up. In indirect systems the primary circuit can be reused after the same technical adaptation measures, while the brine system can remain unchanged.

---

[48]   A major specialised service company, who had converted air conditioning systems in 29 cargo ships from North-Sea riparian states in the 2003-2009 period, reported the following substitutes for R-22: 14 x R-404A, 4 x R-134a, 4 x R-407C, and 1 x R-417A. In addition, they converted 10 navy ships, 7 to R-404A, 3 to R-407C. All ships had been built in the early 1990s.

If from 2011 onwards all R-22 systems should be converted not to HFCs but to the natural refrigerant NH_3, the existing R-22 refrigeration circuit cannot be re-used but has to be changed completely. If the existing R-22 system is indirect, the brine system can be re-used by the new primary NH_3 circuit. If the existing system is direct, not only a new primary refrigeration circuit must be installed but also a completely new brine system which did not exist before. Extensive reconstruction measures are necessary because NH_3 can be operated indirect only, a fact that considerably raises the replacement cost of R-22 by NH_3 compared to straight replacement by HFCs.

Under option 2, four comparisons must be carried out for HFC and NH_3 based indirect systems (following indirect R-22 systems), and another four comparisons must be made for the successive systems of direct R-22 systems, which are direct HFC systems on the one hand, and indirect NH_3 systems on the other hand. We subsume comparisons of indirect systems in sub option a, and comparisons of successive direct HFC systems with successive indirect NH_3 systems in sub option b.

Sub option 2a: Comparison between indirect HFC and NH_3 systems

Table 86   Differences in annual costs and emissions between indirect HFC and NH_3 operated systems in ships built before 2002, by four ship types

	Annual Cost in Euro					Annual Emiss. t CO_2 (eq.)			Abatement
	Energy	Refrigerant	Invest	Maintenance	Additional cost of NH_3 system	Fuel	Refrigerant	Emission reduction of NH_3 system	Euro per t CO_2
1. Reefer ship									
R-22/brine → 404A/brine	98.017	3.000	49.083	20.000	+10,323	1.010	784	- 806	12,81
R-22/brine → NH_3/brine	95.936	160	62.328	22.000		988	0		
2. Medium Freezer Trawler									
R-22/brine → 404A/brine	157.112	6.000	76.092	20.000	+8,334	1.618	1.569	-1,536	5.05
R-22/brine→ NH_3/brine	149.150	300	96.089	22.000		1.536	0		
3. Large Freezer Trawler									
R-22/brine → 404A/brine	471.037	18.000	228.276	40.000	+23,002	4.852	4.706	-4,952	4.65
R-22/brine→ NH_3/brine	447.149	900	288.267	44.000		4.606	0		
4. RSW Trawler									
R-22→404A	109.422	3.000	96.608	10.000	+ 0.94	1.127	784	- 915	0.10
R-22→ NH_3	96.774	160	112.190	10.000		997	0		

Source: All data provided by Alexander Cohr Pachai, Johnson Controls, Aarhus, 2009.

1

In option 1, reefer ships were not discussed because it is assumed that from 2011 new ships will not be equipped with HFC systems but with natural refrigerants only (Reefer Operators Forum 2009). In option 2, we suppose that 50 ships built before 2002 and originally equipped with R-22 systems will be in service by 2020. The mode of operation is half direct and half indirect.

Under sub option 2a, in the paired comparison of existing indirect reefer systems, both the reference ship and the ship with natural refrigerants reuse the existing brine system. In the primary circuit, R-22 replacement by NH_3 requires completely new equipment, while R-404A can be used in the existing equipment, after some technical modification. Consequently, the conversion from R-22 to NH_3 costs more than to R-404A. The cost difference of 25%, however, is much lower than in the replacement of direct R-22 systems, where new piping all over the ship must be installed. The new primary NH_3 system causes lower costs for energy (not only the NH_3 but also the HFC system requires a brine pump) and refrigerant refill, so that on balance the annual additional costs of the NH_3 system amount to € 10,323. The abatement costs per tonne CO_2 eq. are moderate, amounting to € 12.81.

2/3

The paired comparison between indirect replacement systems in both medium and large freezer trawlers shows that the increment in annualised investment costs of NH_3 systems is 25%. This surplus cost results from the fact that the primary refrigeration circuit must be converted in the NH_3 case, but can largely be re-used in the HFC case. The energetic advantage of NH_3 against HFCs and the lower refrigerant cost of NH_3, decrease the difference in annualised additional costs, to € 8,334 and € 23,002, respectively. In the face of the high HFC emissions, the abatement cost of one tonne CO_2 eq. amounts to € 5.05, and € 4.65, respectively.

4

In RSW trawlers, the comparison between natural refrigerants and HFCs is even more favourable for the NH_3 system. The higher annualised investment cost (+ 15%) is almost completely balanced by savings in annual costs for energy and refrigerant. The energy savings result from the fact that at high temperatures as required for cooling of sea water, NH_3 is much more superior to HFCs than at low temperature as required for freezing. The specific abatement cost of one tonne CO_2 eq. amount to € 0.10 only.

Sub option 2b: Comparison between direct HFC and indirect NH$_3$ systems

Table 87   Differences in annual costs and emissions between direct HFC and indirect NH$_3$ operated systems in ships built before 2002, by four ship types

| | Annual Cost in Euro | | | | Annual Emiss. t CO$_2$ (eq.) | | | Abatement |
	Energy	Refrigerant	Invest	Maintenance	Additional cost of NH$_3$ system	Fuel	Refrigerant	Emission reduction of NH$_3$ system	Euro per t CO$_2$
1. Cargo ship air conditioning									
R-22 dx → 407C dx	10,949	900	3,116	10,000	+3,278	113	106	- 117	27.90
R-22 dx → NH$_3$/brine	9,875	20	9,349	9,000		102	0		
2. Reefer ship									
R-22 dx → 404A dx	92.977	18.000	49.083	22.000	+185,347	958	4.706	- 4,675	39.64
R-22 dx → NH$_3$/brine	95.936	160	249.312	22.000		988	0		
3. Medium Freezer Trawler									
R-22 dx → 404A dx	153.212	12.000	64.925	22.000	+151,224	1.578	3.137	-3,179	47.57
R-22 dx → NH$_3$/brine	149.150	300	231.912	22.000		1.536	0		
4. Large Freezer Trawler									
R-22 dx → 404A dx	459.637	36.000	194.775	44.000	+453,373	4.734	9.412	-9,540	47.52
R-22 dx → NH$_3$/brine	447.149	900	695.737	44.000		4.606	0		

Source: All data provided by Alexander Cohr Pachai. Johnson Controls, Aarhus, 2009.

1
It is assumed that an existing direct R-22 system is converted to the HFC blend R-407C, which is, because of the similarity in pressure, a well suited substitute in air conditioning. The costs for conversion are considerably lower than for a new system. The converted existing system serves as reference system for the same new NH$_3$/brine system as under option 1, because the application of NH$_3$ requires completely new equipment.

Although the R-407C system consumes significantly more energy than the new NH$_3$ system (and the old R-22), causing higher energy costs (+€ 1,000) compared to the NH$_3$ system, and makes greater demands on maintenance (+€ 1,000), the low conversion costs lead to lower total annual costs. This is the more the case as the remaining life of existing systems is quite short (10 vs. 20 years), thus increasing the annualised investment costs. The additional annual total costs for the NH$_3$ systems are higher than in option 1 and amount to € 3,278. The high GWP of R-407C (1,744) vs. GWP of R-134a (1,430) is the reason why the specific abatement costs are not higher than in option 1, amounting to € 27.90/t CO$_2$ eq. (compared to € 29.23 in option 1).

2

As to existing direct systems in reefer vessels, the reference ship is assumed to be converted from R-22 to R-404A. R-404A is well qualified to provide low temperature. The investment cost for the conversion is moderate (€ 49,000), however, expenses for refrigerants are very high (€ 18,000) because the charge is approx. 6 times higher than that in indirect systems. The 'natural' alternative is a new indirect system based on NH_3 in the primary circuit. It is not combined with CO_2 but with brine, which is energetically less advantageous, but much cheaper in investment. Nevertheless, the annualised investment costs (€ 249,000) are five times higher than for the straight conversion from R-22 to R-404A in the reference case, causing additional annual costs of € 185,000. In spite of the high GWP value of R-404A (3,921), the abatement cost of one tonne CO_2 eq. is high, with € 39.64.

3/4

In medium-sized and large freezer trawlers, the relation between costs and emissions is structurally identical to that in reefer ships.

In comparison with R-22 replacement by 404A in existing systems, investment for new indirect NH_3/brine systems costs a multiple sum (+ € 167,000 in medium sized, + € 500,000 in large freezer trawlers). Although savings in consumption of energy and refrigerant are high the annualised additional costs of new NH_3 based systems are significantly higher (+ € 151,000 in medium sized, + € 450,000 in large freezer trawlers). In spite of the high GWP value of R-404A (3,921) the abatement cost of one tonne CO_2 eq. amount to € 47.57 and € 47.52, respectively.

Summary on comparisons of systems in existing ships

Considering the replacement of indirect R-22 refrigeration systems (sub option 2a), the comparison between HFC and NH_3 based substituting systems shows that the annualised additional costs of NH_3 operation over HFC operation are moderate. In reefer ships and freezing vessels, where existing brine systems can be re-used, they amount to € 23,000 at the maximum. Specific abatement cost per tonne CO_2 eq. ranges from € 4.65 to € 12.00. The cost difference between HFC and NH_3 systems is even smaller in non-freezing RSW trawlers, with annualised additional operating cost and emission abatement cost below € 1.00.

The situation is different when replacing direct R-22 systems (sub option 2b).

HFCs can easily be applied in existing one-circuit equipment, with some technical adaptation measures. Natural refrigerants like NH_3 must be operated indirect and require a second circuit (brine), which has to be installed first. In consequence, the annualised cost of the new-installed NH_3 based systems in reefer ships and freezing trawlers are extremely high, amounting to a multiple of the costs of HFC systems. The absolute differences per ship are € 151,000 at the minimum, and € 453,000 at the maximum, with specific emission abatement cost per tonne CO_2 eq. between € 39.60 and € 47.50.

In cargo ship air conditioning, the difference in annualised cost between NH_3 and HFC systems is much smaller in absolute terms, with € 3,300 only. This however results from the fact that the systems are comparably small-sized and low-priced. The specific emission abatement costs are in the same range as those of freezing fishing vessels and reefers, with € 27.90.

14.7 Impact assessment of the replacement of HFCs by natural refrigerants

So far, additional costs and emission reduction potential of the application of natural refrigerants in place of HFCs in refrigeration and air conditioning systems have been assessed for the five relevant ship types. The policy option for natural refrigerants does not relate to individual ships but to the total number (fleet) of ships of the same type. In this chapter, the analysis of the environmental, economical and social impacts from the use of natural refrigerants will be carried out for option 1, and the sub options 2a and 2b. Subsequently to the impact assessment, the overall option for natural refrigerants can be evaluated by each relevant ship type.

We distinguish the overall option for natural refrigerants into three parts.

Option 1
Natural refrigerant systems instead of HFCs systems in new cargo ships and fishing vessels to be built in 2011-2020.

Sub option 2
Indirect systems with natural refrigerants vs. indirect systems with HFCs, replacing existing indirect R-22 systems, re-using the existing brine system.

Sub option 3
Indirect systems with natural refrigerants and new brine system vs. direct systems with HFCs, replacing existing direct R-22 systems.

Option 1 Natural refrigerants in new ship systems as of 2011
This measure affects all operators of cargo ships and of medium and large fishing vessels to be built in the 2011-2020 period. Subsequent to a ban of HFCs, the operators would no longer order new air conditioning or refrigeration systems based on HFCs but on NH_3 as the primary refrigerant, which is a technically available alternative.

Table 88   Cost-effectiveness of Option 1: Natural refrigerants in new ship systems as of 2011

Option 1	Emiss. red per ship t CO_2 eq.	Add Cost per ship k€	Number of ships 2020	Emiss. red total kt CO_2 eq.	Add cost total k€	Abatement cost €/t CO_2 eq.
Cargo Ships	87	2.5	3,400	294.5	8,608	29.23
Medium Freezer Trawlers	1,657	20.6	26	43.1	534	12.40
Large Freezer Trawlers	4,972	59.7	6	29.8	358	12.00
RSW Trawlers	915	1.9	9	8.2	17	2.13
Total	0	2.8	3,441	376	9,518	25.34

All indications relate to one year.

Environmental impacts

1. The application of natural refrigerants (NH$_3$ with brine or CO$_2$) completely eliminates the projected 2020 global warming HFC emissions of 368 kt CO$_2$ eq.
2. The better energetic performance of natural refrigerants, i.e. lower energy consumption for the same refrigerating capacity, reduces the demand for electric energy by 14 million kWh/a, compared to the use of HFCs. This reduces the predicted 2020 CO$_2$ emissions by 8 kt CO$_2$ increasing the overall emission reduction to 376 kt CO$_2$ eq.
3. NH$_3$ emissions of 85 t/a arise from leakages of refrigeration systems. In high concentrations, NH$_3$ may cause pH changes in aqueous ecological systems. The quantities of emitted NH$_3$ refrigerants absorbed in sea water, however, are marginal only, and do not specifically damage the overall water quality. NH$_3$ is a natural gas which is found throughout the environment in air, water, soil, animals, bacteria, and plants, from which it is rapidly taken up. In our case it is of relevance that NH$_3$ does not contribute to global warming.

Direct economic and social impacts on the operators

All operators of new ships with natural refrigerants are facing additional expenses for refrigeration equipment and maintenance on the one hand and savings from lower consumption of fuel and refrigerant on the other hand. Savings do not compensate for higher investment and maintenance cost. The additional annualized net cost for all ships built in 2011-2020 amount to 9.5 million € per year. Considering individual vessels, annualized additional net costs range from € 2,500 for cargo ships and € 1,900 for RSW trawlers to € 20,600 for medium sized and € 59,700 for large sized freezer trawlers.

It is assumed that the operators of cargo ships can afford additional costs of € 500 per year for an air conditioning system, as well as the operators of the 9 new RSW trawlers can afford the annual surplus cost of € 900.

In contrast, the operators of the 26 medium sized and the 6 large freezer fishing vessels are facing large financial burdens. We assume that additional costs of € 60,000 per year will set one job at risk because € 60,000 is considered the average annual salary in the EU fishing industry. As a consequence, the obligation to apply the natural refrigerants NH$_3$ and CO$_2$ to new freezer trawlers would pose a risk to about 15 jobs in the EU maritime fishing sector.

During normal operation of the refrigeration plant, the toxicity of NH$_3$ does not pose a threat to the occupational health of the crew, provided that the plant is regularly maintained by service personnel. Even small leakages would not harm because the entire NH$_3$ containing equipment is enclosed in a gas tight and ventilated room and the handling personnel is equipped with protecting goggles and respiratory protection. However, a major breakdown could put serious health risks at eyes, skin and lungs of the crew on board. So far, such severe accidents have not been reported from reefer ships or fishing vessels. It should be noted that NH$_3$ features a specific odour that effectively warns against leakages far below the 20 ppm concentration (i.e. present exposure limit at the workplace).

In contrast to the job risk, the risk for occupational health is not assessed quantitatively.

Indirect economic and social impacts
Positive impacts are expected for actors affected indirectly by the conversion, in particular the manufacturers of refrigeration and air conditioning equipment.

EU based specialised suppliers of ship refrigeration systems can expect additional gains of ca. € 9 million/year from delivery and installation of systems for natural refrigerants instead of HFCs. This sum is the equivalent to the additional annualised investment costs of the operators. According to the aforementioned study for the European Commission[49], we presume that a new job will be created if the turnover of equipment suppliers increases by € 200,000/year. As a consequence, approx. 45 new positions will be created at equipment manufacturers in the EU.

The providers of service and maintenance will gain about € 3.5 million/year in turnover. A growth of € 80,000/year is assumed to cause one job. Based on this assumption, another 45 jobs can be created in servicing companies. It must be pointed out that the servicing companies are mostly identical with the equipment manufacturers, which gain twice from the application of natural refrigerants.

While the sale of fuel will only be affected by minor decreases in turnover, the distributors of HFC refrigerants are facing a significant decrease in sales of ca. € 2.2 million. We assume that a decrease in sales of € 500,000 would set one job at risk; therefore a decrease of € 2.2 million threatens four positions.

In total, the number of jobs increases if option 1 would be applied. About 90 jobs will be generated at equipment and service companies. In the fishing sector and in gas trade about 20 jobs would be at risk.

Option 2: Natural refrigerants in existing systems in ships built before 2002

This option affects all operators of cargo ships, reefer ships, RSW trawlers and medium and large freezing fishing vessels which were built before 2002, and thus had been equipped with R-22 based systems. Subsequent to a mandatory replacement of R-22 by natural refrigerants instead of HFCs, the operators of R-22 brine systems (indirect systems) would have to exchange the primary refrigeration circuit only, reusing the existing brine systems, while operators of direct R-22 systems must install new refrigeration and freezing equipment all over the ship.

---

[49] BiPRO, Study on the potential application of Art 3 and 4 of Regulation (EC) n° 842/2006, December 2008.

Sub option 2a (indirect systems vs. indirect systems)

Table 89   Cost-effectiveness of Option 2a: Natural refrigerants in new ship systems as of 2011 (indirect
systems vs. indirect systems)

Sub option 2a indirect/indirect	Emiss. red per ship t CO_2 eq.	Add Cost per ship k€	Number of ships 2020	Emiss. red total kt CO_2 eq.	Add cost total k€	Abatement cost €/t CO_2 eq.
Reefer Ships	806	10.3	25	20.1	258.1	12.81
Medium Freezer Trawlers	1,651	8.3	31	51.2	258.4	5.05
Large Freezer Trawlers	4,952	23.0	30	148.6	690.1	4.65
RSW Trawlers	915	0.1	17	15.5	1.6	0.10
Total		11.7	103	235.4	1,208.1	5.13

All indications relate to one year.

Environmental impacts

1   The application of natural refrigerants (NH_3 with brine instead of HFCs with brine) eliminates the projected 2020 global warming HFC emissions of 222.7 kt CO_2 eq.
2   The better energetic performance of natural refrigerants reduces the electric energy demand by 20.5 million kWh/a, compared to the use of HFCs. This reduces the predicted 2020 CO_2 emissions by 12.7 kt CO_2 raising the overall emission reduction to 235.4 kt CO_2 eq. in 2020.
3   NH_3 emissions of 43 t/a which arise from leakages of refrigeration systems, do not specifically damage the environment (for details see comment in option 1).

Direct economic and social impacts on the operators

All operators of ships built before 2002 and originally equipped with indirect R-22 systems, are facing additional expenses for new equipment and maintenance if they apply NH_3 instead of HFCs in the primary stage of the refrigeration system. The savings from lower consumption of fuel and refrigerant do not compensate for higher investment and maintenance cost. The additional annualized net costs for all systems converted to NH_3 amount to 1.2 million € per year. Considering individual vessels, annualized additional net costs range from € 940 for RSW trawlers and € 10,300 for reefer ships to € 8,300 for medium sized and € 23,000 for large sized freezer trawlers.

It is assumed that the operators of the 17 RSW trawlers, of the 31 medium sized freezer trawlers, of the 30 large sized freezer trawlers, and of the 25 reefer ships can afford the additional costs from the conversion to natural refrigerants without risking jobs. Only if one operator runs more than two large freezer trawlers, his financial burden exceeds the threshold of € 60,000, from which onwards we assume one job set at risk.

During normal operation of the refrigeration plant, the toxicity of NH_3 does not pose a threat to the occupational health of the crew (for details see comment in option 1). The risk for occupational health cannot be assessed quantitatively.

Indirect economic and social impacts
Positive impacts are expected for actors affected indirectly by the conversion, in particular the manufacturers of refrigeration and air conditioning equipment.

EU based specialised suppliers of ship refrigeration systems can expect additional gains of ca. € 3 million/year from delivery and installation of systems for natural refrigerants instead of HFCs. This sum is the equivalent to the additional annualised investment costs of the operators. We presume that a new job will be created if the turnover of equipment suppliers increases by € 200,000/year. As a consequence, the implementation of sub option 2a would lead to approx. fifteen new positions at equipment manufacturers in the EU.

The providers of service and maintenance will gain about € 232,000 /year in turnover. A growth of € 80,000/year is assumed to cause one job. Based on this assumption, another 3 jobs can be created in servicing companies. It must be pointed out that the servicing companies are mostly identical with the equipment manufacturers, which gain twice by the application of natural refrigerants.

While the sale of fuel will only be affected by minor decreases in turnover, the distributors of HFC refrigerants are facing a significant decrease in sales of ca. € 800,000. We assume that a decrease in sales of € 500,000 would set one job at risk; therefore the decrease threatens 1 position.

In total, the number of jobs increases if sub option 2a would be applied. About 18 jobs will be generated at equipment and service companies. In the gas trade one job would be set at risk.

Sub option 2b (indirect NH_3 systems vs. direct HFC systems)

Table 90   Cost-effectiveness of Option 2b: Natural refrigerants in new ship systems as of 2011 (indirect NH3 systems vs. direct HFC systems)

Sub option 2b direct/indirect	Emiss. red per ship t CO_2 eq.	Add Cost per ship k€	Number of ships 2020	Emiss. red total kt CO_2 eq.	Add cost total k€	Abatement cost €/t CO_2 eq.
Cargo Ships	117	3.3	800	94.0	2,623	27.90
Reefer Ships	4,675	185.3	25	116.9	4,634	39.64
Medium Freezer Trawlers	3,179	151.2	30	95.4	4,537	47.57
Large Freezer Trawlers	9,540	453.4	23	219.4	10,428	47.52
Total		25.3	878	525.7	22,221	42.27

All indications relate to one year.

Environmental impacts
1   The application of natural refrigerants in new NH_3/brine systems instead of HFCs in existing direct systems eliminates the projected 2020 global warming HFC emissions of 513.4 kt CO_2 eq.
2   The better energetic performance of natural refrigerants reduces the demand for electric energy by 20 million kWh per year, compared to the use of HFCs. This lowers the predicted 2020 CO_2 emissions by 12.3 kt CO_2, increasing the overall emission reduction to 525.7 kt CO_2 eq.
3   NH_3 emissions of 56 t/a which arise from leakages of refrigeration systems, do not specifically damage the environment (for details see comment in option 1).

Direct economic and social impacts on the operators
All operators of ships built before 2002 and originally equipped with direct R-22 systems, are facing high additional expenses for completely new indirect operated refrigeration equipment and for its maintenance if they use NH_3 instead of HFCs. The savings from lower consumption of fuel and refrigerant are low compared to the high investment cost. The additional annualized net costs for all new-installed indirect NH_3 systems amount to € 22.2 million per year. Considering individual vessels, annualized additional net costs range from € 3,300 for cargo ships to € 151,200 for medium sized freezer trawlers, € 185,300 for reefer ships and even € 453,400 for large sized freezer trawlers.

It is assumed that the operators of the 800 cargo ships can afford the additional costs from the use of natural refrigerants without risking jobs. This is otherwise with fishing vessels and reefer ships, where the financial burden per ship is high.

Annual additional costs of € 153,000 put the profitability of medium-sized freezer ships at high risk. We assume that additional costs of € 60,000 per year jeopardize one job. As a consequence, two and a half jobs per ship or 10-20% of the crew are threatened. This also applies to reefer ships. The financial burden is even more severe to operators of large freezing trawlers, where more than seven positions or one quarter of the crew cannot longer be employed, on average. In total, almost 350 jobs in the EU fishery and reefer operation are seriously threatened.

During normal operation of the refrigeration plant, the toxicity of NH_3 does not pose a threat to the occupational health of the crew. For details see comment in option 1. The risk to occupational health cannot be assessed quantitatively.

Indirect economic and social impacts
Positive impacts are expected for actors affected indirectly by the conversion, in particular the manufacturers of refrigeration and air conditioning equipment.

EU based specialised suppliers of ship refrigeration systems can expect additional gains of ca. € 26 million/year from delivery and installation of systems for natural refrigerants instead of HFCs. This sum is the equivalent to the additional annualised investment costs of the operators. According to the aforementioned study for the European Commission[50], we presume that a new job will be created if the turnover of equipment suppliers increases by

---

[50]   BiPRO, Study on the potential application of Art 3 and 4 of Regulation (EC) n° 842/2006, final report December 2008.

€ 200,000/year. As a consequence, approx. 130 new positions will be created at equipment manufacturers in the EU.

The providers of service and maintenance will not gain in turnover compared to HFC systems because converted old R-22 systems do not raise less expenditure of service work than new NH_3 systems.

While the sale of fuel will only be affected by minor decreases in turnover, the distributors of HFC refrigerants are facing a significant decrease in sales of ca. € 2.3 million. We assume that a decrease in sales of € 500,000 would set one job at risk; therefore the decrease threatens 4 positions.

In total, the number of jobs strongly decreases if sub option 2b would be applied. More than 300 jobs would be at high risk in fishery and reefer operation, only 135 new jobs would be created at equipment suppliers.

14.8 Evaluation and recommendation of options for natural refrigerants

We distinguish the option for natural refrigerants into option 1 (systems in new-builts 2011-2020), sub option 2a (replacement of existing indirect R-22 systems) and sub option 2b (replacement of existing direct R-22 systems). The evaluation is carried out for each relevant ship type, under the criteria effectiveness, efficiency, and coherence.

14.8.1 Effectiveness
The three options (sub options) are in equal measure qualified to completely eliminate the projected 2020 HFC emissions from ship refrigeration or air conditioning systems in cargo ships, reefer ships, medium and large freezer trawlers, and RSW trawlers. In addition, all of them can reduce slightly energy-related CO_2 emissions from fuel burning. The new emissions of ammonia which arise in small quantities from systems with natural refrigerants are of marginal importance for the aqueous environment. The health risk for the crews by the use of ammonia can also be considered controllable.

14.8.2 Efficiency (cost effectiveness)
The three options (sub options) significantly differ by specific annual costs of ship operators to reduce one tonne CO_2 eq. (abatement costs). Table ZA shows that sub option 2b (indirect new NH_3 systems vs. HFCs in existing direct systems) features by far the highest average cost, amounting to € 42.27. In the light of the common threshold of € 20 for politically feasible climate protection measures sub option 2b is very expensive for all ship types. In contrast, option 1 and sub option 2a shows low abatement costs for fishing vessels and reefer ships (below or slightly above € 10).

Table 91   Abatement costs of options and sub options for natural refrigerants, by ship types, in €/t CO_2 eq.

	Option 1	Sub Option 2a	Sub Option 2b
Cargo Ships	29.23	n.a.	27.90
Reefer ships	n.a.	12.81	39.64
Medium Freezer Trawlers	12.40	5.05	47.57
Large Freezer Trawlers	12.00	4.65	47.52
RSW Trawlers	2.13	0.10	n.a.
Total	25.34	5.13	42.27

Sub option 2a (indirect existing systems vs. indirect existing systems) is not applicable (n. a.) to air conditioning systems of cargo ships. The applicable option 1 (new indirect systems vs. direct existing systems) is comparably costly with abatement costs in the range of those of sub option 2b.

In terms of abatement costs (€/t CO_2 eq.) sub option 2a is the most cost effective measure for fishing vessels and reefer ships. Option 1, which is not relevant to reefer ships, is likewise cost effective, but only for the three types of fishing vessels; it is less cost effective for cargo ships. Sub option 2b is the least cost effective solution.

14.8.3   Consistency (coherence)

In the fishery and reefer sector, option 1 and sub option 2a for 'natural refrigerants' do not conflict with the general objective of the EU climate policy on fluorinated greenhouse gases. Cost effective reduction of HFC emissions is also fully in line with the overall position of the EU in the international climate negotiations for possibly phasing down HFCs.

Consistency with the EU policy cannot be attributed to option 2b, in the same sectors. This sub option is not only the least cost effective measure. The assessment of direct economic impacts on ship operators has also shown that it poses high risks at employment in fishery and transportation of refrigerated cargo. In consequence of extremely high annualised investment costs per ship of over € 150,000, up to 350 jobs will be seriously jeopardized if the operators are obliged to install new ammonia based indirect systems in place of existing direct systems in ships built before 2002. This fact clearly contradicts the principles of the EU employment policy.

Such a conflict does not exist in the sector of cargo shipping. Although the installation of new indirect NH_3 systems in place of direct HFC systems (option 1 and sub option 2b) does not meet the criterion of cost effectiveness in terms of abatement cost per t CO_2 eq. (ranging € 28-29), the absolute annual net cost per ship is comparably low, ranging € 2,500-3.500, and can be paid by operators without risking jobs. This is because air conditioning requires relatively small-sized equipment. Therefore, we hold the position that the option 'natural refrigerants for cargo ships' meets the evaluation criterion consistency.

In spite of the relatively high abatement cost, with some reservation both option 1 and sub option 2b can be recommended to policy makers for cargo ship air conditioning.

The concluding Table 92 shows our recommendations on the policy option for natural refrigerants by the five relevant ship types.

Table 92   Recommendation of the policy option 'natural refrigerants for ship systems'

	Option 1	Sub Option 2a	Sub Option 2b
Cargo Ships	(YES)	n.a.	(YES)
Reefer ships	n.a.	YES	NO
Medium Freezer Trawlers	YES	YES	NO
Large Freezer Trawlers	YES	YES	NO
RSW Trawlers	YES	YES	NO

(YES) means recommendation with reservations because of high abatement cost.

n. a. = non applicable.

The HFC emission reduction potential of the entire option 1 is 368 kt CO_2 eq., and the emission reduction potential of the sub option 2a plus application of sub option 2b to cargo ships amounts to 308 kt CO_2 eq. The overall emission reduction potential of the recommended options (sub options) is estimated at 676 kt CO_2 eq.

However, 428 kt CO_2 eq. of the projected 2020 HFC emissions remain unchanged in consequence of non-application of sub option 2b to reefer ships, medium and large freezer trawlers.

14.9   Conclusions

The 2008 assessment of the impacts from application of Art 3 and 4 F-Gas Regulation, which was subject of a study for the European Commission, came to the estimation that this measure can reduce the overall HFC emissions from the maritime sector by 40% or ~ 813 kt CO_2 eq. The abatement cost was estimated at € 22 per t CO_2 eq., and the absolute annual cost at € 2,000 to € 4,000 per ship. This measure features the advantage that it can be applied to the totality of ships in EU registers whatever their year of built (including those from 2002-2010) and their types, including passenger ships. In addition, the absolute cost per ship is of similar height for all ships.

In this study, the emission reduction potential of the recommended option 'natural refrigerants' is estimated at 676 kt CO_2 eq. with average abatement cost of ~ € 19.50, and high differences in annual additional cost per ship type ranging from €100 to € 23,000.

HFC emissions from ships built 2002-2010 and from reefer ships, medium and large sized freezer trawlers with direct refrigeration systems built before 2002, and from passenger ships of all age classes are not covered by the option (sub option) natural refrigerants.

Application of Art 3 and 4 to the maritime sector must be considered the more effective and coherent overall option, compared to the overall option 'natural refrigerants', if the two options are considered alternatively.

As shown in this study, for some ship types 'natural refrigerants' is the better solution. Therefore, a combination of the two options should be considered as an effective measure to reduce projected 2020 HFC emissions.

15 Conclusions

15.1 Problem definition and policy objectives

CO_2 emissions from maritime transport account for 3.3% of global anthropogenic emissions and maritime transport to and from EU ports for 6.1% of EU emissions. In all scenarios of future maritime emissions, emissions are forecasted to rise despite gains in efficiency. Even if efficiency gains were to be higher than expected, and all the cost-effective abatement options identified in this report implemented, emissions would still probably continue to increase.

The increase in maritime emissions offsets some of the emission reductions achieved in the EU. In order to meet its emission objectives, the EU would have to reduce emissions more in other sectors if maritime transport emissions were left unabated.

The main drivers of maritime transport emissions are growing transport demand and fleet operational efficiency. Demand for maritime transport depends on many factors, most of which are in turn dependent on GDP growth. Addressing these factors could to some extent be in the realm of other policies (e.g. making European manufacturing more competitive), but it would be unwise to try to reduce maritime emissions by targeting any of these factors.

Fleet operational efficiency is determined by the carbon content of the fuels, design efficiency of the fleet and operational factors such as ship speed and logistics. Some of these factors can be addressed in a policy.

It appears that there is scope to cost-effectively reduce emissions, but not all cost-effective measures currently seem to be implemented due to market barriers and market failures, three of which are argued to remain relevant in the coming decades: split incentives, transaction costs and time lag.

Even though the removal of these market failures and barriers would probably not result in a reduction of emissions below current levels, the continuing existence of cost-effective abatement options diminishes the overall cost-effectiveness of climate change mitigation.

We conclude that the main problem to be addressed by a climate policy for maritime transport is significant and rising GHG emissions of CO_2.

The secondary problem involves the apparent market barriers and imperfections. Addressing this problem would improve the cost-effectiveness of any policy aimed at limiting or reducing maritime GHG emissions.

15.2 Policy instruments to reduce CO_2 emissions from maritime transport

Several policy instruments can be conceived to address the policy objectives of significant and rising emissions and the apparent market barriers and imperfections. This section describes their main design choices. The next section evaluates their contribution to reaching the policy objectives.

15.2.1 Design of a cap-and-trade system for maritime transport emissions

The most important design elements of a cap-and-trade system for maritime transport emissions are the choice of the responsible entity, enforcement, the geographical scope, and the initial allocation of emissions is also of prime importance. Each of these is discussed below.

The responsible entity for surrendering allowances in an emissions trading scheme for maritime transport should be the ship owner who can take action to improve the design efficiency of the ship and, in the case that the owner is also the ship operator, the operational efficiency of the ship. He can be unequivocally identified and is already liable for other forms of pollution, such as oil pollution.

A disadvantage of making the registered owner the responsible entity would be that he is often a special purpose vehicle with no other assets and no real independence - if the ship is sold, action against that entity to recover the allowances is pointless. Thus, it is necessary that the system allows for action against the direct source of emissions, i.e. the ship. Therefore the accounting entity should be the ship. Hence, a ship owner is required to report emissions and surrender allowances for each ship he owns, with enforcement able to target both the ship owner and the ship.

In general, the enforcement by the EU of any scheme with the aim of reducing carbon emissions would in practice have to be carried out at EU ports as member states exercise exclusive jurisdiction over their ports and ships calling at EU ports are required to comply with the laws of that port state.

Member States will transpose EU legislation into national legislation with the ship being accountable for reporting to the appointed authority in that member State. The ship owner will take steps to independently verify the emissions reported. In most jurisdictions, the administrative authority would need to be given specific statutory power to demand compliance and to detain vessels that do not comply.

In order to maintain the environmental effectiveness of the scheme, the geographical scope should maximise the amount of emissions to be covered by the scheme yet minimise avoidance, which is a possibility in any scheme that covers moveable emission sources. The environmental effectiveness would be significant when emissions on voyages to EU ports are included in the scheme. We find that avoidance by making an additional port call becomes prohibitively expensive for ships with a single bill of lading when a voyage is defined as the route from the port of loading to the port of discharge. For ships with multiple bills of lading (container ships, general cargo ships), it is not possible to unequivocally determine a port of loading. Hence, for these ships, some avoidance will inevitably occur. Yet the amount of emissions that could be subject to avoidance appears to be limited as a large share of emissions is on ships with a single bill of lading and/or on intra-EU voyages.

As for the initial allocation, auctioning allowances has major economic advantages as it promotes economic efficiency, avoids windfall gains associated with free allocation; and has positive effects on industry dynamics as it treats new entrants, closing entities, growing and declining entities alike. Still, it could be desirable to allocate some allowances for free to give maritime transport an equitable treatment as other sectors that are subject to emissions trading and in order to allow it time to adjust to new circumstances.

As a basis for free allocation, it is not possible to set an output based benchmark for the entire shipping sector as output is very diverse. Neither is it possible to set a historical baseline per ship, as the amount of emissions a ship has under the scope of the ETS may vary significantly from year to year. Therefore, we recommend to recycle the allowances if the financial impact on the sector needs to be reduced.

15.2.2 An emissions tax with hypothecated revenues

An emissions tax provides incentives for a reduction of emissions. However, as efficiency gains are offset by growing demand, and because demand for shipping is rather inelastic, an emissions tax would not result in a reduction of emissions below current levels or in a trend of decreasing emissions. In order to achieve the policy objective, tax revenues would have to be hypothecated for emission reductions outside the shipping sector.

Many of the design elements of an emissions tax with hypothecated revenues would be the same as for an emissions trading scheme, including the choice of the responsible entity, enforcement, the geographical scope.

15.2.3 A mandatory efficiency limit

In principle, a mandatory limit for a ships efficiency could be set. The Energy Efficiency Design Index (EEDI), which is currently being developed by IMO, may become a good indicator, although currently it is not yet mature.

As the efficiency limit can only be enforced in EU ports, the geographical scope would be confined to EU ports. Since the EEDI of a ship is independent of its operation, adopting this scope would, in fact, cover ships sailing anywhere in the world that visit EU ports. While the scope of emissions under this policy would be large, so would the scope for avoidance. Because ships are moveable objects, it is possible to avoid the system by deploying ships with an EEDI over the baseline outside the EU, and deploy compliant ships in the EU. Such avoidance would relocate emissions, but would not significantly reduce them.

The policy instrument may be open to legal challenge depending on how this index evolves and the practical effect it has on ships trading to EU ports. If compliance with the index can be effected at little cost or disturbance to the ship's trading pattern, then such a challenge may not emerge. However, in that case the environmental impact is likely to be small. If compliance requires major modifications that involve time in shipyards and leads to ships being banned permanently from EU ports due to their inherent design and inability to comply with the EEDI, then this may lead to legal challenge from ship owners and the users of such tonnage.

15.2.4 A baseline-and-credit trading scheme

A way to address the design efficiency of ships with a much smaller risk of successful legal action is a baseline-and-credit trading scheme for maritime transport. In such a scheme, efficient ships generate credits while inefficient ships need to surrender credits. The owner of an efficient ship can sell credits to the owner of an inefficient ship.

The traded unit would be based on the Energy Efficiency Design Index, which is currently being developed by IMOs MEPC. Credits would be generated or surrendered in proportion to the difference of a ship's EEDI with the baseline value for that ship and in proportion to the miles sailed from the last port of loading to an EU port.

The baseline would depend on ship type and ship size, in conformity with the current discussion in MEPC. The value of the baseline would gradually be reduced in order to improve the design efficiency of the fleet.

The geographical scope of a system determines the amount of emissions under the scheme and thus its incentive to improve design efficiency. As ships are moveable objects, any geographical scope can in principle be avoided. This reduces the incentive. Moreover, there are legal and practical considerations in setting the scope. The incentive would be large when emissions on voyages to EU ports are included in the scheme. Avoidance in a baseline-and-credit scheme can take two forms. First, the system can be avoided by making an additional port call outside the scope of the system. As argued in the section on the cap-and-trade scheme, such avoidance can be limited by determining a voyage as the port of loading to the port of discharge for ships with a single bill of lading. Second, the system can be avoided in the same way as the mandatory EEDI limit can be avoided, i.e. by deploying ships with an EEDI over the baseline outside the EU, and deploying more efficient ships in the EU. This type of avoidance cannot be effectively limited without interfering with the free movement of ships. It would lead to an oversupply of credits and therefore to a small incentive to improve efficiency.

15.2.5 Voluntary action

Voluntary action policy consists of the EU and/or its Member States promoting the use of a Ship Energy Efficiency Management Plan by ships. It would not result in emission reductions below the business-as-usual baseline, and, as argued above, not in emission reductions below current levels.

15.3 Policy instruments and policy objectives

Table 93 summarises the extent to which the policy instruments achieve the policy objectives.

We conclude that the cap-and-trade scheme for maritime transport and the emissions tax with hypothecated revenues are best capable of reaching the primary policy objective of reducing CO_2 emissions of maritime transport.

The cap-and-trade system is feasible to implement. Since avoidance can be limited, it provides a large degree of certainty in meeting the primary objective of reducing emissions.

The emissions tax with hypothecated revenues may be harder to implement as it requires unanimity amongst member states not only on the implementation of the tax but also on the hypothecation of revenues. Moreover, since the degree to which the primary objective of reducing emissions is met depends on the use of the hypothecated revenues, the tax provides a lower degree of certainty.

Table 93   Summary table of achievements of policy objectives by policy instruments

Policy instrument	Primary policy objective: reduce CO_2 emissions of maritime transport	Secondary policy objective: remove the market failures and barriers that prevent cost-effective abatement options from being implemented
A cap-and-trade system for maritime transport emissions	The emissions are capped. An increase of emissions of maritime transport over the cap will be compensated by a reduction of emissions in another sector. The price of allowances will provide an incentive to reduce emissions in the maritime transport sector, but by 2030, the impact on shipping emissions is likely to be small. Some avoidance will occur in some segments of shipping.	CO_2 emissions become valuable, thus attracting the attention of the ship owner. Monitoring and reporting requirements draw ship owners attention to emissions and to emissions abatement measures.
An emissions tax with hypothecated revenues	The emissions tax creates an incentive to reduce CO_2 emissions. By 2030,there will be a limited impact on shipping emissions, but the use of the revenues to support mitigation efforts elsewhere would reduce overall emissions. Some avoidance will occur in some segments of shipping.	CO_2 emissions become valuable, thus attracting the attention of the ship owner. Monitoring and reporting requirements draw ship owners attention to emissions and to emissions abatement measures.
A mandatory efficiency limit for ships in EU ports	In principle, the efficiency of ships would be improved, but emissions can continue to rise if demand growth outpaces efficiency improvement rate. The effect can be significantly reduced by avoidance of the system.	In principle, the efficiency limit would create an incentive to improve the EEDI of non-compliant ships through buying more newly built fuel-efficient ships or improving the EEDI of existing ships through technical retrofits. It also creates an incentive to avoid the system by deploying compliant ships in Europe and non-compliant ships in other parts of the world. It would not increase attention for measures not reflected in the EEDI.
A baseline-and-credit system based on an efficiency index	In principle, the efficiency of ships would be improved, but emissions can continue to rise if demand growth outpaces efficiency improvement rate. The effect can be significantly reduced by avoidance of the system.	A baseline-and-credit scheme would be more flexible than a mandatory limit and create incentives to improve the EEDI of all ships through buying more newly built fuel-efficient ships or improving the EEDI of existing ships through technical retrofits. However, it also creates an incentive to avoid the system by deploying compliant ships in Europe and non-compliant ships in other parts of the world. The system would not increase attention for measures not reflected in the EEDI.
Voluntary action	No or very limited impact beyond business-as-usual emissions.	The energy efficiency management plan might draw attention of ship owners implementing it to take cost-effective options to reduce emissions.

16 References

AEA,2007
M. Hobson, E. Pell, M. Surgand, S. Kollamthodi, S.Moloney, E. Mesbahi,
P. Wright, O.C. Basurko and K. Pazouki
Low Carbon Commercial Shipping : Report for the Department for Transport
Didcot : AEA Energy & Environment, 2007

Aghion et al., 2005
Philippe Aghion, Nick Bloom, Richard Blundell, Rachel Griffith and
Peter Howitt
Competition and Innovation: An Inverted-U Relationship
The Quarterly Journal of Economics, Vol. 120, No. 2, (2005); p. 701-728

Allen, et al., 2009
M.R. Allen, D.J. Frame, C. Huntingford , C.D. Jones, J.A. Lowe M.
Meinshausen and N. Meinshausen
Warming caused by cumulative carbon emissions towards the trillionth tonne
In : Nature 458 (2009); p.1163–1166

Baumol and Vinod, 1970
W.J. Baumol and H.D. Vinod
'An Inventory Theoretic Model of Freight Transportation Demand'
In : Management Science, vol.16, no.7 (1970); p. 413-21

BBC, 2009
R. Harrabin
Harrabin's notes: Shipping out
http://news.bbc.co.uk/1/hi/sci/tech/8263084.stm

Becker et al., 2004
J.F.F. Becker, A. Burgess and D.A. Henstra
No Need for Speed in Short Sea Shipping
In : Maritime Economics & Logistics, no.6 (2004); p.236-251

Betz, 2007
Regina Betz
Emissions trading to combat climate change: The impact of scheme design on
transaction costs, working paper
Sydney : Centre for Energy and Environmental Markets (CEEM),University of
New South Wales (UNSW), 2007

Beuthe et al., 2001
M. Beuthe, B. Jourquin, J.F. Geerts, C. Koul à Ndjang'Ha
Freight transport demand elasticities: A geographic multimodal transportation
network analysis
In : Transportation Research E, Volume 37, p. 253-266

BIMCO, 2008
The Baltic and International Maritime Council (BIMCO)
Thinking of slow steaming? Check your charter party first!
https://www.bimco.org/Members%20Area/News/General_News/2008/08/04_T
hinking_of_slow_steaming.aspx
Retrieved November 16, 2009

BIMCO, 2009a
The Baltic and International Maritime Council (BIMCO) : General Time Charter
Party
https://www.bimco.org/Corporate%20Area/Products/idea/~/media/Documen
ts/Document%20Samples/Time%20Charter%20Parties/GENTIME.aspx

BIMCO 2009b
The Baltic and International Maritime Council (BIMCO)
Documentary Committee meets in Athens
https://www.bimco.org/Members%20Area/News/General_News/2009/06/10_
DC_report_athens.aspx
Retrieved November 16, 2009

BIPRO, 2008
Study on the potential applications of Art. 3 and 4(1) of Regulation (EC) No
842/2006 on certain fluorinated greenhouse gases to air conditioning and
refrigeration systems contained in different transport modes
München : Beratungsgesellschaft für integrierte Problemlösungen (BiPRO
GmbH), 2008

Bossche et al., 2005
M. van den Bossche, J. Bozuwa, W. Spit, en K. Vervoort
Effecten gebruiksvergoeding in het goederenvervoer : Eindrapport
Rotterdam : ECORYS, 2005

Bureau of Transport and Communications Economics, 1990
Freight Flows in Australian Transport Corridors. Occasional Paper 98
Canberra(Australia) : Bureau of Transport and Communications Economics,
1990

Campbell et al, 2005
N. Campbell, R. Shende , M. Bennett, O. Blinova, R. Derwnt, A. McCulloch, M.
Yamabe, J. Shevlin and T. Vink
HFCs and PFCs: current and future supply, demand and emissions, plus
emissions of CFCs, HCFCs and halons
In : Safeguarding the Ozone Layer and the Global Climate System. Issues
related to hydrofluorocarbons and perfluorocarbons. B. Metz et al. (eds),
Intergovernmental Panel on Climate Change,
Cambridge (UK) : Cambridge University Press, 2005

Cariou and Wolff, 2006
P. Cariou , F.C. Wolff
'An analysis of bunker adjustment factor and freight rates on the Europe Far
East market 2000-2004
In : Marine Economics and Logistics, vol. 8, (2006); p. 187-201.

CE et al., 2004
CE Delft, KNMI, RIVM-MNP, MMU
Climate impacts from international aviation and shipping : State-of-the-art on climatic impacts, allocation and mitigation policies
Delft : CE Delft, 2004

CE et al., 2006a
CE Delft, MMU and MNP
Aviation and maritime transport in a post 2012 climate policy regime
Delft : CE Delft, 2006

CE et al, 2006b
CE Delft, Germanischer Lloyd, MARINTEK, Det Norske Veritas
Greenhouse Gas Emissions for Shipping and Implementation of the Marine Sulphur Directive
Delft : CE Delft, 2006

CE, 2008a
Jasper Faber and Karen Rensma
Left on the High Seas: Global Climate Policies for International Transport
October 2008 update
Delft : CE Delft, 2008

CE et al., 2008b
M. Maibach, C. Schreyer, D. Sutter, (INFRAS); H.P van Essen, B.H., Boon, R. Smokers, A. Schroten, (CE Delft); , Doll (Fraunhofer Gesellschaft – ISI), B. Pawlowska, M. Bak, (University of Gdansk)
Handbook on estimation of external costs in the transport sector: Internalisation Measures and Policies for All external Costs of Transport (IMPACT), Version 1.1
Delft : CE Delft, 2008

CE et al, 2009a
CE Delft, DLR, Fearnley Consultants
A Global Maritime Emissions Trading System :Design and Impacts on Developing Countries, Second Interim Report
Ongoing

CE, 2009b
Richard Smokers, Ab de Buck, Margaret van Valkengoed
Marginal abatement costs for greenhouse gas emission reduction in transport compared with other sectors (not yet published)
Delft : CE Delft, 2009

CE, 2009c
Marc Davidson, Jasper Faber, Gijs Verbraak
Impacts of proposed MBIs on the competitiveness of the Dutch maritime sector
Delft : CE Delft, 2009 (not yet published)

CE and Resource Analysis, 2008
Analyse van de implicaties voor Vlaanderen van beleidsmaatregelen voor de internationale scheepvaart inzake klimaat en verzurende emissies – 'IMPLIVAART'
Delft/Antwerpen : CE Delft/Resource Analysis, 2008

Chiffi and Fiorello, 2009
Cosimo Chiffi, and Davide Fiorello
Energy intensity of maritime trades: Evidences from the EX-TREMIS database
In : Energy Policy vol. 37 (2009); p. 3752–3757

Comtois and Slack, 2007
C. Comtois and B. Slack
Restructuring the Maritime Transportation Industry, global overview of sustainable development practices
Québec : Ministère des Transports du Québec, 2007

Corbett and Koehler, 2003
James J.Corbett and Horst W. Koehler
Updated emissions from ocean shipping
In : Journal of Geophysical Research, vol. 108, Is., D20, (2003); pp. ACH 9-1

Corbett et al, 1999
J.J. Corbett, , P. S. Fischbeck, and S. N. Pandis
Global nitrogen and sulfur inventories for oceangoing ships
In : Journal of Geophysical Research, vol. 104, no.3 (1999); p. 3457-3470

DeCanio, 1993
S. DeCanio
Barriers within firms to energy-efficient investments
In : Energy Policy, vol. 21 (1993); p. 906-914

Denman et al., 2007
K.l. Denman, G. Brasseur, A. Chidthaisong,, et al.
Couplings between changes in the climate and biogeochemistry
In : 'Climate Change', Fourth Assessment Report of Working Group I of the Intergovernmental Panel on Climate Change
Cambridge (UK) : Cambridge University Press, 2007

DK Group, 2009
J.P. Winkler
One ship pollutes as much as 50 million cars, presentation
http://dkgmt.com/Files/Billeder/Presentations/Presentation.pdf
Rotterdam : DK Group Netherlands B.V., 2009

DNB, 2009
De Nederlandsche Bank (DNB)
Rendement 10-jaar staatsleningen, eurogebeid, VS en Japan : Maandgemiddelde in procenten, December 15, 2008
http://www.dnb.nl/en/home/index.jsp
Retrieved: November, 2009

DNV, 2007
M.S. Eide, O. Endresen, A. Mjelde , L.J. Mangset and G. Gravir
Ship emissions of the future : Global emissions inventories for scenarios of future maritime shipping for 2035, 2050 and 2100.
S.l. : DNV, 2007

EC, 1998
CODISSART : comparison of documentation in short sea shipping and road transport
Brussels : European Commission (EC), 1998

EC, 2007
Winfried Schwarz (Öko-Recherche) and Jan-Martin Rhiemeier (Ecofys)
The analysis of the emissions of fluorinated greenhouse gases from
refrigeration and air conditioning equipment used in the transport sector other
than road transport and options for reducing these emissions. Maritime, Rail,
and Aircraft Sector
Brussels : European Commission (EC), 2007

EC, 2008
EU Energy and Transport in figures
Statistical Pocketbook 2007/2008
Luxembourg : Office for Official Publications of the European Communities,
2008

EC, 2009a
Commission Staff Working Document accompanying the Communication from
the Commission to the European Parliament, the Council, the European
Economic and social committee and the Committee of the regions Towards a
comprehensive climate change agreement in Copenhagen – Extensive
background information and analysis, Part 2 (COM(2009) 39 final)
Brussels : European Commission, 2009

EC, 2009b
JRC/IPTS
POLES model summary
http://iatools.jrc.ec.europa.eu/bin/view/IQTool/ModelSummaryPoles.html

EC, 2009c
Council Conclusions on EU position for the Copenhagen Climate Conference
(7 – 18 December 2009): 2968th Environment Council meeting
Luxembourg : EU Council (EC), 2009

EC, 2009d
Tourist facilities in ports : Growth opportunities for the European maritime
economy: economic and environmentally sustainable development of tourist
facilities in ports, Study report
Luxembourg: Office for Official Publications of the European Communities,
2009

EC, 2009
Communication from the Commission to the European Parliament, the Council,
The European Economic and Social Committee and the Committee of the
Regions : Strategic goals and recommendations for the EU's maritime transport
policy until 2018, COM(2009) 8 final
Brussels : Commission of the European communities, 2009

ECMWF, 2009
ERA 40, Daily Fields
S.l. : European Centre for Medium-Range Weather Forecasts (ECMWF), 2009
Available at : http://data-portal.ecmwf.int/data/d/era40_daily/

Ecofys, 2009
Ecofys, NTUA, JRC/IPTS, AEA Energy and Environment, CE Delft
Sectoral Emission Reduction Potentials and Economic Costs for Climate Change
(SERPEC-CC) Summary report
Utrecht : Ecofys, 2009
http://www.ecofys.com/com/publications/documents/SERPEC_executive_su
mmary.pdf

EEA, 2002
R. Thomas, R.D. Lauretis, J.-P , Fontelle, N. Hill, N. Kilde, K. Rypdal,
Shipping Activities, Chapter B842,
In EMEP/CORINAIR Emission Inventory Guidebook - October 2002 UPDATE,
edited by K. Lavender, G. Reynolds, A. Webster, and K. Rypdal
Copenhagen : European Environment Agency (EEA), 2002

EEA, 2008
Application of the Emissions Trading Directive by EU Member States : reporting
year 2008
Copenhagen : European Environment Agency (EEA), 2009
http://www.eea.europa.eu/publications/technical_report_2008_13

Endresen, et al., 2003
Ø ,Endresen,., E. Sørgård , J.K. Sundet, S.B. Dalsøren, I.S.A. Isaksen,
T.F. Berglen, and G. Gravir
Emission from international sea transportation and environmental impact,
In : Journal of Geophysical Research, 108 (D17), (2003); p. 4560

Endresen et al., 2007
Endresen, Ø., E. Sørgård, H. L. Eide, P. O. Brett, I. S. A Isaksen
A historical reconstruction of ships fuel consumption and emissions.
In : Journal of Geophysical Research 112, (2007) D12301

Entec, 2005a
EC Service contract on ship emissions : Assignment, abatement and market-
based instruments
Task 1: Preliminary assignment of ship emissions to European countries,
Final report
London : Entec UK Limited, 2005

Entec, 2005b
EC Service Contract on Ship Emissions : Assignment, Abatement and Market-
based Instruments.
Task 2b and c – NO_x and SO_2 Abatement
London : Entec UK Limited, 2005

Eurostat, 2009
EXTRA EU27 Trade Since 2000 By Mode of Transport (HS2-HS4) (DS_043327)
http://epp.eurostat.ec.europa.eu/portal/page/portal/external_trade/data/d
atabase
Accessed on 15 November 2009

Eyring et al., 2005a
V. Eyring, H.W. Koehler, J. van Aardenne, and A. Lauer
Emissions from international shipping, Part 1: The last 50 years
In : Journal of Geophysical Research, Vol. 110, No. D17, p. D17305.1-D17305

Eyring et al., 2005b
V. Eyring, H. W. Koehler, A. Lauer, and B. Lemper
Emissions From International Shipping, Part 2. Impact of Future Technologies on Scenarios Until 2050
In : Journal of Geophysical Research, Vol. 110, No. D17, D17306

Eyring et al., 2009a
V. Eyring, I. S. A. Isaksen, T. Berntsen, W. J. Collins, J. J. Corbett, O. Endresen, R. G. Grainger, J. Moldanova, H. Schlager, and D. S. Stevenson
Transport impacts on atmosphere and climate: Shipping
In : Atmospheric Environment, in press, 2009

Eyring et al., 2009b
V. Eyring, I. Cionni, C. Klinger, and J. Faber
Ship emissions for policy relevant allocation criteria
In : Environmental Science and Technology, in preparation, 2009

Eyring and Lee, 2009c
V. Eyring and D.S. Lee
Impact of NO_x and other ozone precursor emissions from ships on the chemical composition and climate. Ad hoc paper for the European Commission, Regional Climate Policies for Shipping project.

Eyring and Lee, 2009c
V. Eyring and D.S. Lee, 2009d
Ship aerosol impacts on climate and human health. Ad hoc paper for the European Commission, Regional Climate Policies for Shipping project

Grenco BV (GEA Refrigeration Division)
Brochures on the website:
Cruise Ships; Grenco cooling system for new Princess Cruise liners; Industrial Fishing; Reefers; Grenco carbon dioxide (CO_2) freezing systems; The Grenco NH_3/CO_2 cascade system is a world first; This super trawler features state of the art refrigeration technology; Grenco Ammonia-Brine Chillers for the Salica Frigo; New generation Flexcon Reefer vessels
At : http://www.gearefrigeration.com/en-us/News-and-Media/Brochures/Pages/default.aspx
November 2009

Farzin et al., 1998
Y.H. Farzin, K.J.M. Huisman and P.M. Kort
Optimal timing of technology adoption
In : Journal of Economic Dynamics and Control, Elsevier, vol. 22, No.5 (1998); p. 779-799

Fairplay, 2009
Planning for people's power
In : Fairplay International Shipping Weekly – Newswatch, November 5, 2009

Fuglestvedt et al., 2009
J. Fuglestvedt, T. Berntsen , V. Eyring, I. Isaksen, D.S. Lee and R. Sausen
Shipping emissions: from cooling to warming of climate - and reducing impacts on health : How should shipping emissions' ability to cool or warm the climate be addressed?
In : Environmental Science and Technology, Vol. *43, No* 24 (2009);
p. 9057–9062

Forster et al., 2007
P. Forster, V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D. W. Fahey,
J. Haywood, J. Lean, D.C .Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga,
M. Schulz, R. van Dorland
Changes in atmospheric constituents and in radiative forcing.
In 'Climate Change', Fourth Assessment Report of Working Group I of the
Intergovernmental Panel on Climate Change,
Cambridge (UK) : Cambridge University Press, 2007

Friends of the Earth, 2008
EU ploughs ahead with biofuels
http://www.foe.co.uk/campaigns/biodiversity/news/eu_biofuels_17442.html
Retrieved: November 2009

Green Ship of the Future, 2009
Organisation's website: http://www.greenship.org/

Greenwave, 2009
WASP (Wind Assisted Ship Propulsion) program
http://www.greenwave.org.uk/wasp.html

Hidalgo, 2007
Ignacio Hidalgo
Maritime transport model : Draft Report
Miñano (Álava) : Fundación LEIA CDT, 2007

House of Commons, 2009
Environmental Audit Committee
Reducing CO_2 and other emissions from shipping : Fourth Report, session
2008-2009
London : House of Commons, 2009

Hummels, et al, 2009
David Hummels, Volodymyr Lugovskyy and Alexandre Skiba
The trade reducing effects of market power in international shipping
In: Journal of Development Economics, Elsevier, vol. 89, no.1 (2009); p. 84-97

IMF, 2009
World Economic Outlook Database
S.l. : International Monetary Fund (IMF), 2009

IMO, 2007
Report on the outcome of the Informal Cross Government/Industry Scientific
Group of Experts established to evaluate the effects of the different fuel
options proposed under the revision of MARPOL Annex VI, BLG 12/6/1
S.l. : S.n., 2007

IMO, 2008
International Maritime Organization (IMO)
IMO environment meeting approves revised regulations on ship emissions,
April 4, 2008
Retrieved:
http://www.imo.org/Newsroom/mainframe.asp?topic_id=1709&doc_id=9123

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

IMO, 2009b
Note by the International Maritime Organization (IMO) : Progress within IMO on
control of greenhouse gas emissions from ships engaged in international trade
Completion of IMO's GHG work plan – finalization of efficient and robust
measures to enhance energy efficiency in shipping and to reduce emissions
from ships
Ad Hoc Working Group on Long-term Cooperative Action under the Convention
(AWG-LCA), intersessional informal consultations 10 to 14 August 2009 – Bonn
Germany
London : International Maritime Organization (IMO), 2009

IMO, 2009c
Guidelines For Voluntary Use Of The Ship Energy Efficiency Operational
Indicator (MEPC.1/Circ.684)
London : International Maritime Organization (IMO), 2009

IMO, 2009d
Second IMO GHG Study 2009, Update of the 2000 IMO GHG Study. (MEPC
59/INF.10)
London : International Maritime Organization (IMO), 2009

Institute of Shipping Analysis, 2008
Consequence Study – IMO's recommendation of SO_x emission reductions in the
Baltic Sea and the North Sea
Göteborg : Institute of Shipping analysis, 2008

IPCC/TEAP, 2005
Working Group I and III of the Intergovernmental Panel on Climate Change,
and the Technology and Assessment Panel
Special Report on Safeguarding the Ozone Layer and the Global Climate
System: Issues Related to Hydrofluorocarbons and Perfluorocarbons,
pp. 254-267
Cambridge (UK) ; New York (USA) : Cambridge University Press, 2005

IPTS, 2007
C. Chiffi, D. Fiorello, L. Schrooten, I. De Vlieger
EX-TREMIS - Exploring non road Transport Emissions in Europe – Final Report.
Seville : IPTS - Institute for Prospective Technological Studies (IPTS), DGJRC,
2007

ISLSCP2, 2009
ISLSCP2 – International Satellite Land Surface Climatology Project
International Satellite Land Surface Climatology Project Initiative II
At : http://islscp2.sesda.com/ISLSCP2_1/data/ancillary/

Jaffe and Stavins, 1994
Adam B. Jaffe, and R,N Stavins
The Energy Efficiency Gap: What Does It Mean?
In : Energy Policy, 22(10), 804-810

Jaffe, et al, 2001
A. B. Jaffe, R. G. Newell and R. N. Stavins
Technological change and the environment : , Discussion paper
Washington DC : Resources for the Future, 2001

Kågeson, 2007
Per Kågeson
Linking CO_2 emissons from International Shipping to the EU ETS
Stockholm ; Nature Associates, 2007

Kågeson, 2008
P. Kågeson
Tools for cutting European transport emissions: CO_2 emissions trading or fuel taxation
Stockholm : SNS Förlag, 2008

Korinek and Sourdin, 2009
J. Korinek and P. Sourdin
Maritime Transport Costs and Their Impact on Trade
http://www.etsg.org/ETSG2009/papers/korinek.pdf
An earlier version of this paper is forthcoming as OECD working paper TAD/TC/WP(2009)7

McDonald and Siegel, 1986
Robert L. McDonald and Daniel Siegel.
The Value of Waiting to Invest
In: Quarterly Journal of Economics, Vol. 101, No. 4, (1986), p. 707-727

Lindborg, 2009
Anders Lindborg,
Viken (Sweden) : Ammonia Partnership AB
pers. comm. 29th July 2009

LAO, 2001
Sales Taxation Of Bunker Fuel
Sacramento : Legislative Analyst's Office (LAO), 2001

Lee, et al., 2009
D.S. Lee, H, Preston, L. L. Lim, B. Owen, V. Eyring and J. Faber
Taking responsibility : setting a CO_2 emissions cap for the aviation and shipping sectors in a 2-degree world, submitted, 2009

Lee and Eyring, 2009
D.S. Lee and V. Eyring
Emissions of black carbon from shipping and effects on climate.
Ad hoc paper for the European Commission, Regional Climate Policies for Shipping project
S.l. : S.n., 2009

Lloyd'slist.com, 2009a
Janet Porter and Graig Eason
Newbuilding deferment cloud has a green lining : Owners look at revising order specifications to cut pollution further
Retrieved at November 9, 2009

Lloyd'slist.com, 2009b
C. Eason and L. Ryan
DNV considers potential for nuclear power on vessels
Lloydslist.com
Retrieved: November 10, 2009

Marbek Resource Consultants et al., 2004
Marbek Resource Consultants ; PricewaterhouseCoopers; International Institute for Sustainable Development
Administration and transaction cost estimates for a greenhouse gas offset system, final report
S.l. : S.n., 2004

Matthews, et al., 2009
H.D. Matthews, N.P. Gillett, P.A. Stott and K. Zickfeld
The proportionality of global warming to cumulative carbon emissions
In : Nature 459 (2009); p. 829–833

Meinshausen, et al., 2009
M. Meinshausen, N. Meinshausen, W. Hare, S.C. B. Raper, K.Freiler, R. Knutti, D.J. Frame and M.R. Allen
Greenhouse-gas emission targets for limiting warming to 2°C
In : Nature 458 (2009); p. 1158–1162

MMA , 2008
Modelling and market failures in the energy sector,
Melbourne : McLennan Magasanik Associates (MMA), 2008

NERA, 2005
David Harrison, Jr., et al.
Economic Instruments for Reducing Ship Emissions in the European Union
London : NERA Economic Consulting, 2005

Newell, et al., 2005
R.G. Newell, , A.B.Jaffe and R.N. Stavins
A Tale of Two Market Failures: Technology and Environmental Policy
In : Ecological Economics, vol. 54 (2005), pp. 164-174

Nickell, 1978
S.J. Nickell
The investment decisions of firms
Cambridge (UK) : Cambridge University Press, 1978

Notteboom and Vernimmen, 2009
Theo Notteboom and Bert Vernimmen
The effect of high fuel costs on liner service configuration in container shipping
In : Journal of transport geography, vol. 17, no.5 (2009); p. 325-337

NYK, 2009
Auriga Leader Recognized as "Ship of the Year" at Lloyd's List 2009 Global Awards, September 18, 2009
Company web site: http://www.nyk.com/english/release/31/NE_090918.html

OCIMF, 2008
Oil Companies International Marine Forum (OCIMF)
Energy Efficiency and Fuel Management
http://www.ocimf.com/view_document.cfm?id=1147

OECD, 1977
Lauri Michaelis
Special Issues in Carbon/Energy Taxation: Marine Bunker Fuel Charges
Paris : OECD, 1977

OECD/IEA, 2007
Mind the Gap : Quantifying Principal-Agent Problems in Energy Efficiency
Paris : OECD/ IEA , 2007

Oum et al., 1990
T.H. Oum, W.G. Waters and J. S. Yong
A survey of recent estimates of price elasticities of demand for transport
Washington, DC : The World Bank, Infrastructure and Urban Development
Department, 1990

Paxian, et al., 2009
A. Paxian, V. Eyring, W. Beer, R. Sausen, and C. Wright
Present-day and future global bottom-up ship emission inventories including
polar routes
In : Environmental Science and Technology, submitted, 2009

Paixão and Marlow, 2002
A.C. Paixão and P.B. Marlow
Strengths and weaknesses of short sea shipping
In : Marine Policy, no.26, (2002); p.167-178

Paixão and Marlow, 2005
A.C. Paixão and P.B. Marlow
The competitiveness of short sea shipping in multimodal logistics supply
chains: service attributes
In : Maritime Policy & Management, Vol. 32, No. 4 (2005); p. 363-382

PC, 2005
The Private Cost Effectiveness of Improving Energy Efficiency, Report no. 36
Canberra : Productivity Commission (PC), 2005

Reefer Operators Forum, 2009
Presentation for the European Commission Directorate General Environment by
EU based reefer operators
Brussels, 23rd July 2009

Rivers and Jaccard, 2005
N. Rivers and M. Jaccard
Combining Top-Down and Bottom-up Approaches to Energy-Economy Modeling
Using Discrete Choice Methods
In : The Energy Journal, Vol.26, No.1 (2005); p. 83-106

RIVM, 1999
J.G.J. Olivier, J.A.H.W. Peters
International Marine and Aviation Bunker Fuel : Trends, Ranking of Countries
and Comparison with National CO_2 Emissions
Bilthoven : RIVM, 1999

Røsæg, 2008
Erik Røsæg
A system for queuing in ports
In : Scandinavian Institute of Maritime Law, Yearbook 2008
Oslo : Scandinavian Institute of Maritime Law, 2008

Schary, 2007
Claire Schary
White Paper Emissions Trading in the Marine Sector
S.l. : US EPA Region 10
http://www.sfgov.org/site/uploadedfiles/sfenvironment/meetings/marine/su
pporting/2008/ExecutiveSummmaryWhitePaperonEmissionsTradinginMarineSec
tor.doc

SEAat, 2006
M.E. Davies, (BMT Ltd)
Sulphur Emissions Offsetting Pilot S-Offset, final report
S.l. : Shipping Emission Abatementand Trading (SEAaT), 2006
http://www.seaat.org/Sulphur-Offsetting-Pilot-Final-Report.aspx

Sea-Web, 2009
Lloyd's Fairplay Register
Sea-Web, the Register of Ships online
http://www.sea-web.com
November 2009

SenterNovem, 2006
Fishery with environmentally friendly cooling systems brochure made by order
of the Dutch Ministry of Public Housing, Spatial Planning and Environment
(VROM), the Ministry of Agriculture, Nature Management and Food Quality
(LNV), and the Ministry of Economic Affairs (EZ)
S.l. : SenterNovem, 2006

Seum, 2009
S. Seum, Personal Communication

Shiptechnology.com, 2009
MS Beluga SkySails - Cargo Ship
http://www.ship-technology.com/projects/msbelugaskysails/
Retrieved 20 November 2009

SkySails, 2009
Company website: http://www.skysails.info/english/

Solar Sailor, 2009
Solar Sailor Holdings Ltd
Presentation at the Green Ship Technology conference. Hamburg 2009
Company website: http://www.solarsailor.com/company_overview.htm

SPRU, 2000
S. Sorrell, J. Schleich , S.Scott, E. O'Malley, F. Trace, U. Boede, K. Ostertag P.
Radgen
Reducing barriers to energy efficiency in public and private organisations
Report to the European Commission, in the framework of the Non-Nuclear
Energy Programme, 2000, JOULE III
Brighton : Science and Technology Policy Research, University of Sussex
(SPRU), 2000

Sustainable shipping, 2008a
Fuel saving system installed on passenger ship
http://www.sustainableshipping.com/news/i73754/Fuel_saving_system_install
ed_on_passenger_ship
Retrieved 20 November 2009

Sustainable Shipping, 2008b
N. Bruckner-Menchelli
It's a 'biofuel revolution', 03 July 2008.
S.l. : Sustainable Shipping News, 2008

Sustainable shipping, 2009a
Container line to save 'millions of dollars' in fuel costs and cut emissions
http://www.sustainableshipping.com/news/popular/i89830/Container_line_to
_save_millions_of_dollars_in_fuel_costs_and_cut_emissions
Retrieved 20 November 2009

Sustainable shipping, 2009b
Maersk introduces 'super slow steaming
http://www.sustainableshipping.com/news/i89685/Maersk_introduces_super_
slow_steaming
Retrieved 20 November 2009

Sutherland, 1991
R.J. Sutherland
Market Barriers to Energy Efficiency Investments
In : The Energy Journal, vol. 12, no.3 (1991); p. 15-34

Tietenberg, 2006
T.H. Tietenberg
Emissions Trading : Principles and Practice
Washington D.C. : Resources for the Future, 2006

Torp and Kravic, 2007
Mr Torp and Mr Ivo Kravic, Halden
Teknotherm Marine & Refrigeration
Norway, pers. comm. 21 May and 14 June 2007

UNCTAD, 2007
Review of maritime transport
Geneva : United Nations Conference on Trade and Development (UNCTAD),
2007

UNCTAD, 2008
Review of maritime transport
Geneva : United Nations Conference on Trade and Development (UNCTAD),
2008

UNEP, 2007
Report of the Refrigeration, Air Conditioning and Heat Pumps Technical
Options Committee. 2006 Assessment.
Nairobi : UNEP, Ozone Secretariat, 2007

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 : United Nations Framework Convention on Climate Change (UNFCCC),
2009

UN-OHRLLS, 2009
UN Office of the High Representative for the Least Developed Countries,
Landlocked Developing Countries and Small Island Developing States
http://www.unohrlls.org/en/home/
Accessed on 24 November 2009

Veenstra en van Dalen, 2008
Albert Veenstra and Jan van Dalen,
Speed and Fuel Consumption Quotation in Ocean Shipping Time Charter
Contracts, Presentation at the International Forum on Shipping, Ports and
Airports, 2008
http://www.lgt.polyu.edu.hk/Event/IFSPA2008/presentation/Y302/Parallel%2
0Session%201/Albert%20Veenstra.pdf

VROM, 1998
Kosten en baten in het milieubeleid : definities en berekeningsmethoden.
Publicatiereeks milieustrategie 1998/6
Den Haag : Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu
(VROM), 1998

Wang, et al., 2008
C. Wang, J.J. Corbett, J. Firestone
Modeling Energy Use and Emissions from North American Shipping: Application
of Ship Traffic, Energy and Environment Model
In : Environmental Science and Technology, vol. 42, no.1 (2008); p. 193-199

Wärtsilä, 2006
High-efficiency waste heat recovery in service
http://www.wartsila.com/Wartsila/global/docs/en/about_us/twentyfour7/2_
2006/High_efficiency_heat_recovery_in_service.pdf
Retrieved 20 November 2009

WBGU, 2009
Solving the climate dilemma: the budget approach, special report
Berlin : German Advisory Council on Global Change (WBGU), 2009

Zickfeld, et al., 2009
K. Zickfeld, M. Eby , H.D.Matthews and . A.J.Weaver
Setting cumulative emissions targets to reduce the risk of dangerous climate
change
In : Proceedings of the National Academy of Sciences, 106 (2009); p. 16129–
16134