



# Analytical framework to regulate air emissions from maritime transport

Miola, A., Ciuffo, B., Marra, M., Giovine, E.

EUR 24297 EN 2010

The mission of the JRC-IES is to provide scientific-technical support to the European Union's policies for the protection and sustainable development of the European and global environment.

European Commission  
Joint Research Centre  
Institute for Environment and Sustainability

**Contact information**

**Apollonia Miola**

Address: Via Enrico Fermi, 2749 - TP 441 Ispra (VA) - Italy

E-mail: [apollonia.miola@jrc.ec.europa.eu](mailto:apollonia.miola@jrc.ec.europa.eu)

Tel.: +39 (0332) 786729

Fax: +39 (0332) 785236

<http://ies.jrc.ec.europa.eu>

<http://www.jrc.ec.europa.eu>

**Legal Notice**

Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

***Europe Direct is a service to help you find answers  
to your questions about the European Union***

**Freephone number (\*):**

**00 800 6 7 8 9 10 11**

Certain mobile telephone operators do not allow access to 00 800 numbers or these calls may be billed.

A great deal of additional information on the European Union is available on the Internet. It can be accessed through the Europa server <http://europa.eu/>

JRC57469

EUR 24297 EN

ISBN 978-92-79-15308-2

ISSN 1018-5593

DOI 10.2788/78254

Luxembourg: Office for Official Publications of the European Communities

© European Union, 2010

Reproduction is authorised provided the source is acknowledged

*Printed in Italy*

## Executive Summary

The increasing awareness of the maritime transport environmental impacts recognises that both legislative actions, regulating the levels of air pollutant or implementing market based mechanisms, and technological improvements are urgently needed.

The final aim of the report is to design a methodological framework to appraise the policy strategy to regulate air emissions (from the ships air pollutants and greenhouse gases) giving some insights on how to design and to apply policy instruments that should be informed by efficiency and equity principles.

The report can be ideally divided in two parts. The first part (1 to 9) outlines the state of the art on methodological frameworks to appraise policy strategies to regulate air emissions from ships (air pollutants and greenhouse gases as well).

The first chapters (1 to 4) of the report analyse the main maritime transportation activities and the related environmental impacts. A detailed description of the impacts on air quality is carried out in Chapter 4 to allow the definition of the main fields of policy intervention to abate air emissions from ships. Chapter 5 provides an overview of the main methods to estimate the emissions deriving from shipping activities and compares their results in order to define a reference framework. In fact, the evaluation of the total amount of emissions deriving from shipping activities (and the scale of these emissions) plays a central role to appraise possible strategies for the reduction of the maritime transportation sector. The analysis highlights some limits of the current methodologies. The scientific debate is still open on which would be the most proper way to reduce these limitations. Indeed, the scarce or limited availability of data concerning maritime transportation activities makes complex the achievement of this objective. The identifications of these limits and constraints are the first steps to allow the improvement of these estimations.

A legislative intervention to control air emissions from international maritime transport requires a clear picture of the international regulatory system and the legal and political framework that regulate this sector. Chapter 6 provides an overview of the complex maritime regulatory system and how environmental issues are integrated in this framework. This is followed by the analysis of criteria to compare and select policy options for an environmental sectorial strategy (chapter 7).

Chapter 8 identifies some methodological constraints to estimating external costs due to air emissions from ships to allow their internalization. Then, a detailed analysis of the technological options to abate air emissions from ships providing some indications of their potential and their costs to abate the emissions is undertaken (chapter 9).

The second part of the report (10 to 12) summarises the international debate on the regulation of Greenhouse Gas emissions from international maritime transport. Chapter 10 briefly describes the international framework to regulate air emissions from international maritime transport giving a complete picture of international Institutions, different positions and decisions regarding these aspects.

The chapter 11, starting with an analysis of the EU emission trading scheme, identifies and analyses the main challenges in designing policies to regulate CO<sub>2</sub> emissions from international maritime transport. The analysis highlights the complexity of the international regulatory system of the maritime transport and several legal and economic constraints for regional (namely, European) and international policies to regulate CO<sub>2</sub> emissions from international maritime transport. In particular, the European Emission Trading scheme applied to the maritime sector and a global scheme are analysed (chapter 12).

The last chapter (13) suggests some directions for future research to cover the lack on data and methods to estimate air emissions (air pollutants and green house gases) and to develop additional policy options.

## Contents

Executive Summary .....	3
1. Introduction.....	10
2. Maritime transportation activity and environment .....	11
3. Main environmental impacts of maritime transportation .....	13
4. Impacts on Air Quality .....	16
5. Evaluating emissions from the Maritime Transportation Sector: State of the Art .....	20
5.1 Classification of the available approaches: bottom-up vs. top-down .....	21
5.2 Estimation of emissions due to the maritime transportation sector: state of the art .....	22
5.2.1 Bottom-up approach in the total emissions evaluations, but top-down in the geographical characterization .....	23
5.2.2 Top-down approach in the total emissions evaluations, but bottom-up in the geographical characterization .....	27
5.2.3 Full bottom-up approach .....	28
5.3 Comparison of results coming from different approaches .....	31
5.4 Summary of possible maritime data sources .....	33
5.4.1 Technical information on International vessels .....	34
5.4.2 Ship activities and geographic distribution of maritime traffic.....	35
5.4.3 Further information.....	40
5.5 A possible improved approach for the estimation of emissions from the maritime transportation sector .....	42
5.6 Conclusions .....	44
6. The law of the sea: Introductory summary.....	44
7. Reducing air Emissions from Ship – Technological and Policy options .....	51
8. Estimating external costs of maritime transport.....	53
9. Abatement Technologies: Estimated Performances and Costs .....	55
9.1 Introduction .....	55
9.2 Available technologies .....	57
9.2.1 Ship design .....	57

9.2.2	Propulsion .....	60
9.2.3	Machinery.....	63
9.2.4	Operation .....	73
9.2.5	Fuel Type .....	79
10.	The international framework to regulate CO2 emissions from international maritime transport. ....	83
11.	Regional approach to regulate CO2 emissions: the European Union Directive on Emission Trading .....	93
11.1	The Carbon Market .....	94
11.2	Carbon leakage.....	97
11.3	The inclusion of shipping into the EU ETS .....	99
11.4	Limits to include the maritime transport sector .....	102
11.5	Some risks .....	105
12.	International mechanisms to reduce maritime transport emissions.....	108
12.1	Common but differentiated responsibilities .....	108
12.2	Maritime Emission Trading Scheme (METS) .....	109
12.3	Maritime Sectoral Crediting Mechanism (MSCM) .....	110
12.4	Maritime Emission Reduction Scheme (MERS).....	111
12.5	Conclusion .....	112
13.	Conclusion and future research directions. ....	113
	References.....	116

## List of Tables

TABLE 1 IMPACTS DUE TO MARITIME TRANSPORT ACTIVITIES, INCLUDING ILLEGAL ONE AND ACCIDENTAL EVENTS.	15
TABLE 2 CLASSIFICATION OF THE MAIN STUDIES CONCERNING THE EVALUATION OF EMISSIONS FROM MARITIME TRANSPORT	22
TABLE 3. CO <sub>2</sub> EMISSIONS FROM INTERNATIONAL SHIPPING: DIFFERENT RESULTS FROM DIFFERENT SOURCES	32
TABLE 4 CRITERIA FOR SELECTION OF POLLUTION CONTROL INSTRUMENTS.	52
TABLE 5 TRANSVERSE THRUSTER OPENINGS	59
TABLE 6 AIR CAVITY SYSTEM	60
TABLE 7 PROPELLER PERFORMANCE MONITORING	61
TABLE 8 PROPELLER/RUDDER UPGRADE	61
TABLE 9 PROPELLER UPGRADE (WINGLET/NOZZLE)	61
TABLE 10 PROPELLER BOSS CAP FINS	62
TABLE 11 TOWING KYTE	63
TABLE 12 POTENTIAL EMISSIONS REDUCTION WITH SHORE-SIDE ELECTRICITY	64
TABLE 13 SHORE-SIDE ELECTRICITY COSTS (€/TONNE) (ENTEC, 2005A, TABLE 5.2, PAGE 39)	64
TABLE 14 SCRUBBER COSTS USED IN AEA (2009) (TABLE 6.4, PAGE 33)	68
TABLE 15 COST EFFECTIVENESS OF NOX REDUCTION MEASURES PER €/TONNE.	68
TABLE 16 INDICATIVE SCRUBBER COSTS FOR DIFFERENT SHIPS CATEGORIES	69
TABLE 17 SCRUBBER COSTS USED IN AEA (2009)	70
TABLE 18 COST EFFECTIVENESS OF SOX REDUCTION MEASURES PER €/TONNE ABATED	70
TABLE 19 MAIN ENGINE TUNING	71
TABLE 20 COMMON RAIL UPGRADE	72
TABLE 21 SHAFT POWER METER	72
TABLE 22 FUEL CONSUMPTION METER	72
TABLE 23 LOW ENERGY/LOW-HEAT LIGHTING	73
TABLE 24 POWER MANAGEMENT	73
TABLE 25 SPEED CONTROL PUMPS AND FANS	73
TABLE 26 PROPELLER BRUSHING	74
	7

TABLE 27 INCREASED FREQUENCY OF PROPELLER BRUSHING	74
TABLE 28 HULL COATING TYPE 1	75
TABLE 29 HULL COATING TYPE 2	75
TABLE 30 HULL BRUSHING	76
TABLE 31 UNDERWATER HYDROBLASTING	76
TABLE 32 DRY-DOCK FULL BLAST	76
TABLE 33 HULL PERFORMANCE MONITORING	77
TABLE 34 10% SPEED REDUCTION	77
TABLE 35 WEATHER ROUTEING	78
TABLE 36 AUTOPILOT UPGRADE/ADJUSTMENT	78
TABLE 37 COST FOR FUEL SHIFTING IN 2020 BOTH WITH RESPECT TO THE TONES OF FUEL AND TO THE ENERGY PRODUCED	80
TABLE 38 COST EFFECTIVENESS OF FUEL SWITCHING FOR SOX REDUCTION MEASURES PER €/TONNE ABATED	81
TABLE 39 CARBON LEAKAGE RATES	98



## List of Figures

FIGURE 1. DECOMPOSITION OF MARITIME TRANSPORTATION ACTIVITIES. SOURCE: BICKEL ET AL. (2006: 3).	11
FIGURE 2. VESSEL TRAFFIC DENSITIES FOR YEAR 2000 BASED ON THE SUM OF REPORTED DISTRIBUTIONS FROM AMVER DATA	23
FIGURE 3. CO2 EMISSIONS GEOGRAPHICAL CHARACTERIZATION VIA IMPROVED TRAFFIC PROXY (WANG ET AL., 2008).	28
FIGURE 4. NOX EMISSIONS DUE TO BALTIC SEA SHIPPING IN 2007	30
FIGURE 5. FUEL CONSUMPTION ESTIMATION AND EVOLUTION FROM DIFFERENT SOURCES	31
FIGURE 6. AIS COVERAGE AREAS FOR THE LMIU NETWORK (IMAGE ON TOP) AND FROM MARINETRAFFIC.COM (DOWN)	36
FIGURE 7. SHIPS' POSITIONS IN THE MEDITERRANEAN SEA IN THE PERIOD 15-18 FEBRUARY 2010 RETRIEVED BY THE MARINETRAFFIC.COM AIS NETWORK	37
FIGURE 8. SCHEMATIC REPRESENTATION OF THE "AT SEA" FUEL CONSUMPTION/EMISSIONS MODULE	42
FIGURE 9. SCHEMATIC REPRESENTATION OF THE "IN PORT" FUEL CONSUMPTION/EMISSIONS MODULE	43
FIGURE 10 MARITIME ZONES.	45
FIGURE 11. SULPHUR CONTENT OF FUELS	80
FIGURE 12. THE MARKET PRICE OF ALLOWANCES 2005 – 2007	95

## 1. Introduction

Maritime transport activity is becoming one of the most important topics on sustainability debate. Indeed, apart from industrial activity and energy production, maritime transport is the largest contributor to air quality pollution and the increasing rate of trade make the problem even more pressing.

During the last decades, transport demand has strongly increased, at or above the GDP growth rate, and maritime trade has become the most important way for merchandise to be transferred. Today, almost 80% of the world goods are carried by sea and maritime transport accounts for over 90% of European Union external trade and 43% of its internal trade (UNCTAD, 2007).

In the last months of 2008 the growth in international seaborne trade was at 3.6%, which is a slower rate compared with the 4.5% in 2007 (UNCTAD, 2010). This is due to the direct correlation of the development of maritime transportation with the level of world trade, which has been influenced by the global economic downturn in 2008 and 2009.

However, this deceleration in the growth rate of the international seaborne trade did not influence the environmental burdens entailed by maritime transport. Indeed, the resource consumption that supports the maritime transportation activities imposes considerable environmental costs, including air and water pollutants, climate change, noise and effects on human health. In addition, the impacts of the climate change may affect the maritime sector.

The increasing awareness of the maritime transport environmental impacts recognises that both legislative actions, regulating the levels of air pollutant and green house gases or implementing market mechanisms, and technological improvements are recognized urgently needed.

The final aim of the report is to design a methodological framework to appraise the policy strategy to regulate air emissions from the ships (air pollutants and green house gases) giving some insights on how to design and to apply policy instruments that should be informed by efficiency and equity principles.

The report can be ideally divided in two parts. The first part outlines the state of the art on methodological frameworks to appraise policy strategies to regulate air emissions from ships (air pollutants and greenhouse gases as well). For this purpose this first part outlines: (i) the main impacts of air emissions from ships on air quality; (ii) available data and methodologies to estimate air emissions from ships (proposing a new methodology of estimation); (iii) international legal framework which regulates maritime transport sector in general and related environmental impacts

in details; (iv) technological and policy options aiming at designing a sectorial environmental policy strategy for maritime transport.

The second part of the report (10 to 12) summarises the international debate on the regulation of Greenhouse Gas emissions from international maritime transport.

The analysis highlights the complexity of the international regulatory system of maritime transport and several legal and economic constraints for regional (namely, European) and international policies to regulate CO<sub>2</sub> emissions from international maritime transport. In particular, the European Emission Trading scheme applied to the maritime sector and a global scheme are analysed.

The report suggests some directions for future research to cover the lack of data and methods related to the estimation of air emissions from ships, and to define new policy options. The objective is to give some insights on how to design and to apply policy instruments that should be informed by efficiency and equity principles.

## 2. Maritime transportation activity and environment

Reducing the impacts of maritime transport impacts on the environment is a challenging task, since these impacts are not only entailed by navigation but are dependent on a number of activities carried out in ports as showed in the figure below (Figure 1).

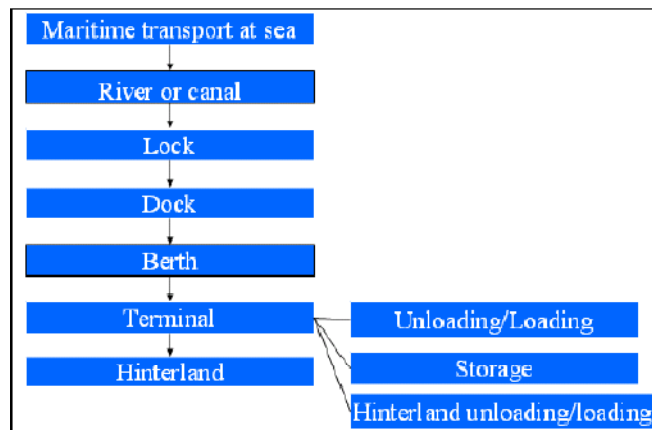


Figure 1. Decomposition of maritime transportation activities. Source: Bickel et al. (2006: 3).

Namely,

- The navigation, i.e. the transport (to the port terminal), the storage and loading of goods and passengers. In particular, before arriving at a port, a ship should be driven from open sea to a part of river or a canal, then reach docks. Once the ship is berthed, other (terminal) activities take place, i.e. unloading/loading; storage and unloading/loading of hinterland modes;

- the construction, maintenance, cleaning and dismantling of ships and vessels. This activity can either be carried out at port or in other areas close to it. Despite their physical location, it is undoubted that their side-effects should be computed as maritime transport external effects.
- the construction and maintenance of port terminal (in terms of land consumption and generated waste).

Regarding navigation, the activities that deserve more attention are: mooring, docking and leaving from the port.

With respect to the ships those can be categorised in several classifications according to their purpose and size. Merchant vessels refer to ships that transport cargo and passengers. A simplified classification is that of Lloyds MIU:

- **Dry Cargo ships** can be classified as bulk carriers and container ships. The former are ocean-going vessels used to transport unpacked bulk cargo (iron, bauxite, coal, cement, grain and other), whose dimensions are determined by ports and sea routes that they need to serve. Bulk cargo can be very dense, corrosive, or abrasive, and presents safety problems. For this reasons, new international regulations have since been introduced to improve ship design and inspection, and to streamline the process of abandoning ship. The latter - container ships transport their cargo in truck-size containers (containerization). Modern container ships can carry up to 15,000 TEU<sup>1</sup>.
- **Tankers** are designed to transport liquids in bulk (crude oil, petroleum products, liquefied petroleum gas; liquefied natural gas; chemicals; vegetable oils; fresh water, wine and other food). Apart from pipeline transport, large tankers are the only method for transporting large quantities of oil.
- **Specialised ships** include reefer and RoRo cargo. A reefer ship is a type of ship typically used to transport perishable commodities which require temperature-controlled transportation (e.g. fruits, meat, fish, vegetables and other dairy products). Roll-on/roll-off (RORO or ro-ro) ships are ferries designed to carry wheeled cargo (e.g. cars, trucks, semi-trailer trucks, trailers or railroad cars). RORO vessels have built-in ramps, which allow the cargo to be efficiently "rolled on" and "rolled off" the vessel when in port.

---

<sup>1</sup> One TEU represents the cargo capacity of a standard shipping container 20 feet long and 8 feet wide.

- **Passenger ships** are vessels whose primary function is to carry passengers. The category does not include cargo vessels, which have accommodations for limited numbers of passengers. Passenger ships include ferries, which are vessels for day or overnight short-sea trips moving passengers and vehicles (whether road or rail); ocean liners, which typically are passenger or passenger-cargo vessels transporting passengers and often cargo on longer line voyages; and cruise ships, which typically transport passengers on round-trips, in which the trip itself and the attractions of the ship and ports visited are the principal draw.

The impacts on environment are related to the vessels, the fuel used and the engine. With respect to the fuel, world ship bunker demand is essentially covered by oil products, ranking from marine distillate to marine fuels, which are mainly: marine gas oil (MGO), a distillate fuel; marine diesel oil (MDO), a heavier distillate fuel, which may contain a proportion of residual fuel oil.

The vessels have main engines (MEs), used for ship propulsion at sea and auxiliary engines (AEs), used for generating electrical power on board. When ships are stationary and at berth the MEs shut down. In general, AEs are used continuously except when shaft generators coupled to MEs are available at sea, or when a shore-side electricity link is provided at berth. Cooper (2003) reports that all AEs are four-stroke marine diesel engines operating at engine speeds of 500–2500 rpm (i.e. so-called medium- and high-speed diesels) with power output in the range of 30–3000 kW. The AE power requirement on board a ship can vary. Once in port, however, the power requirement is usually less but can still vary depending on the type of ship activity, e.g. hotelling, loading operations.

Marine distillates are normally used for the main engines of small vessels and for the auxiliary engines of larger vessels. Large vessels normally use marine fuels.

Finally, the size of a vessel is mainly identified by considering the number of main engines (ME) and auxiliary engines (AE) installed per ship.

### **3. Main environmental impacts of maritime transportation**

Each maritime transportation activity occurring in ports, at sea or during ship construction/maintenance/dismantling, results in different environmental impacts, on air, water, ecosystem and other. These impacts plus those deriving from accidental events or illegal actions have to be considered when evaluating the overall contribution of the maritime transportation sector to environmental quality. The interrelation between environmental impacts and activities/events of the maritime transportation sector are reported in Table 1 and the main ones are analysed in the following sections, on the basis of a large literature review.

It has to be noted that congestion costs are considered a negligible component, due to overcapacity of existing infrastructure with respect to the current demand. Regarding accident costs, the same considerations made for other transport modes hold. Consequences of ship accidents, like victims or severe injuries should be assessed similarly for other transport modes.

Marginal noise costs due to maritime shipping and inland waterway transport are assumed to be negligible, because most of the transport activities take place outside densely populated areas.

Environmental impacts regards both air quality and water pollution. Regarding air impacts, ship emissions include ozone and aerosol precursors ( $\text{NO}_x$ , CO, VOCs,  $\text{SO}_2$ , etc) and the emissions of greenhouse gases (including  $\text{CO}_2$ ). Effects of these pollutants are well known.  $\text{SO}_2$  and  $\text{NO}_x$  can become converted into sulphate and nitrate particles. Exposure to fine particles is associated with increased mortality and morbidity. Shipping emissions contribute notably to the formation of ground-level ozone, especially in the Mediterranean region, which affects human health and crop yields. The deposition of sulphur and nitrogen contribute to exceedances of critical loads of acidity. Nitrogen oxides lead to eutrophication, which affects biodiversity both on land and coastal waters. Finally, emissions from ships contribute to climate change.

With respect to other transport modes, ship emissions let out a more relevant quantity of sulphur and  $\text{NO}_x$  per ton kilometers.

In the case of ship emissions, the degree of exposure varies considerably with respect to land transport, and depends on ports distance from city centre.

With respect to other transport modes, ship transport has significant impacts on water, due to the effects of ballast water and the use of antifouling varnish.

Last but not least, maritime transport produces important impacts on soil, due to the high land use consumption entailed by location of harbours and due to sediment deposition. Indeed the occurrence of these external effects varies according to the different activities entailed by maritime transport (namely cruising, manoeuvring, hotelling, tanker offloading and auxiliary generators).

For the scope of this report the next paragraph will give a detailed analysis of the impacts of maritime transport on air. This analysis will allow the definition of the main fields of policy intervention to abate air emissions from ships.



## 4. Impacts on Air Quality

Emissions from the maritime transport sector represent a significant and increasing air pollution source<sup>2</sup>. Health and environmental impacts of air pollutants are highly dependent on the proximity of the emission sources to sensitive receptor sites. This means that, compared to land-based sources, at least some of the maritime emissions have less health and environmental impacts since they are released, sometimes, far from populated areas or sensitive ecosystems. However, in harbour cities ship emissions are in many cases a dominant source of urban pollution and need to be addressed, in particular when considering fine particulate matter. Furthermore, as for all other sources, also emissions from ships are transported in the atmosphere over several hundreds of kilometres, and thus can contribute to air quality problems on land, even if they are emitted on the sea. This pathway is especially relevant for deposition of sulphur and nitrogen compounds (Cofala et al., 2007).

In general, all ships activities are responsible for air pollutant emissions and particularly: cruise, ships movement in port, ships activities in hotelling phase (lighting, heating, refrigeration, ventilation, etc.), tanker loading and unloading (Trozzi, 2003).

As concerns ship building/maintenance/dismantling activities, the principal emissions are dust, particles, gases (e.g. from welding), smell, aerosols. Considering specific activities, a main problem is the emission of volatile organic compounds from metal degreasing and painting (European Environment Agency, 2002). As regards hull surface cleaning, paint removal, changes of zinc anodes, and paint application, the important environmental aspects are dust emissions (from sandblasting, grinding etc.) and emission of solvents, where solvents contain volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) (Hayman et al., 2000). Demolition or main modification of ships, produce asbestos, heavy metals, hydrocarbons, ozone depleting substances and others. As already mentioned, all these ship building/maintenance/dismantling activities can either be concentrated within the port or carried out in other areas. When focusing on ships, it to be taken into account that, for economic reasons, many vessels use heavy fuel oil which has very high sulphur content (90% higher than petrol or conventional diesel) (Butt, 2007). The main air emissions from burning this type of fuel are:

---

<sup>2</sup> This paragraph synthesises the analysis carried out in the EU report “External costs of Transportation Case study: Maritime transport”(A. Miola et al, 2009)



- Sulphur Dioxide (SO<sub>2</sub>);
- Nitrogen Oxides (NO<sub>x</sub>);
- Volatile Organic Compounds (VOC);
- Primary Particulate Matter (PM);
- Carbon Dioxide (CO<sub>2</sub>).

The amount of gases emitted from marine engines into the atmosphere is directly related to total fuel oil consumption, which depends on different factors, such as the actual hull shape, the loading condition, the hull roughness, the state of the engine, etc. Auxiliary engines also contribute to the total exhaust gas emissions. This contribution is particularly important for cruise ships, that have a continuous need for ancillary power to meet lighting and ventilation demands both at sea and in port. In general, ship emissions in-port depend on manoeuvring time, time spent, and cargo operations (vessel-type dependent) (Endresen et al., 2003).

Emissions can also come from incineration of waste aboard; in this case, dioxins and other heavy metals can be released into the atmosphere.

Focusing on all port operations and air pollution, the main factor to take into consideration is that each category – ocean/sea-going vessels, harbour craft, cargo handling equipment, trucks and locomotives – is mainly powered by diesel engines, that are significant contributors to air pollution.

The most relevant ship activities as concerns air pollution identified by Trozzi (2003) are:

- loading and unloading of petroleum products, produces volatile organic compound emissions;
- dry docks, produce evaporative volatile organic compound emissions;
- passenger car traffic, produces combustion products and evaporative volatile organic compound emissions;
- heavy vehicle traffic, produces combustion products emission;
- railway traffic, produces combustion products emission.

As results, in and around ports harmful pollutants are present, e.g. particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>), ozone (O<sub>3</sub>), nitrogen dioxide (NO<sub>2</sub>), sulphur dioxide (SO<sub>2</sub>), carbon monoxide (CO), and Lead (Pb) (IAPH, 2007).

The presence of these pollutants has local and global impacts. Impacts on local (or regional) air quality, are mainly linked to pollutants such as PM, NO<sub>x</sub> and Sulphur. While the emission of greenhouse gases (e.g. CO<sub>2</sub>) have a global impact on climate.

With regards to local air pollution, it has to be taken into consideration that port areas have historically developed very close to urban areas and port operations can affect the people living and working in these areas. As already mentioned, local air quality and the negative effect on human health is largely dominated by the presence of nitrogen oxides, PM (2,5 or 10), acid deposition and nitrogen deposition. Nitrogen (NO<sub>x</sub>) and particulate matter (PM) contribute to serious health problems such as premature mortality, asthma attacks, millions of lost work days, and numerous other health impacts. (IAPH, 2007)

In particular, NO<sub>x</sub> and VOC emissions contribute to the formation of ground-level ozone (photochemical smog). While stratospheric ozone protects the surface of the earth from harmful ultraviolet radiation, tropospheric ozone, formed from the reaction of nitrogen oxides and hydrocarbons when combined with sunlight, is a powerful oxidant that damages human lung tissue, vegetation, and other materials. Short-term exposure to high concentrations can cause a range of acute adverse human health effects from irritation and shortness of breath to decreased immune functions and increased inflammation and permeability of lung tissue. Young children, the elderly, and individuals with pre-existing respiratory disease are at particular risk of serious acute adverse effects from ozone exposure. The chronic human health effects of ozone exposure are less well known, but there is the possibility of irreversible morphological changes of the lung, genotoxicity, and carcinogenicity. (IMO, 2000)

SO<sub>2</sub> emissions also negatively impact on public health, in particular sulphate particles can induce asthma, bronchitis and heart failure.

As concerns CO, health effects can result from the reduction of oxygen delivery to the body's organs (such as the heart and the brain) and tissues. Cardiovascular effects are the most serious effects of CO for those who suffer from heart disease. There are also effects on the central nervous system. Breathing in high levels of CO can result in blurred vision, reduced ability to work or learn, and reduced manual dexterity. CO also contributes to the formation of smog. IAPH, (2007)

Also impacts not linked directly to human health can derive from maritime transport emissions. For instance, sulphur and nitrogen compounds emitted from ships, oxidizing in the atmosphere, can contribute to acidification, causing acid depositions that can be detrimental

to the natural environment (lakes, rivers, soils, fauna and flora). Emissions of these compounds at sea can exert an influence on land-based objects, many thousands of kilometres away, and vegetation.

NO<sub>x</sub> emissions also can cause nutrient overload in water bodies, which can result in eutrophication. The excess of nutrient nitrogen can be detrimental to the fragile balance of ecosystems, including marine ecosystems.

Particles and NO<sub>2</sub> linked to air emissions from maritime transport activities, as highlighted by Holland et al. (2005), can have impacts on visibility, by reducing the visual range.

Considering the global effects, although carbon dioxide is the most important trace constituent as concerns global climate change and shipping is one of the contributors to the world's total CO<sub>2</sub> emissions (870 million tons in 2007, according to IMO (2009)), other pollutants emitted from ships (e.g. nitrogen oxides, carbon monoxide, volatile organic compounds (VOC)) can contribute to the greenhouse effect, leading to enhanced surface ozone formation and methane oxidation (Endresen et al., 2003). Ozone global warming potential occurs because it absorbs both incoming solar radiation in the ultraviolet and visible regions and terrestrially emitted infrared radiation in certain wavelengths. Stratospheric ozone absorbs more energy than it re-radiates, acting as a net source of warming, although it exerts both heating and cooling influences. Ozone resulting from ship emissions – as the NO<sub>x</sub> from ships reacts with ship-based and biogenic ocean/coastal VOCs, or mixes with land-based emissions and reacts – can contribute directly to the warming in the surface-troposphere system.

In particular, the study by IMO (2000) highlights that, due to the highly nonlinear response in ozone formation from emissions of precursors like CO and NO<sub>x</sub>, with higher efficiency in regions that are affected little by pollutants, ozone formation due to ship emissions over oceans away from industrial regions like the Atlantic and Pacific Oceans are more efficient than emissions over polluted coastal regions (e.g., the North Sea).

Moreover, Schreier et al. (2006), underlines that particle emissions from ships change the physical properties of low clouds, due to the so-called indirect aerosol-effect. Particles and their precursors from ship emissions are able to act as cloud condensation nuclei (CCN) in the water-vapour saturated environment of the maritime cloud. Aerosols can re-radiate sun's energy, causing temporary cooling effects that mask the long-term warming of GHGs. This study by Schreier demonstrates that ship emissions modify existing clouds by decreasing the effective radius, while they increase droplet concentration and optical thickness. In particular,

these effects seem more relevant in areas where the background pollutant concentration are low, as at open sea. While modifications of clouds by international shipping can be an important contributor to climate on a local scale, but further studies are needed to assess the global impact of ship-track formation on climate. This cooling also need to be seen in the wider context, according to the Second IMO GHG Study 2009, the CO<sub>2</sub> emissions from international maritime transport are estimated to increase by a factor of 2.2 to 3.3 between 2007 and 2050.

Considering these impacts a legislative intervention in the sector is recognised as being urgently needed. The first step to achieve this objective is to quantify the air emissions from the maritime transport. The next paragraph will give an overview of the main methods to estimate the emissions deriving from shipping activities and will compare their results to define a reference framework.

The focus is on air emissions from international maritime transport.

## **5. Evaluating emissions from the Maritime Transportation Sector: State of the Art**

In the appraisal of possible strategies for the reduction of the maritime transportation sector pressure on the European environment, a key role is played by the evaluation of the total amount of emissions deriving from shipping activities (and possibly of its evolution). However, a debate is still open on which would be the most appropriate way to achieve this. Indeed, the scarce or limited availability of data concerning maritime transportation activities has resulted, during the last decades, in the widespread use of different calculation methodologies. In addition, the application of recently available new technologies for more detailed traffic data acquisition is further questioning the usefulness of methodologies proposed so far. For these reasons a discussion of the approaches followed hitherto as well as of the data actually available is provided in the following sections. All the most important steps found in the scientific literature are considered. In the second section they have been first classified on the basis of approach followed (whether bottom-up or top-down) for what concerns the total emission calculation and the emissions geographic characterization. Then they are briefly described and commented on. It is important to underline from the beginning that it is not possible to indicate a “best” model, but probably it is possible to choose the model that is more suitable for the specific application considered. In the fourth section, data sources which have been used as input among the different approaches are described and discussed. The final section consists of the conclusions of the work.

### **5.1 Classification of the available approaches: bottom-up vs. top-down**

Emissions from the maritime sector account for a non-negligible portion of the total emissions, contributing to human health and climate change problems at all the scales. For this reason their estimation as well as their geographical characterisation are important inputs to the work of, e.g. atmospheric scientists or policy makers who try to analyze and fight the problems connected with them. The level of details (and thus the efforts necessary to reach them) required are different depending of the specific application. As an example, emissions of CO<sub>2</sub> may be analysed at a global scale, whereas NO<sub>x</sub> and SO<sub>x</sub> emissions have to be analysed at a more local scale since they produce the greatest effects on the environment in which they are released. In general, the level of details achieved and achievable within a certain study depends on the approach followed. In a bottom-up approach the single elements involved in a certain phenomenon are modelled and then their impact at a more aggregated level is evaluated by the composition of the impact due to each element.

For the evaluation of emissions due to maritime transport two dimensions have to be considered, namely *how much* emissions do we have and *where* are they emitted. For both of them we can use a bottom-up or a top-down approach and thus we can have a total of four possibilities:

- *Full bottom-up approach*: the evaluation starts from the pollution that a single ship emits in a specific position. Integrating the evaluation over the time and over the fleet it is possible to evaluate total emissions and their geographical distribution;
- *Bottom-up approach in the total emissions evaluations, but top-down in the geographical characterisation*: the single vessel is considered in the analysis, but nothing is known about its position. Making some assumptions it is possible to give an estimate of the total emissions which are later geographically characterised following some criteria;
- *Top-down approach in the total emissions evaluations, but bottom-up in the geographical characterization*: the analysis starts considering the single maritime route or even the single world's geographic cell and evaluating the global activity which is carried out on it no matter which vessel makes the activity. Then some assumptions are used to estimate which categories of ships have used that geographical features;

- *Full top-down approach*: emissions are calculated without considering the single vessels characteristics and are later spatially assigned.

**Table 2 Classification of the main studies concerning the evaluation of emissions from maritime transport**

		Dimension 2: <i>Emissions geographical characterization</i>	
		<i>Bottom-up</i>	<i>Top-down</i>
Dimension 1: <i>Emissions evaluation</i>	<i>Bottom-up</i>	Entec (2005) Wang et al. (2007a, 2007b) Corbett et al. (2009) Jalkanen et al. (2009) Olesen et al. (2009) Schrooten et al. (2009) Miola et al. (2009) Wang et al. (2010) Paxian et al. (2010) Tzannatos (2010)	Endresen et al. (2003,2004*, 2007) Corbett and Koehler (2003*, 2004*) Eyring et al. (2005) Winther (2008)* Dalsoren et al. (2008) IMO (2009)
	<i>Top-down</i>	Georgakaki et al. (2005) Wang and Corbett (2005, 2007) Wang et al. (2008) Winebrake et al. (2009)	Endresen et al. (2007)

\* This papers actually lack of a geographically characterization of emissions

In the table above the main works retrieved in literature are subdivided according to the previously described classification.

### ***5.2 Estimation of emissions due to the maritime transportation sector: state of the art***

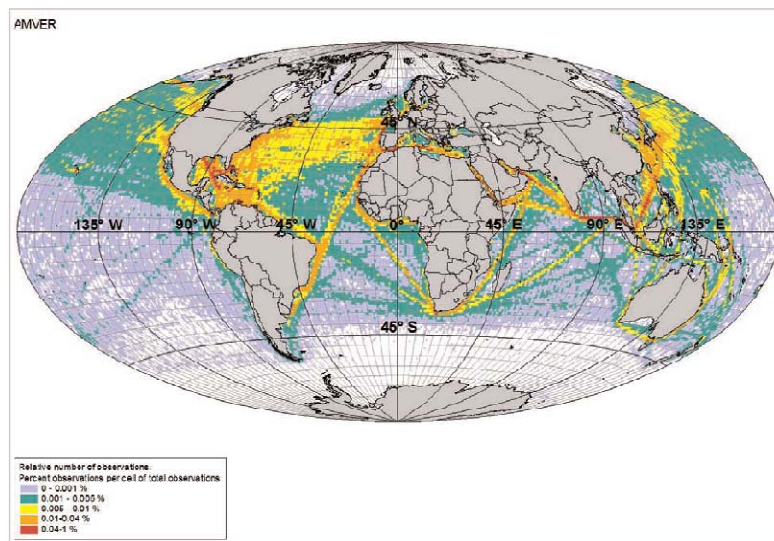
In the present section, an overview of the approaches used in the literature for the estimation of emissions coming from the maritime sector is provided. It is worth considering from the beginning that almost all the studies try to evaluate emissions due to vessels whose gross tonnage (in the following GT) is higher than 100. This has obviously an impact on the evaluations to be considered in the successive analyses.

During the previous two decades several shipping emission inventories have been established. While these are very interesting (for example Olivier et al., 2006; Corbett and Fishbeck, 1997; Corbett et al., 1999), they have not been reported here since they have already been widely discussed in some more recent works. The works are ordered on the basis of the classification provided in the preceding paragraph.

### 5.2.1 Bottom-up approach in the total emissions evaluations, but top-down in the geographical characterization

This approach has been the first to be followed in the last decade.

The first study considered is **Endresen et al. (2003)**. The approach used starts from the single emitter and aggregates to obtain the total emissions. In it the vessels are classified in different categories based on their type, their size, the engine type. The exhaust gas emissions are derived from the fuel consumption of each vessel category by using an emission factor. In particular, given a specific vessel category the fuel consumption is calculated from the product of the specific engine fuel consumption, the average engine load, the average number of annual operating hours and the average installed engine power. What is obtained is then multiplied by the number of vessels pertaining to the specific category considered to obtain the overall contribution of this category to the total emissions. All the parameters are obtained from the literature and considered as average constant and independent values. The number of vessels of each category is derived from the Lloyd's World fleet statistic for the years 1996-2000 (Lloyd's Register of Shipping, 1996, 2000).



**Figure 2. Vessel traffic densities for year 2000 based on the sum of reported distributions from AMVER data**

Source Endresen et al., 2003

The installed engine power is estimated from the vessel size. Emissions calculated in this way do not consider those due to port operations. Since this estimation would be more complex a correction factors ranging from 4 to 9% (depending on the vessel category) has been applied to the total emissions. Authors have used the Norwegian International Fleet Register

(Norwegian Maritime Directorate, 2000) in order to draw inference about the amount of emissions due to international trade and that due to domestic shipping. Uncertainty analysis on the models parameters show that for CO<sub>2</sub> a non negligible uncertainty of 16-20% can be assumed. A further validation of the results obtained has thus been performed, comparing the fuel consumption estimates, with data of the total fuel sales in international shipping as reported in Skjolsvik et al. (2001). Finally, AMVER (U.S. Coast Guard, 2003), COADS (Woodruff et al., 1998) and Purple Finder (Purple Finder, 2001) data (see Figure 1) were then used to geographically distribute emissions.

In **Corbett and Koehler (2003)** a similar approach has been used. First of all they examine the hypothesis followed in Endresen et al. (2003) and elsewhere to drive their models to achieve agreement with international marine fuel statistics, since not all statistical sources define international marine fuels the same way and then some ambiguities may arise. The model taken into account makes direct use of engines power and vessels activity. In particular, they divide the international fleet in subgroups of ships (>100GT). Per each subgroup emissions are evaluated multiplying the *accumulated installed engine power* by the engine load factor based on duty cycle profiles, by the average engine running hours and by the power-based emission factor. The vessels engine power was determined using ship registry data (Lloyd's Maritime Information System, 2002) and engine specific data supplemented by an engine manufacturer. In this way they were able to subdivide vessels in different subgroups (in the number of 132) on the basis of the engine types and to evaluate the total amount (accumulated) installed power per each subgroup. The annual number of hours a marine engine operates was estimated, by several observations, to be around 6500 h/year for main engines and 3500 h/year for auxiliary ones. 80% for main engines and 50% auxiliary ones were the average load factors considered. Emission factors were estimated per each subgroup and per each fuel type following the approach considered in European Commission and ENTEC (2002). Fuel consumption and emissions coming by using this approach resulted sensibly higher than those coming from previous studies. After discussing about the reliability of the results obtained, the study presents a possible cause of the discrepancy between fuel statistics and fuel actual usage. Later on **Endresen et al. (2004)** try to answer to the critics arisen in Corbett and Koehler (2003) pointing out that results obtained in this latter work overestimate the reality having been used in it too high values for the vessels' average number of hours at sea and average load factors. Then, **Corbett and Koehler (2004)** using parameters suggested by Endresen et al. (2004) in their model showed how, even in these more conservative conditions, results are not sensibly affected, thus confirming the overall underestimation there had been in the previous



appraisals on the emissions due to the maritime sector. In addition, according to the authors, the spatial emission representation (which is fundamental for atmospheric modellers to study the pollution dispersion) is still a topic on which is worth investigating. These results have been further confirmed in **Eyring et al. (2005)**. The authors, indeed, apply an activity-based approach similar to that applied in Corbett and Koehler (2003), even if using updated input data.

Following the discussions started in the scientific literature, the National Environmental Research Institute (NERI) of Denmark decided to update their national emission inventories (**Winther, 2008**). In the context of the United Nations Framework Convention of Climate Change (UNFCCC) and the United Nations Economic Commission for Europe Convention of Long Range Transboundary Air Pollutant (UNECE LRTAP) every nation is requested to provide a national emission inventory. For shipping activities it is recommended to link the information to fuels sales data. Due to the inconsistencies detected in previous studies connected to this procedure, NERI decided to update the inventories using an activity-based approach (similar to those presented in Corbett and Koehler, 2003 or Endresen et al., 2003) where possible (due to information availability). In particular it was done for regional ferries (for which very detailed information are available), for local ferries and for other national sea transport. On the other hand, for fisheries and for international sea transport the methodology remains fuel based. Unfortunately, international sea transport accounts for the biggest amount of emissions and thus further refinements are still required.

In **Endrsen et al. (2007)** a new attempt of estimating emission from the maritime transportation sector is provided. Authors present two alternative methodologies for the emissions evaluations. The first approach totally relies upon data on world and national fuel sales (for this reason this work can be classified also as a *full top-down approach*). Applying different emission factors to different fuels they estimate total CO<sub>2</sub> and SO<sub>2</sub> emissions. High uncertainties in fuel sales estimates led authors to consider the derived emissions largely unsatisfactory. On the other hand they apply a bottom-up approach similar to those applied previously but the estimation of the time a single ship spends at sea. In particular they consider different vessels categories depending on the combination of vessels and fuels type. Per each category they consider an *average ship* representing the whole category (with an average fuel consumption, an average number of hours spent at sea, an average installed main engine power, an average engine load). The main declared improvement with respect to the previous work is the estimation of the average time at sea. Indeed, instead of fixing this value

to a “common sense” fixed value, they try to estimate it on the basis of the number of voyages required by the average ship to transport the yearly total cargo volumes. The authors claim that even if approximate, the application of this methodology will result in a substantial improvement of the evaluation reliability. At the same time they discuss about the necessity of considering more detailed data such as AIS (Automatic identification system) data which, however, were still difficult to obtain. Results obtained are in a similar range of uncertainty of those reported in Corbett and Koehler (2004) and Eyring et al. (2005). However the estimates do not consider emissions from auxiliary engines, military ships and from ships whose gross tonnage is lower than 100. This of course should be considered for a more reliable assessment. Detailed ships characteristics are derived from the 2005 Lloyd’s Register of Ships (Lloyd’s Register of Shipping, 2005).

In **Dalsoren et al. (2008)** an approach combining those reported in Endresen et al. (2003, 2007), Corbett and Koehler (2003) and Eyring et al. (2005) is reported. Fleet power is directly evaluated using data from individual ships and 105 ships categories are considered. Ship categories influence the engine load considered, while the operation profile is derived from individual movements of 32000 ships (Lloyd’s MIU, 2004). Results of the study confirm that the estimation problem is far to be solved. Differences in models adopted an inputs values cause the situation to be confusing. Anyway, apart from results coming from IMO (2007), which provide a higher emission estimation, all the other studies seem to pertain to the same range of uncertainties. The approach used in Dalsoren et al. (2008) has been combined with the emission spatial distribution as developed in Wang et al. (2008) to include the maritime transportation sector in the Emissions Database for Global Atmospheric Research (EDGAR, 2009)

AIS data is also used in a recent study published by the International Maritime Organization (**IMO, 2009**) for the prevention of air pollution from ships. In this case, however the approach used for the emissions calculation is more similar to that applied in Endresen et al. (2007), with the ships subdivided in different categories with common features. However input data such as the average number of days at sea per each vessel category (which is considered one of the main source of uncertainty in Enderesen et al., 2007) has been evaluated using information coming from the AISLive network for the whole of 2007. This increases considerably the reliability of the results obtained. In this light it is worth underlying here that emissions estimations presented in this IMO report are in good accordance with those reported in Corbett and Koehler (2003), while in a previous study (IMO, 2007) they considerably

overestimate global emissions. The work, which has led to this report, is particularly interesting, since it has allowed all the main experts in the field to discuss the results reached and to define a *consensus estimate* of emissions that now should be considered as reference point for next studies.

With the evaluation of emissions on a smaller scale such as, for example, a single port, more detailed approaches are considered which rely upon direct measurements of emissions (as in Miola et al., 2009) or upon detailed ships activities (as in Tzannatos, 2010).

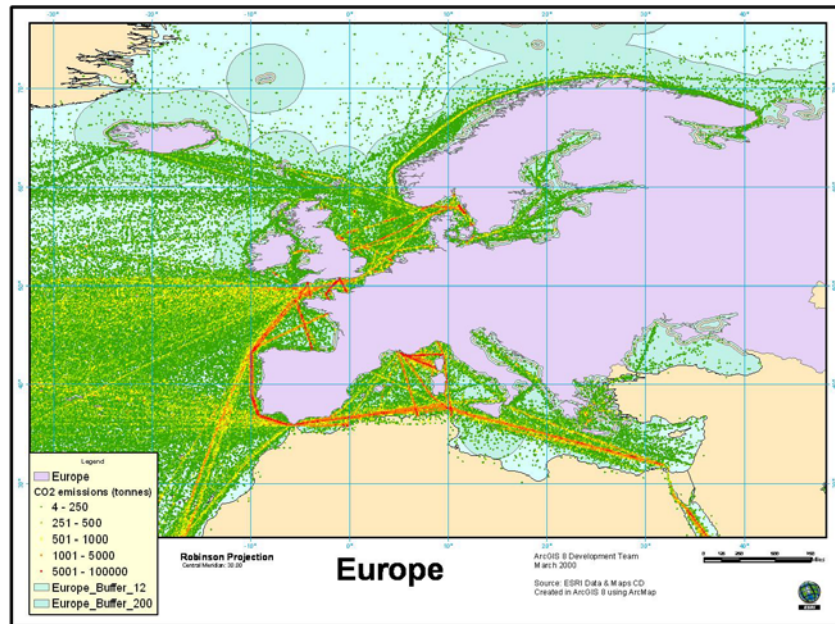
### **5.2.2 Top-down approach in the total emissions evaluations, but bottom-up in the geographical characterization**

This approach has been the first alternative to the previous works.

A different approach is indeed used in **Georgakaki et al. (2005)**. It cannot be classified as bottom-up for emissions, since it does not make any hypothesis on the vessels activities, using in their place a proxy of the European Origin/Destination matrix for goods. On the other hand the approach is bottom-up for the emissions spatial characterization, having been maritime routes explicitly taken into account. In this way the distance travelled by all the ships is known. Then using the Lloyd's Register of Shipping for the year 1994-1995 they try to estimate the other required information for the emission calculation (such as the engine load factor, etc.). The main shortcoming of the work is the lack of any attempt of the validation of the results.

The problem of the geographical characterization of ship traffic and emissions has been investigated also in **Wang and Corbett (2005)** which used ICOADS data (Woodruff et al., 1998, containing information related to actual shipping activities) and domestic traffic databases (such as the USACE Vessel Entrances and Clearances, U.S. Army Corps of Engineers, 2004) to draw inference about the traffic intensity in all the 0.1°x0.1° cells of the world. Such data are used in Wang and Corbett (2007) to evaluate the effect of reducing SO<sub>2</sub> emissions from ships in US West waters. Such estimations have then been improved in **Wang et al. (2008)**. The work carried out in this work is complementary with the development of STEEM (Wang et al., 2007a). Indeed, results derived from the bottom-up STEEM are more accurate, but its use is more complex. For atmospheric modellers and policy makers, a top-down approach could lead to satisfactory results. The improvements introduced to inventories derived in Wang and Corbett (2005) derived from the integration of both AMVER and ICOADS datasets for the emissions spatial representation. The obtained results are unsatisfactory above all in Europe, in which the penetration of both AMVER and ICOADS is less evident. Anyway the work

represents a considerable step forward for the global characterization of emissions from ships and now looks for further improvements coming from regional studies. In addition, the results of the study are publicly available at <http://coast.cms.udel.edu/GlobalShipEmissions/Inventories/>. Through some GIS manipulation it is not hard to perform some preliminary analysis using such data.



**Figure 3. CO2 emissions geographical characterization via improved traffic proxy (Wang et al., 2008).**

In Figure 2 we have used them to evaluate emissions in the European territorial seas (less than 12 nautical miles from the shoreline) and in the European exclusive economic zone (less than 200 nautical miles from the shoreline). Emissions derived using this approach has however been used to study the effects on health of reducing the sulphur content in marine fuel (Winebrake et al., 2009).

### **5.2.3 Full bottom-up approach**

This approach is the most challenging one, above all in terms quality and quantity of data required as input. Anyway, also thanks to the new possibilities offered by technological advancements (in particular AIS data) this approach will see the main research efforts in the future.

In **Entec (2005)** emissions in the European area are calculated by considering ship (port-to-port) movements data (from the Lloyd's Maritime Intelligent Unit, LMIU, database) combined with ships' characteristics (from the Lloyd's Maritime Information System, LMIS database).

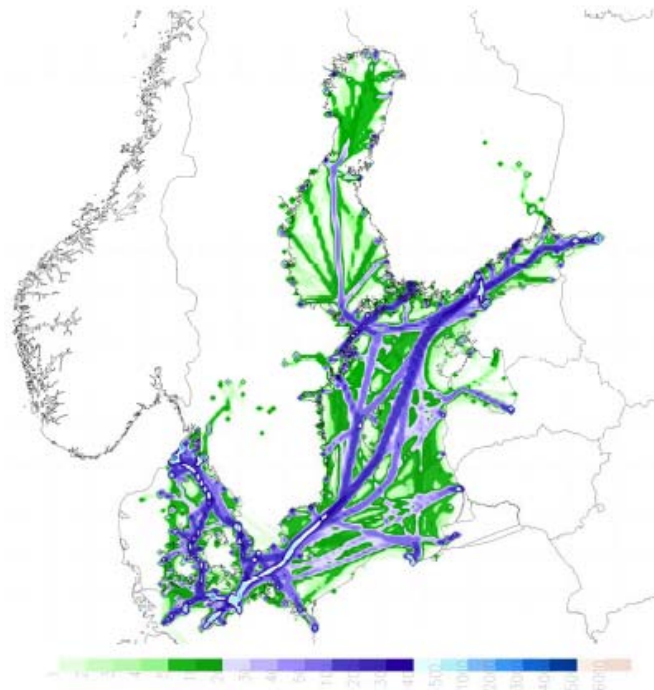
Starting from such information, the study reports seven emission estimations, depending to whom (or what) such emissions are assigned (assigned according to location, to flag of ship, to fuel sales, to fuel consumption, to freight tonnes loaded, to national emissions and to country of departure/destination). In this way they were able to perform different scenarios of emission reductions, basing on the particular assignment considered.

In **Wang et al. (2007a)** a new approach is instead considered. The authors present the STEEM model, which uses a bottom-up approach for emission evaluation and their spatial characterization. The aim of the model is the detailed description of the vessels activities. From the activities it is then possible to derive emissions using detailed vessels information. Using ICOADS data and port data (available at <http://apps.unece.org/unlocode/>) they have first derived a maritime traffic network. They have then assigned to the traffic network all the available ship movements (derived from the U.S. Army Corps of Engineering and from Lloyd's Maritime Intelligence Unit). Finally, knowing ships' activities, technical features and distances travelled, considering the same engines load factors as in Corbett and Koehler (2003), fuel consumption and emissions have been evaluated. The model has been applied in the evaluation of emission deriving from the North American Shipping. Compared from results coming from Wang and Corbett (2005), they have found a considerable improvement of results quality (if compared with dedicated with port/Regional inventories). This approach has been used for improving the cost-effectiveness evaluation of reducing sulphur emissions from ships in United States (Wang et al., 2007b) and for evaluating the cost/effectiveness of reducing the service speed from international shipping (Corbett et al., 2009, Wang, 2010)). A similar approach has then been used also in Wang et al. (2010) for evaluating the economic reasons of China's stance on ships emissions' reductions negotiations.

An evolution of the approach presented in Georgakaki et al. (2005) is that presented in **Schrooten et al. (2009)** in the framework of the EX-TREMIS project (<http://www.ex-tremis.eu>). In this case, the available data was much more accurate. The EUROSTAT database (Eurostat, 2000) provided detailed information regarding the port calls, the total cargo tonnage handled in main ports (also by cargo type and partner entity), etc. This data allowed the authors to create a detailed origin/destination matrix with all the vessels attracted and emitted by each European country.

Recently, a fully bottom-up approach for emissions calculation and their geographical characterization have been presented in **Jalkanen et al. (2009)**. The novel character of this approach is twofold. First of all, ships activities are collected in real time using AIS data (and

thus the actual speed as well as the actual time at sea can be considered for each vessel). In addition, integrating AIS data with data coming from Lloyd's Register of ships, it is possible to rely upon the actual vessels technical characteristics in real time. On the other hand, for the first time the approach used considers the effect of waves on fuel consumption and therefore on emissions. Secondly, the model's results have been validated using data collected directly on-board some vessels. The major accuracy of this model can be appreciated in Figure 4, for what concerns the estimation of NO<sub>x</sub> emission in the Baltic Sea. The only problem may arise using this approach is a low penetration of the AIS monitoring system among the ships. A similar approach has also been recently used by the Danish National Environmental Research Institute to estimate emission from maritime sectors (Olesen et al., 2009).



**Figure 4. NO<sub>x</sub> emissions due to Baltic sea shipping in 2007**

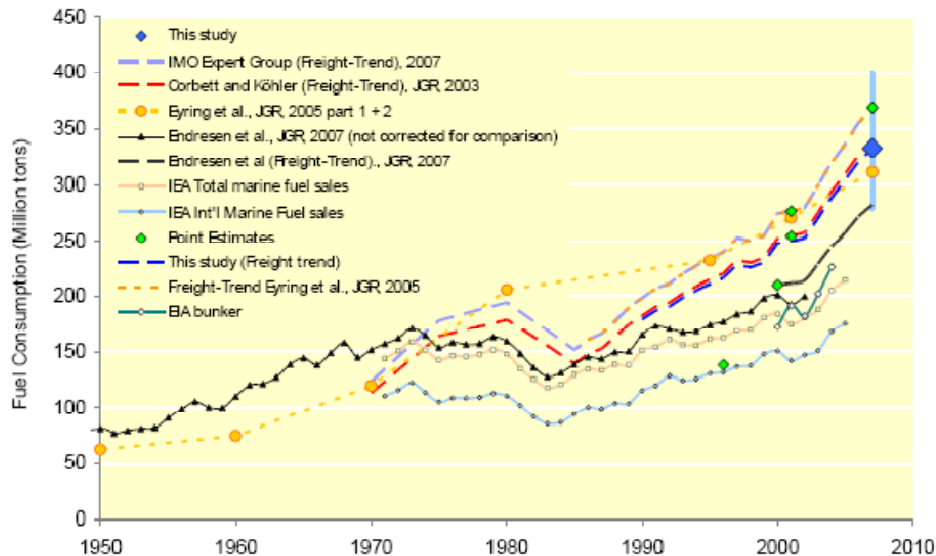
Source Jalkanen et al. (2007)

An alternative full bottom-up approach has been recently presented in **Paxian et al. (2010)** and applied in Faber et al. (2009). In order to overcome the uncertainties connected to the lack of information on ships activities, the authors suggest using vessels movements data which are available in the Lloyd's Marine Intelligence Unit (LMIU) ship statistics. Such movements are identified per each vessel by successive port calls. Then for each couple of ports (in origin and in destination) the shortest path is considered to be followed by the ship. In this way, a single source of information (LMIU statistics) are used both for technological and activity related

ships' information. The only approach limitation is the fact that only a part of the vessels fleet's movements are monitored (approximately 50%) and thus further refinements are required. In Faber et al. (2009), the authors evaluate the total fuel consumption and emissions from maritime sector and compare them with the so-called "consensus" estimated of IMO (2009). Then they apply the ratio between consensus estimates and their estimates to correct results for a more limited context (i.e. fuel consumption and emissions from Europe maritime trades). This of course introduces errors in the results that should be properly evaluated.

### 5.3 Comparison of results coming from different approaches

The debate on the maritime emissions evaluation, which is still open in the literature, has provided during the last decade several different estimations. Their comparison is not that easy, since different scenarios are taken into consideration.



**Figure 5. Fuel consumption estimation and evolution from different sources**

Source IMO, (2009)

In IMO (2009) an attempt to homogenise results coming from different studies has been carried out. It is shown in Figure 5. From the graph it seems that IMO has finally confirmed results coming from Corbett and Koelher (2003) and from Eyring et al. (2005). In the following table we use global CO<sub>2</sub> emissions from international shipping to compare the different studies. The year of reference varies accordingly and no attempt is provided here to homogenise the results, in order not to introduce further distortions. However most of the studies consider the 2001 as reference and thus the comparison is sufficiently meaningful. Table 2 shows the convergence process of the different studies, which is leading to an estimate

with a higher degree of consensus (it is not by chance that more similar results are obtained now that more reliable information on vessels activities are available). In the table also the estimate provided by the International Energy Agency (IEA) and by the U.S. Energy Information Administration (EIA) as reported by IMO (2009) (for what concerns tonnes of fuel sales that have been here transformed into tonnes of CO<sub>2</sub> according to Corbett et al., 2009). It is still surprising to see how they underestimate total emissions.

Among the studies reported in Figure 5 and Table 2, however, there is only one full-bottom up approach (namely Paxian et al., 2010). This can be explained by the fact that these studies have been mainly used in smaller contexts so far (as already underlined in Paxian et al., 2009, the authors derive the global emission estimates only in order to have the coefficient by which correcting results carried out on smaller contexts).

**Table 3. CO<sub>2</sub> emissions from International Shipping: different results from different sources**

	<i>Study</i>	<i>Base Year</i>	<i>Global CO<sub>2</sub> emissions from International Shipping (Mt)</i>
<i>International Shipping*</i>	<i>Endresen et al. (2003)</i>	2001	557
	<i>Corbett and Koelher (2003)</i>	2001	805
	<i>Corbett and Koelher (2003)</i>	2001	805
	<i>Eyring et al. (2005)</i>	2001	812
	<i>Endresen et al. (2007)</i>	2000	625
	<i>Wang et al. (2008)</i>	2001	650
	<i>Edgar (2009)</i>	2001	440
	<i>IEA</i>	2001	550
	<i>EIA</i>	2001	610
	<i>IMO consensus (2009)</i>	2001	652
	<i>Total Shipping</i>	<i>Edgar (2009)</i>	2004
<i>Dalsoren et al. (2008)</i>		2004	654
<i>IMO consensus (2009)</i>		2004	755
<i>Corbett and Koelher (2003)</i>		2001	912
<i>Total Shipping</i>	<i>Eyring et al. (2005)</i>	2001	887
	<i>IMO consensus (2009)</i>	2001	784
	<i>Paxian et al. (2010)</i>	2006	695
<i>IMO consensus (2009)</i>	2006	1008	

\* International shipping is defined as the shipping activities carried out between ports of different countries. International Shipping, Domestic Shipping and Fishing compose the Total Shipping

In the authors' opinion, using together different sources of information can compensate the limitations that each of them holds. However, it is expected this gap to be filled in the next



years in particular with the spread of the newest techniques for maritime traffic data collection.

In the next section taxonomy of the different data sources ,which are available (or will be in the next future) for researchers in maritime traffic, is provide.

#### ***5.4 Summary of possible maritime data sources***

As already pointed out, a key role in defining the best approach to use for emissions evaluation is the availability of information concerning both the maritime traffic and vessels information. First approaches adopted (bottom-up for the emissions evaluation, but top down for the geographical characterizations) relied exclusively upon vessels information, making different assumptions on their activities. Probably this approach is plausible (at least to a certain extent, see for example IMO, 2009), but for sure it has led to the still existing high level of uncertainties. In the following sub-sections we will describe the main source of information.

Before going on, however, we first point out which are the information that are usually necessary for ships emissions evaluation:

1. *Ship's type/category/length/gross tonnage (for possible aggregation in groups)*
2. *power (kW) of ship's main and auxiliary engines;*
3. *age of main engines*
4. *ship's service speed*
5. *engines specific consumption (g/kWh)*
6. *engines running hours*
7. *engine load*
8. *fuel type*
9. *emission factors ( $g_{\text{pollutant}}/g_{\text{fue}}$ ) or ( $g_{\text{pollutant}}/kWh$ )*
10. *routes covered by maritime traffic*

Information of points 1, 2, 3, 4 and 8 are typical vessels technical information. Some of them can also be found in publicly accessible data-sources, while some other (in particular the power, the engine number and types, the fuel used) are only available in few (expensive) databases. Information at points 4, 6 and 7 are instead typical vessels activity information which have to be collected on purpose or by exploiting some available source. Emission factors and other information that can be useful for refining the estimation have to be searched in the scientific literature. Routes of the maritime traffic are instead important for the spatial characterization of activities.

We will start with vessels technical information, then we will present possible sources of vessels activities and we will end with some further useful information.

### 5.4.1 Technical information on International vessels

Only two sources of vessels information have been used in the studies which have been analyzed here.

- the World Merchant Fleet Database provided by the *Lloyd's Register Fairplay* (LRF), (<http://www.lrfairplay.com/>)
- the *Lloyd's Marine Intelligence Unit* (LMIU) database (<http://www.lloydsmiu.com/lmiu/index.htm>)

The common derivation of the two societies suggested by their name is only apparent. Indeed they take the name from the famous insurance company, the Lloyd's of London, but now they represent two well distinct bodies. Only to understand why the name "Lloyd's" is so appealing in this field, it is worth mentioning, that in 1760, marine insurers, based at Lloyd's coffee house in London, developed a system for the independent inspection of the hull and equipment of ships presented to them for insurance cover. A Committee was formed for this express purpose, the earliest existing result of their initiative being Lloyd's Register Book for the years 1764-65-66.

After that a number of ships registers appeared from all around the world resulting in some cases still existing (e.g. the Registro Italiano Navale, RINA, Germanischer Lloyd, GL, and so on). In any case at the moment there is a very small number of societies owning information concerning the entire world's fleet. Actually there exists another source claiming to be the World Shipping Register (available at <http://e-ships.net/>). However, it has never been mentioned in the scientific literature (and it has also never answered our previous requests).

Both LRF and LMIU have developed dynamic systems able to make complex queries on the ships database also on the base of ships movements. The amount of information available for each ship goes much beyond what is really needed for the purpose of our studies (they both have more than 100 fields of information per each vessel concerning its nationality, flag, ownership, details on the cargo and so on). For the purpose of the study it is possible to make the following observations:

- LMIU had probably been designed to be primarily aimed at collecting information concerning vessels movements. It has indeed also an internal AIS engine, while LRF need to be connected to the AISLive engine (<http://www.aislive.com/>) (a separate subscription is also required). From our personal communications with both of them,

LMIU seems also more ready to perform also complex queries involving ships movements.

- LRF, on the other hand, probably holds the largest amount of information. For the purpose of this study, it is very important to underline that LMIU has no information concerning the fuel type(s) used by the ship, which is on the contrary important for the evaluation of different pollutant emissions and the number of auxiliary engines, which is important as well for the evaluation of the total consumption. In addition no information is collected on the ship's fuel consumption, which, even if not indispensable, may be useful for validation of some calculation.
- Finally it is important to underline that both LRF and LMIU have their own vessel classification. This is important to keep in mind in case one would compare information coming from the two sources.

Other, less complete information about ships can be found in some specific search engines such as Equasis (<http://www.equasis.org/EquasisWeb/public/HomePage?fs=HomePage>), or Digital Seas (<http://www.digital-seas.com/start.html>).

#### **5.4.2 Ship activities and geographic distribution of maritime traffic**

An important parameter for the emission calculation is the definition of the number of hours each ship spends at sea. This information has been retrieved, up to some years ago, from specific studies providing average information (in Endresen et al., 2003, it is suggested to use data from [http://www.ssb.no/emner/10/12/40/nos\\_sjofart/arkiv/nos\\_c582/nos\\_c582.pdf](http://www.ssb.no/emner/10/12/40/nos_sjofart/arkiv/nos_c582/nos_c582.pdf) providing statistics from Norway for the year 2000, or from CONCAWE, 1994).

Such references (and of course more modern ones) can be useful for a rough emission estimation, but they cannot be considered satisfactory if compared with another source for this kind of information, the *Automatic Identification System (AIS)*.

AIS system has been introduced by the International Maritime Organization's (IMO) International Convention for the Safety of Life at Sea (SOLAS, 1974). From December 2004 (for further details see [http://www.imo.org/Safety/mainframe.asp?topic\\_id=754](http://www.imo.org/Safety/mainframe.asp?topic_id=754)) it is now required to all international voyaging ships with gross tonnage (GT) of 300 or more tons and all passenger ships regardless of size to have this system aboard. The main motivation for the adoption of this system was its capability of providing precise information about the ships' position that could be used for collision avoidance (Ou and Zhu, 2008). It consists of a shipboard broadcast transponder system in which ships continually transmit their ID, position

and other features to all other nearby ships and shore-side authorities. It is estimated that about 40,000 ships carry AIS equipment.

Information exchanged by each ship are (Ou and Zhu, 2008):

- *STATIC*: IMO number, length and beam, call sign and name, vessel type
- *DYNAMIC*: position, time, course and speed over ground, heading, rate of turn
- *VOYAGE RELATED*: draft, possible hazardous cargo, destination

The signal sent by each ship is not encrypted and thus can be read by any AIS receiver in a range of about 10 nautical miles. This allowed groups of volunteers and private companies to collect such data making them available (for free or not). To the authors' knowledge, main providers of AIS data are *Marinetraffic.com* (available online at <http://www.marinetraffic.com>) and *Lloyd's MIU AIS* (<http://www.lloydsmiu.com/lmiu/ais/index.htm>).

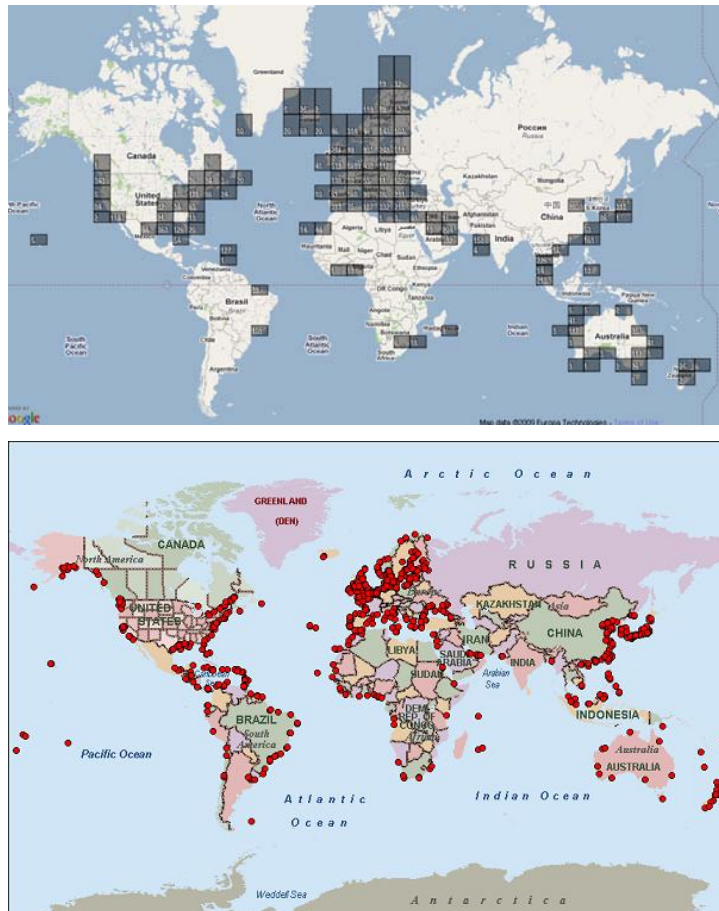


Figure 6. AIS coverage areas for the LMIU network (image on top) and from Marinetransport.com (down)

Marinetraffic.com is developed and Hosted by the Department of Product & Systems Design Engineering - University of the Aegean (<http://www.syros.aegean.gr/>). The consortium of

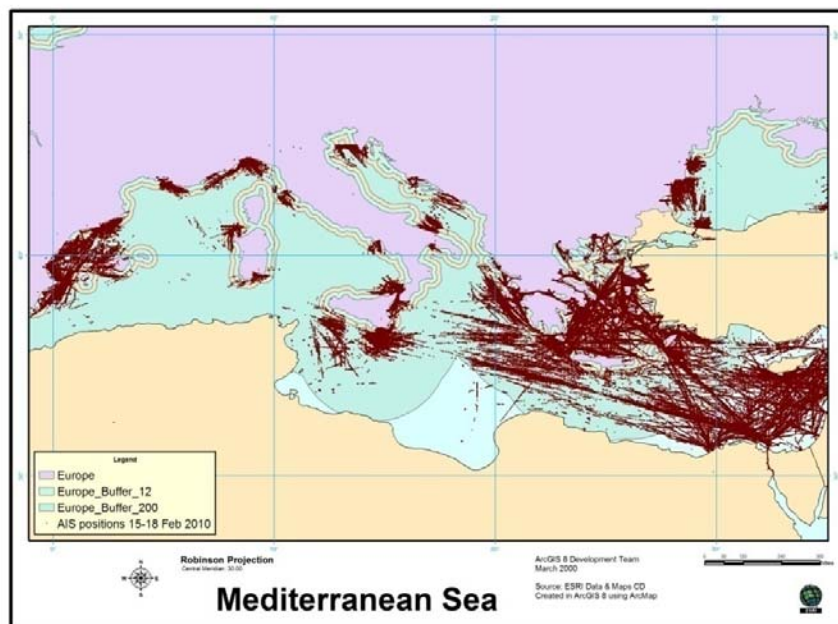
volunteers is composed by 518 receivers which allow the spatial coverage showed in Figure 6. Data retrieved by the site can be used respecting some terms of use (<http://www.marinetraffic.com/ais/terms.aspx>).

Lloyd's MIU AIS has already been presented previously. The network of receivers is totally owned by the society and accounts for 1273 receivers in the world. Access to the data is restricted to the service subscribers.

Anyway there are many other providers both with global or more local spatial coverage (see for example <http://www.aislive.com/>, <http://www.atlantic-source.com/trafico-maritimo> for Spain, <http://www.maritimedata.co.uk/default.aspx> for UK and so on).

Recording AIS data for a certain period it is possible to produce accurate estimations of vessels activities improving emissions and fuel consumption models reliability. This approach has been followed, as an example, for the last report provided by the IMO (IMO, 2009).

In addition, such data can be naturally applied to define actually used maritime transportation networks and, of course, to improve the geographical characterisation of emissions (as done in Jalkanen et al., 2009).



**Figure 7. Ships' positions in the Mediterranean Sea in the period 15-18 February 2010 retrieved by the marinetraffic.com AIS network**

Some risks however exist with AIS data. They are mainly connected with a possible erroneous idea (for an end user) that they always show a comprehensive image of maritime traffic. As already stated (and also showed in Figure 6) an important role is played by the spatial

coverage that the AIS network chosen has. In Figure 7 this role is pointed out. As it is clear the difference in spatial coverage between the Aegean sea and the other waters brings to the definition of a misleading picture of the maritime traffic (Italian and Spanish traffic, as well as the African one and that carried out in the black sea are significantly reduced). For this reason it is crucial having clear information about the uncertainties of the data source one is considering. Another source of possible errors is the penetration of the AIS technology in the fleet working in the area one is considering. Indeed if it is true that at a global level approximately the 50% of ships have this system working on-board (Ou and Zhu, 2008), it is also true that at local scale the picture may be also very different (according to a recent study, MARIN, 2008, the coverage rise up to 90% in the Baltic Sea meaning that in other areas the percentage will be much lower). Finally, as already considered, another problem with AIS data may be the fact that a ship does not exist until it enters the receivers' range. This means that, potentially, during the entire route one can have information only connected with the departure and the arrival. In this way it is always possible to give an estimate of the average cruise speed, but this is of course an approximation. This is a problem in particular when AIS data are used to define an international waterway network. Indeed, using a straight line to cover areas without AIS signal leads to an overestimation of the distance travelled by the single ship. Indeed, even if ships usually do not follow the shortest path (which is given by the "Orthodromic" line) but a route which on a map using a Mercator projection is identified by a straight line (the "Rhumb" or "Loxodromic" line), for long distances they correct their route in order to reduce the total distance travelled (that is to say they follow different "Rhumb" lines trying to follow the "Orthodromic" one). For this reason over long distances the path followed by a ship should appear as a curve. To overcome this problem there exists another source of data, with less frequent (collected only four times per day) information, but available everywhere. It is the *Long Range Identification and Tracking* (LRIT) of ships. It was established as an international system in 2006 by the International Maritime Organization. It applies to ship engaged on international voyages (in particular to all passenger ships, cargo ships of 300 gross tonnage and above, and mobile offshore drilling units).

All these problems may be reduced whether a single entity would take the responsibility for an accurate data collection and distribution. In Europe this role is going to be played by the European Maritime Safety Agency (EMSA) which will take care of both AIS and LRIT data. This would lead to a considerable improvement in the data accuracy for European researchers in the maritime transportation field.

Other sources of information for analyzing vessels activities are vessels' movements data which are provided, for example, by Lloyd's MIU regarding the instant in which each ship has made a port-call. Time elapsed between two successive port-calls may be used as an estimate of the average time spent by the ship at sea. As already described, such information have been used by Paxian et al. (2010) to refine the estimation of the average ships' activities. However also these data are affected by the fact that only a limited percentage of ships register the time of the port call (around 50% according to Paxian et al., 2010), and thus it is necessary to pay attention using them.

Further sources of vessels activities, also useful for the spatial characterization of emissions are the *ICOADS* and *AMVER* datasets. They are not as accurate and complete as AIS data, but can be used for some application (as done, e.g. in Wang et al., 2008).

*ICOADS* (International Comprehensive Ocean-Atmosphere data-set) report ship positions voluntarily recorded by ships. In 2003 about 4000 ships reported to *ICOADS* their data (around 5% of the world fleet). Historical information go back to 1662 and for this reason they are very interesting for analyzing the evolution of the routes and of the navigation over decades. Data are available previous subscription to the *ICOADS* web-site.

*AMVER* (Automated Mutual-Assistance Vessel Rescue System) is used worldwide by search and rescue authorities to give assistance to ships and persons in distress at sea. In 2004 about 9000 ships reported to *AMVER*. Data, however, are not as easily accessible as *ICOADS*.

Finally, to improve the geographical emissions characterization, Wang et al. (2008) used both *AMVER* and *ICOADS* data set to create spatial proxies of traffic activities. *AMVER*, *ICOADS* and their combination are available at <http://coast.cms.udel.edu/GlobalShipEmissions/> as well as the estimates the authors provided of world's emissions from maritime transport.

*AMVER* and *ICOADS* data may be also used for the definition of an international waterway network as has been already done in Wang et al. (2008).

An alternative way to draw inference about maritime traffic activities as well as their spatial distribution is to use origin/destination information of freight and people carried by ships. Information of this type are available from different sources. In U.S. such information are collected and published by the U.S. Army Corps of Engineers, which creates every year the Import Waterborne Data Bank (Wang et al., 2010).

In Europe, on the other hand, traffic data are collected by the European Commission EUROSTAT (<http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home>), which asks

to each member state a summary of the annual transport activities. Data are freely available at <http://epp.eurostat.ec.europa.eu/portal/page/portal/transport/data/database>, per each transportation sector. In the database are available goods and passengers attracted (emitted) by the main ports of each member state from 1997 (where available) classified by type of cargo, nationality of vessels and nationality of origin (destination). In addition, information on the number of vessels each European port handle annually are also available. Using such information it is possible to achieve the transportation demand (in the form of origin/destination matrix) to use as input to understand annual traffic on the different routes. In order to accomplish this aim, however, analysts and practitioners have to create their own transportation network to use for the demand assignment. This can be done, for example considering ICOADS and AMVER data to retrieve maritime routes (as done in Wang et al., 2007a). Some other useful information for this purpose, such as the position of main ports or the port-to-port distance can be found on internet and will be discussed in the following.

Finally, it is also possible to find some information on traffic and emissions as output of some funded projects. As an example, EX-TREMIS project (<http://www.ex-tremis.eu>) gives free access to the methodology adopted for the evaluation of emissions at a European level as well as to the outputs obtained.

As a conclusive remark of the section it is possible to say that a source of information which is better than all the others for all the possible applications in terms of accuracy, coverage and comprehensiveness still does not exist. However, and this is very important, different data sources may be jointly used in order to reduce their overall uncertainties. This consideration has hardly be followed in the literature, also due to the difficulties in achieving different sources of data but will be used in the following in the definition of a possible methodology for the evaluation of emissions from the maritime sector.

### **5.4.3 Further information**

Other useful information, for emissions estimation, are the emission factors<sup>3</sup>.

---

<sup>3</sup> The advantages of permits schemes in terms of pollution control may be undermined by political uncertainties regarding trading and banking provisions (see Hahn [10]), in as much as the performance of emission permits is crucially linked to the commitment of regulators (see, among others, Ben-David et al. [4], Laffont and Tirole [12], Leston [13] and Stavins [21]).



Usually the first step in the emissions evaluation is the estimation of the fuel consumed by each ship (or by each group of them) on the basis of its activities (and thus on the basis of the energy consumed). Specific fuel oil consumption (*SFOC*, measured in g/kWh) is therefore an important input to the appraisal. In IMO (2009) a possible estimation of *SFOC* is provided together with a discussion of the sources adopted (Appendix 1, page 185). For auxiliary engines a possible source of *SFOC* can be found in Oonk et al. (2003)

Once the fuel consumed has been calculated, it is possible to use emission factors to estimate the emission of different pollutants. In IMO (2009) emission factors have been derived from IPCC (2006) for CH<sub>4</sub>, N<sub>2</sub>O, CO<sub>2</sub> and from EMEP CORINAIR (Thomas et al., 2002) for CO, NMVOC, CH<sub>4</sub>, N<sub>2</sub>O, SO<sub>2</sub>, PM<sub>10</sub>. For NO<sub>x</sub> emissions they followed the IMO regulation. It also provides information on other pollutants such as refrigerants (HFCs, CFCs, HFC-22, R717), VOCs and PFCs.

Other sources of emission factors can be Cooper (2003), Dalsoren et al. (2008) for black and organic carbon, Corbett et al. (2009) for a discussion on the CO<sub>2</sub> emission factor.

In addition, for maritime traffic analysis it is very important achieving the geographical location of main ports (to be directly imported in a GIS environment) or the sea distance among them.

Port characteristics data sets may be found at the sources suggested by Wang et al. (2007a). Unfortunately these locations are no more available. A good source can be found already in shapefile (.shp) format at <http://www.evs-islands.com/search/label/download>. Here World Port Index data are reported.

For more macroscopic analysis, one can be interested at knowing only the distance (along maritime routes) among ports. Distance information can be found on internet in several websites (see for example <http://www.distances.com/>, <http://e-ships.net/dist.htm> or on the sea rates website available at <http://www.searates.com/reference/portdistance/>). However by means of these on-line tools it is possible to find the port-to-port distance couple by couple (and therefore they are practically of no use). More useful is instead the NetPass tool (<http://www.netpas.net/>) which allows multiple queries (unfortunately there is a limit of five queries per day in the free trial version).

### 5.5 A possible improved approach for the estimation of emissions from the maritime transportation sector

Following the considerations made previously on the different methodologies applied for estimating air emissions from ships and on the available sources of information on maritime traffic, in this section a possible methodology trying to overcome some of the existing problems is presented. It divides the problem of the air emissions estimation into two sub-problems and thus into two analytical modules:

- “at sea” module in which estimation deriving from ships’ activities far from the shore are evaluated;
- “in port/near the coast” module which mainly uses the available dynamic information on ships to evaluate emissions due to vessels’ manoeuvres in port or near the coasts.

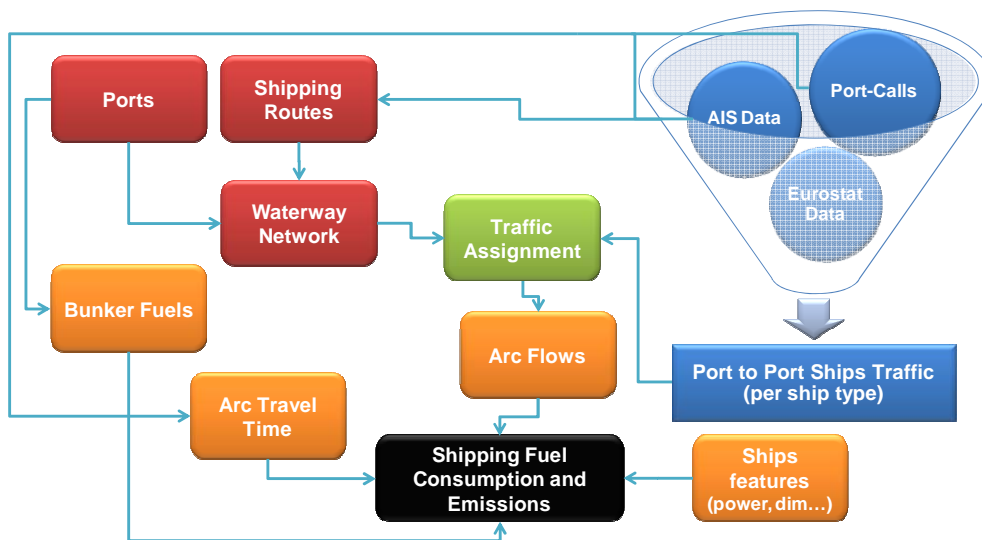
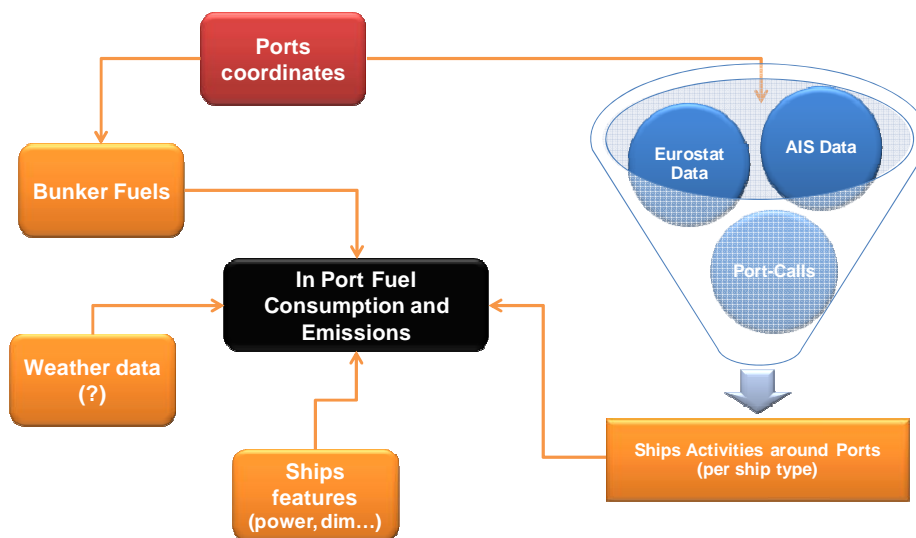


Figure 8. Schematic representation of the “at sea” fuel consumption/emissions module

This difference is relevant in order to evaluate the several impacts that the maritime sector may have on the environment. Air emissions at sea have, indeed, a more global impact, while emissions in port have more local consequences. In addition, while for the evaluation of emissions at sea it is possible to use a more static approach which may only partially consider real-time ships activities, air emissions in port cannot be reliably evaluated without detailed information on ships activities (at least an estimation of the acceleration/deceleration phases would be necessary).

In Figure 8 a schematic representation of the first module is provided. Given the position of the European ports and detailed information on the shipping routes (by means of AIS data as

well as of the other possible information such as LRIT and ICOADS data) it is possible to define a graph representing the international waterway network. AIS data, port-calls data and other aggregated data such as data from maritime transport statistics of Eurostat may be used to estimate annual (or other aggregation periods) origin/destination matrices (different per different vessels types) of the vessels moving among the ports (such data may be used both directly or to calibrate a transportation demand model). Assigning the origin/destination matrix to the network it is not hard deriving the number of ships flowing on the different links of the waterway network graph. Per each link of the graph it is not only known their length but also the statistical distribution of their travel times (using AIS, LRIT and movements data) and thus an estimation of the ships activities on the different links is feasible. Using data concerning ships technical information derived from LRF or LMIU databases and considering (where available) information regarding the type of fuel used in the different ports it is possible to estimate the aggregate emissions from different vessels categories.



**Figure 9. Schematic representation of the “in port” fuel consumption/emissions module**

In the second module (showed in Figure 9) the coordinates of each port are the only geographic information used. Then AIS data, which represent the only source of dynamic information regarding the ships’ movements (or at least those with the highest temporal resolution), may be used in order to have detailed information on ships maneuvers. The other sources of data are then used to obtain information about the number of ships which do not have an AIS receivers working on board in order to improve the total emission estimation. Then the same information as before (ships technical information and information regarding the type of fuel used in the different ports) and possibly also information concerning local

weather conditions might be used to calculate fuel consumption and air emissions. Finally air emissions should be the input of a pollution dispersion model which would provide information regarding the final pollution concentration and therefore the risks to human health.

At the present stage, this methodology is still under development. The oncoming intensive work of data analysis and processing will shed light on additional problems and peculiarities of the data sources that will be considered and thus becoming part of the research itself.

## **5.6 Conclusions**

The evaluation of the total amount of emissions deriving from current and future shipping activities plays a central role to appraise possible strategies for air pollution and green house gases abatement in the maritime transportation sector. However, our analysis has highlighted some limits of the current methodologies as well as scarcity and limited availability of data concerning maritime transportation activities, which makes the achievement of transparent emission reduction strategies a complex task. The scientific debate is still open on which would be the best way to approach this issue, but the identification of before mentioned limits and constraints are the first steps to allow the improvement of estimating emissions from maritime transport.

## **6. The law of the sea: Introductory summary**

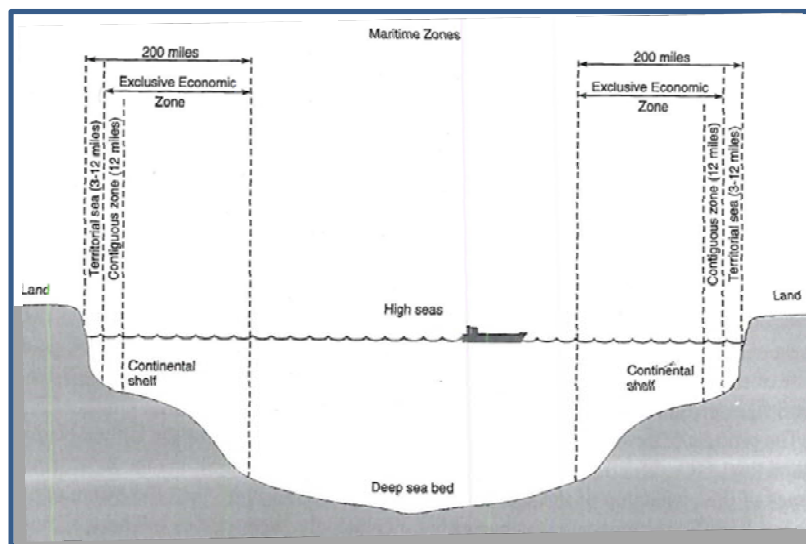
A legislative intervention to control air emissions from international maritime transport requires a clear picture of the international regulatory system and the legal and political framework that regulate this sector. This chapter gives an overview of the complex maritime regulatory system and how the environment issue is integrated in this framework.

The developing process of the law of the sea changed from an initial approach based on separate *ad hoc* attempts to regulate specific problems such as dumping or pollution from ships to a more comprehensive legislative action and it finds its mile stone in the 1982 UN Convention of the Law of the Sea (UNCLOS). In its Preamble UNCLOS defines itself as a *“legal order for the seas and oceans which will facilitate international communication, and will promote the peaceful uses of the seas and oceans, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment”*.

Providing a global framework which could guarantee the importance of freedom of navigation while regulating exploitation and conservation of the sea's resources and the protection of the environment UNCLOS has been seen as innovative framework in the field of international environmental law. To set limits of national jurisdiction over ocean space, access to the sea, navigation, protection and preservation of the maritime environment, UNCLOS distinguishes three levels of enforcement jurisdiction:

- by flag States;
- by coastal States;
- by port States.

This distinction is further broken by UNCLOS depending on whether it relates to States' legislative or exclusive jurisdiction. The first define the limit and the scope to which States may adopt legally binding provisions and rules, while the latter one circumscribes States' power to take measures to ensure the observation of the same provisions<sup>4</sup>.



**Figure 10 Maritime zones.**

Source: Stopford (2009)

The primary jurisdiction over ships is exercised by their flag State, namely a State of which a vessel possesses the nationality and whose flag the vessel is entitled to fly. Flag State jurisdiction can be seen as an extension of the jurisdiction of a State to their ships. Regardless of where it is operating a ship must therefore comply with the laws of their own flag. However

<sup>4</sup> See *The law of the sea: obligations of states parties under the United Nations Convention on the law of the sea and complementary instruments*, United Nations Publications, 2004, pp. 35-41.

Flag State's jurisdiction is exclusive when its vessel is sailing in the Flag State's own waters. The responsibility of regulating safety at sea, preventing collisions, manning the ships and the competence of their crews, fulfilling with labor laws and setting standards of construction, design, equipment and seaworthiness falls on flag States<sup>5</sup>.

UNCLOS Art 94.5 then imposes a duty on flag states to take any steps which may be necessary to secure observance with generally accepted international regulations, procedures and practices. The obligation is repeated in relation to oil pollution in Art 217.

A state having a coastline is entitled under international law to take certain limited steps to protect its own interests. UNCLOS recognises four main zones of varying Coastal States' jurisdiction: internal waters - bays ports and similar enclosed areas of the sea; territorial waters - extending 12 miles to seaward of defined "baselines" along the shore; a contiguous zone - covering the territorial waters and a further 12 miles to seaward; and the exclusive economic zone (EEZ)- extending to 200 miles. A state's powers range from full sovereign powers within internal waters, to rights limited to the exploitation of natural resources on and above the EEZ. According to UNCLOS Article 86 all parts of the sea which are not included in the abovementioned zones form the high seas. Within these zones ships "*shall sail under the flag of one State only and...shall be subject to its exclusive jurisdiction*"<sup>6</sup>.

According to customary law, only flag states can enforce regulations applicable to vessels on the high seas<sup>7</sup>. This principle can also be indirectly read by analysing the combined provisions of Articles 218 and 228 regulating pollution from ships. Whilst under Article 218 Port state may take legal proceedings for discharge violation, Article 228 states that for discharges occurred on the high seas flag states are empowered to intervene and suspend those proceedings<sup>8</sup>.

---

<sup>5</sup> 1982 UNCLOS, Articles 94, 211. On this topic see P. Birnie, A. Boyle, C. Redgwell, *International Law and the Environment*, Oxford University Press 2009, pp. 400-405.

<sup>6</sup> 1982 UNCLOS, Article 92

<sup>7</sup> The Permanent Court of International Justice, in the *Lotus Case* (PCIJ, 1927, Ser. A, No 10, 169), referred to the principle that no state may exercise any kind of jurisdiction over foreign vessels on the high sea, meaning, by this, only that foreign vessels could not be arrested or detained while on the high seas, not that regulations could not be enforced by other states once a ship had voluntarily entered port.

<sup>8</sup> See Ho-Sam Bang, *Port State Jurisdiction and Article 218 of the UN Convention on the Law of the Sea*, *Journal of Maritime law and Commerce*, Vol. 40, No. 2, April 2009.

Going back to Coastal State jurisdiction UNCLOS set three core limitations to this power.

- Under Article 94.5 *“each State is required to conform to generally accepted international regulations, procedures and practices and to take any steps which maybe necessary to secure their observance”*.
- Under Article 227 States shall adopt any measure, which could create a discrimination in form or in fact against vessels of any other State.
- In the territorial sea, the sovereignty of the Coastal State is subject to the right of innocent passage by foreign ships: Coastal states are required by UNCLOS Art 24 not to hamper the innocent passage of foreign ships through the territorial sea.

The right of innocent passage represents a cornerstone of international law of the sea: under Articles 18 and 19 ships are passing when they simply navigate through territorial waters without *“entering internal waters or calling at a roadstead or port facility”*<sup>9</sup> and their passage is considered as innocent when it is not *“prejudicial to the peace, good order or security of the coastal State”*.

However, according to UNCLOS Article 21 Coastal States keep specific powers to adopt laws and regulations in conformity with international laws, which limit the right of innocent passage through the territorial sea. Such powers do not exceed territorial sea and States may adopt laws and regulation only in respect of all or any of Article 21.1 conditions. As for example States may adopt them for regulating maritime traffic, protecting navigational aids cables and pipelines, conserving living resources and protecting the environment generally, preventing reducing or controlling pollution, and preventing the infringement of customs, fiscal, immigration or sanitary laws<sup>10</sup>.

Concerning marine pollution from ships UNCLOS Article 211 strengthens Coastal States' authority: in the exercise of their sovereignty within their territorial sea coastal states may adopt laws and regulations for the prevention, reduction and control of pollution, provided

---

<sup>9</sup> 1982 UNCLOS, Article 18.1 (a). Article 18.2 also states that passage is to be continuous and expeditious, which includes stopping and anchoring which is incidental to ordinary navigation or necessary due unpredictable distress.

<sup>10</sup> However 1982 UNCLOS Article 21 specifically states that the legislation of coastal states *“shall not apply to the design, construction, manning or equipment of foreign ships, unless they are giving effect to generally accepted international rules or standards”*.

they do not hamper innocent passage of foreign vessels. They may include the EEZ in these measures, provided they conform to and give effect to generally accepted international rules and standards.

Finally States exercise Port State jurisdiction over the ships calling at their ports or inland waters. In particular under Article 218 “*when a vessel is voluntarily within a port or at the off-shore terminal of a State, that State may undertake investigations and, where the evidence so warrants, institute proceedings in respect of any discharge from that vessel outside the internal waters, territorial sea or exclusive economic zone of that state in violation of applicable international rules and standards established through the competent international organization or general diplomatic conference*”<sup>11</sup>. Port States, in order to prevent damage to the marine environment by substandard ships, can also, under Article 219, take administrative measures to prevent vessels from sailing allowing them to proceed only until the nearest repair yard or just after the causes of the violation have been removed.

These provisions have been issued following the so called “Port State control” movement which rose within the international community to limit ships registration under flags of convenience which were not enforcing international maritime regulations<sup>12</sup>. To get a complete picture of it the above mentioned articles have though to be read together with 1982 Paris memorandum of Understanding (MoU) in which 14 European States agreed to cooperate in order to increase the standards of ships visiting their ports and waters and to restrict or even ban ships that do not comply with international conventions setting standards on safety and pollution<sup>13</sup>. Such a MoU has been signed on a regional basis to establish a high degree of

---

<sup>11</sup> As it has already been mentioned port state jurisdiction can be limited by flag state jurisdiction when discharges have occurred on the high seas. See footnote n. 4.

<sup>12</sup> See Martin Stopford, *Maritime Economics*, Taylor & Francis, 2009, pp.686-7.

<sup>13</sup> *Ibidem*. The Port State control movement started in 1978 when eight European states located around the North Sea agreed informally to inspect ships entering their internal waters and to share information about eventual deficiencies. Regarding International Conventions setting standards on safety and pollution here a non exhaustive list of them: International Convention on Load Lines 1966 and Protocol of 1988; International Convention for the Safety of Life at Sea 1974 and Protocols of 1978 and 1988; International Convention on Standards of Training, Certification and Watchkeeping for Seafarers 1978; Merchant Shipping (Minimum Standards) Convention 1976 and Protocol of 1996; International Convention on the Control of Harmful Anti-Fouling Systems on Ships 2001.



control over such vessels. Paris MoU, as well as other similar agreements which have been found in other regions of the world<sup>14</sup>, set out that authorities are entitled to carry out inspections on foreign vessels and their documents to ensure their compliance with the above mentioned Conventions and to detain non complying ships until the rectification of all detected deficiencies has been achieved<sup>15</sup>.

International law of the sea finds its highest authority in the International Maritime Organization (IMO) which is a body of the United Nations appointed to set international standards for safety and pollution. It consists of representatives from 152 major maritime nations, including the US. The purpose of IMO's agreement is to settle internationally accepted common standards for Flag States and Coastal States, to reduce the threat to marine environment posed by maritime accidents or discharge of pollutants and invasive species. Therefore IMO could be seen as the main regulatory and supervisory authority concerning maritime law<sup>16</sup>.

Regarding the protection of marine environment the 1973/1978 International Convention for the Prevention of Pollution from Ships (MARPOL) represents the most important IMO's Convention currently into force. The convention's principle articles mainly deal with jurisdiction and powers of enforcement and inspection while more detailed anti-pollution regulations are pointed out within the annexes, which can be adopted or amended by the Marine Environment Protection Committee (MEPC) of IMO with the acceptance of a number of parties representing 50 per cent gross tonnage of the world merchant fleet<sup>17</sup>. Six Annexes of

---

<sup>14</sup> In particular Asia Pacific (Tokyo MoU), the Caribbean, Black Sea and Indian Ocean.

<sup>15</sup> Under Paris MoU each participating Party's administration should inspect at least 25 per cent of foreign vessels calling at its ports annually. This means that every year roughly 14.000 vessels sailing to Europe are inspected to ensure compliance with MARPOL. On this topic see P. Birnie, A. Boyle, C. Redgwell, *International Law and the Environment*, Oxford University Press 2009, p. 407.

<sup>16</sup> See C. Copeland, *CRS Report for Congress, Cruise Ship Control: Background, Laws and Regulation and Key Issues*, 2008, pp. 7-22.

<sup>17</sup> Annex I deals with regulations for the prevention of pollution by oil. Annex II details the discharge criteria and measures for the control of pollution by noxious liquid substances carried in bulk. Annex III contains general requirements for issuing standards on packing, marking, labelling, and notifications for preventing pollution by harmful substances. Annex IV contains requirements to control pollution of the sea by sewage. Annex V deals with different types of garbage, including plastics, and specifies the

the Convention cover the various sources of pollution from ships and provide an overarching framework for international objectives, but they are not sufficient alone to protect the marine environment from waste discharges, without ratification and implementation by sovereign states. All six have been ratified by the requisite number of nations; the most recent is Annex VI, which took effect in May 2005<sup>18</sup>. Each signatory nation is responsible for enacting domestic laws to implement the convention and effectively pledges to comply with the convention, annexes, and related laws of other nations<sup>19</sup>.

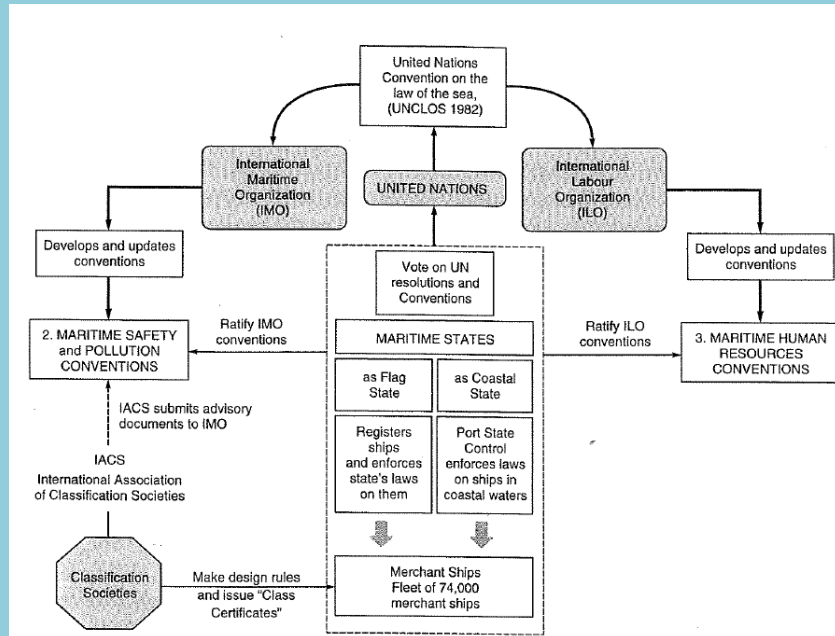
---

distances from land and the manner in which they may be disposed of. Annex VI sets limits on sulphur oxide, nitrogen oxide, and other emissions from marine vessel operations and prohibits deliberate emissions of ozone-depleting substances.

<sup>18</sup> Annex VI regulations have been recently amended by MEPC within its 57<sup>th</sup> session (31 March-4 April 2008). See [http://www.imo.org/environment/mainframe.asp?topic\\_id=1484](http://www.imo.org/environment/mainframe.asp?topic_id=1484).

<sup>19</sup> See on this topic A.K. Tan, *Vessel-source Marine Pollution: The Law And Politics Of International Regulation (Cambridge Studies In International And Comparative Law)*, Cambridge University Press, 2006, pp. 107-75.

**Box 1: The maritime regulatory system**



The maritime regulatory system does not have a supreme legislative body making a single set of international laws. Currently the United Nations Convention on the Law of the Sea (UNCLOS 1982) sets a broad framework including the core principles and rules of international law of the sea, whilst the task of setting and issuing specific regulations consistent with UNCLOS is delegated to two UN agencies, namely the International Maritime Organization (IMO) and the International Labour Organization (ILO). The latter one is responsible for the laws governing people working on board vessels while IMO's main remit includes safety, environmental concerns, legal matters, technical co-operation, maritime security and the efficiency of shipping. At present there are 166 countries, worldwide involved in the shipping sector, which are members of IMO and have to enact its conventions. IMO's governing body is the Assembly. It gathers every two years and it elects a Council, consisting of 32 member states, which act as a governing body in between its meetings. The IMO structure includes five technical and legal committees: Maritime Safety, Marine Environment Protection, Technical Co-operation, Legal and Facilitation. IMO started operating in 1958 mainly with the aim of drafting conventions (especially covering safety, pollution prevention, liability and compensation). However from the 1981 the Assembly decided (Resolution A500 XII) to focus IMO's efforts not only on drafting but also on effective implementation of the conventions. In fact the level of effectiveness of maritime conventions depends mostly on the percentage of countries which actually decide to enact them. As for an example the 1974 International Convention for the safety of Life at Sea still represents one of the most important IMO's conventions due to the fact that it has been accepted by countries whose combined merchant fleets correspond to 99% of the world total.

## 7. Reducing air Emissions from Ship – Technological and Policy options

Designing a sectorial policy strategy to abate air emissions requires the combination of several policy options, which can be categorised into three main groups:

- 1) Technical options reducing emissions without changing the activity involved, but implementing the available technology;

- 2) Operational and behavioural options changing the activity, but not its results;
- 3) Demand or volume options, including a reduction of economic activity.

Which of those is the most suitable instrument depends on the particular circumstances such as the form of the external costs under consideration, as well as the social acceptability of the option in question. A relevant policy dilemma is how to select the most appropriate option for the chosen target. The table 4 illustrates an example of criteria that can be followed to select environmental pollution control options.

**Table 4 Criteria for selection of pollution control instruments.**

Criterion	Brief description
<b>Cost- effectiveness</b>	Does the instruments attain the target at least cost?
<b>Long run effects</b>	Does the influence of the instruments strengthen, weaken or remain constant over time?
<b>Dynamic efficiency</b>	Does the instrument create continual incentives to improve product production processes in pollution reducing ways?
<b>Ancillary benefits</b>	Does the use of the instruments allow a 'double dividend' to be achieved?
<b>Equity</b>	What implications does the use of an instrument have for the distribution of income or wealth?
<b>Dependability</b>	To what extent can the instrument be relied upon to achieve the target?
<b>Flexibility</b>	Is the instrument capable of being adapted quickly and cheaply as information arises, as condition change, or as targets are altered?
<b>Cost if user under uncertainty</b>	How large are the efficiency losses when the instrument is used with incorrect information?
<b>Information requirements</b>	How much information does the instrument require that the control authority possess, and what are the costs of acquiring it?

Source: Perman (2003), p. 203.

The focus of this report is on the cost effectiveness analysis whose basic criterion is the selection of the option achieving some specified objective at the least cost. Typically, cost effectiveness analysis involves calculating a cost effectiveness ratio using the least-cost method, which holds the output constant and seeks the cheapest way to achieve it. Within a cost effectiveness analysis the impacts of different technical alternatives can be determined, but a comprehensive weighting is not done. This method of analysis offers a ranking of regulatory options based on "cost per unit of effectiveness" of each measure. The cost per unit of outcome achieved is usually the criterion of judgment and it is only helpful if the benefit can be measured in one single physical unit (such as, for instance, 8% reduction in CO<sub>2</sub>).

The literature distinguishes three different perspectives to consider the costs: the end users, society (as a whole) and government perspectives.

The perspective of end users (this category includes companies, institutions, households) takes into account the costs directly related to the options and distributed over the various actors.

A society as whole perspective considers external benefits, the government implementations costs related to a policy. The cost-effectiveness analysis for climate change abatement options usually opts for the social perspective. The last perspective, the government one, takes into account the costs of implementation or the government subsidies. However, all these perspectives are in common the central element of the cost effectiveness analysis, which is the direct expenditure, involved in the implementation of the considered abatement options (M. Davidson, H. Van Hessen, 2010). The direct expenditures include: capital costs (the sum total of one-off costs associated with the implementation of the abatement option (*Ibidem*); operating costs (the costs to make the option or the technology operational); regulatory costs (the costs of policy estimation, implementation and enforcement). A comprehensive approach should include: (i) the welfare effects of the overall costs related to an option such as the reduction of air pollutants as ancillary benefits of an option to abate CO<sub>2</sub> emissions; (ii) the indirect effects due to the distortion arising in associated markets (labour or capital markets); (iii) the transaction and information costs.

The following paragraph will identify some methodological constraints to estimate external costs due to air emissions from ships to allow their internalisation will follow. Then, the chapter 9 gives a detailed analysis of the technological options to abate air emissions from ships giving also some indications of their potential and their costs to abate the emissions will be done. The last paragraphs, starting with an analysis of the EU emission trading scheme, will identify and analyse the main legal and economic challenges to design regional and international policies to regulate CO<sub>2</sub> emissions from international maritime transport.

## **8. Estimating external costs of maritime transport**

The placing of monetary values on the externalities associated with transport, although not a necessary condition for policy formulation has a number of distinct associated benefits. Valuing externalities provide an important basis for the implementation of fair and efficient pricing structures, in order to: internalize the social effects of each transport mode; allocate traffic in an efficient manner (modal split, peak and off peak times, optimal environmental performance) and guarantee income (for the financing of infrastructure and transport services). Not to internalize the external costs can cause a wrong market signals and lead to

inefficiencies in the form of congestion, lack of safety and health, and environmental impacts. On the one hand, demand side policies (regulation, taxation and pricing) require estimation of externalities to define optimal terms of mitigation and abatement measures for their internalisation. On the other hand, supply side policies (infrastructures, policies and services) need to assess and to compare alternative options on an equitable basis where all social costs (i.e. internal and external) are taken into account in a consistent and homogeneous approach. The economic valuation of environmental impacts produced by maritime transport represents a challenge for scientific community, due to a variety of effects that shipping has on the natural environment, both at local and global scale. However, besides the increasing awareness of the need for policy interventions in this sector, a comprehensive framework for the assessment of external costs is still lacking. A detailed analysis of the main methodological approaches and their results to estimate air emissions from ships is carried out in A. Miola et al (2008; 2009). Considering the local scale of the environmental impacts of air emissions from maritime transportation, the health effects of air pollutants' are the main externalities that should be taken into account and a bottom up approach has been considered the most indicated to assess these impacts. In particular, this report refers to the methodologies proposed by IIASA *et al.* (Cofala *et al.*, 2007), assessing the impacts of maritime transportation at the EU scale, and by the Clean Air for Europe (CAFE) program (Hurley *et al.*, 2005), which is the most up-to-date and comprehensive study on health impacts. In order to monetize the external impacts of maritime transport (with reference to air pollutants) through a bottom up approach, the following tasks should be carried out: (1) estimation of ship emissions; (2) estimation of ships contribution to pollutant concentration; (3) estimation of exposure of receptors; (4) application of dose-response functions to determine various impacts, (5) monetisation of these impacts. The previous chapters have already underlined the complexity of each phase to estimate air emissions and related impacts. According to Miola et al (2009) we can group broadly in an externalities approach:

- Estimation of impacts. The detailed (quantitative and qualitative) description of the impacts on air pollution has clarified how it is possible, with a certain degree of accuracy, to isolate the contribution of ships and vessels to local pollution. However, one major source of uncertainty (and a crucial point that has to be investigated by future research) is the isolation of the worsening of local environmental quality entailed by ship activities by the concentration of pollutants as measured by local environmental statistics;

- Improvement of impact valuation. All the methodological limitations related to the monetisation of environmental impacts are of interest for the practice of environmental valuation per se.
- Enlargement of scope for analysis. The analysis so far has considered maritime transport in isolation. Nonetheless, it needs to enlarge the scope of the analysis. The reasons are two-fold. On the one hand, shipping and port activities constitute only a step in the transport of goods and persons. Once berthed in port, cargos have to be transported to their final destination through other transport means. This requires port terminals to be served by a complex network of infrastructures. Considering the intermodality patterns of transport is crucial, since the monetisation of external effects of shipping and port activities is not sufficient to give the complete picture of the impacts entailed by transportation. Secondly, the overall environmental performance of shipping and port activities is conditioned by the choice of the other means of transport. For instance, the choice to serve the port with the rail or through road transport has different consequences on the overall impacts entailed by such activities.

## **9. Abatement Technologies: Estimated Performances and Costs**

### **9.1 Introduction**

Despite its higher efficiency if compared with other transportation means, maritime transportation sector is responsible for a conspicuous amount of the total CO<sub>2</sub> emissions (different estimates provide different results, anyway in the range of 3-5%, see for example IMO, 2009). In addition, the existing trends suggest that in the future the situation will worsen (with respect to other fields, maritime sectors has an higher inertia to possible changes and thus it is not surprising if the estimates show that in 2050 it will contribute for the 15% of the total CO<sub>2</sub> emissions). For what concerns other pollutants, the situation is difficult as well. In Lauer et al. (2009) it has been estimated that without any countermeasure, in 2012 sulphate emissions will increase of 10-20% over the main routes, contributing up to 5.2% to the total tropospheric sulphate burden. Furthermore it is also pointed out that the possible decrease of SO<sub>x</sub> emissions is partly compensated by increasing NO<sub>3</sub> if restrictions also on NO<sub>x</sub> are not implemented (Winebrake et al., 2009)). Following this analysis, the authors also show that in 2012 the maritime sector will be responsible for around 90,000 deaths per year due to cardiopulmonary illness and lung cancer. By adopting a global emission restriction policy on

the maritime sector the number of annual deaths may be halved. These results show the complexity of the situation and how starting moving is urgent.

However, there is a possibility that the sector will move towards a more sustainable development using the side door (Motorship, 2009). Indeed, air emissions are directly connected with the fuel consumption. The period of economic uncertainty we are living in has also seen the profits of the ship companies' owners reduced. The main driver of this phenomenon has been the unpredictable increase of the fuel costs. In fact, it is the dependency on fossil fuels that makes the maritime sector very fragile. This renewed consciousness may represent the catalyst that leads shipping to move towards an increased efficiency (with of course usually also means more environmental friendly). This is the reason why a lot of new strategies and technologies to reduce the ships fuel consumption are now attracting the interest of the entire community. There are technologies that are also now available, ready to be employed immediately, and with proven results. These include air cavity systems, wind power, fuel additives, twin propellers, new propeller blades, recovering the waste gas heat and so on. All of them together with the use of alternative "greener" fuels can contribute to reduce NOx emissions by up to 80%, PM up to 90%, SOx up to 90% and CO<sub>2</sub> emissions up to 70% (IMO, 2009).

The estimation of the costs of such technologies is fundamental information to assess the feasibility of their application in the sector. However, this task is not trivial, since a lot of additional information are required. In general terms, the costs related to abatement technologies can be divided into capital (or investments) or operating costs. The capital costs include the construction, the work, the license fees, the delivery of the installation and all the expenditures accumulated until the start-up of the installation. The operating costs are related to the annual expenditures. They include fixed expenditures, as the costs of maintenance and administrative overhead, and variable costs, as the additional labour demand or the increased energy demand for operating the device. The average annual costs are calculated taking into account the investment costs, the fixed and variable operating costs and the normal technical lifetime of the installation. The unitary costs are calculated by relating the annual costs to the abatement emissions. The cost effectiveness is calculated by dividing the annual cost of any measure by the annual emissions reduction of that measure. Moreover, the costs related to abatement technologies are different between new or retrofit vessels.



In the reminder of the chapter a review of the existing possibilities are described. It is worth mentioning that most of them have been taken from the Wartsila's on-line catalogue<sup>20</sup>, this company is a global leader in complete lifecycle power solutions for the marine and energy markets. As will be explained in the following, where available, an estimate of the costs or of the cost-effectiveness of the single technology is also provided.

## **9.2 Available technologies**

In this paragraph, technologies that might be used to reduce fuel consumption and pollutant emissions are presented. The different technologies are grouped into five categories depending on the specific sector they are implemented into. These categories are (Wartsila, 2009):

- Ship design
- Propulsion
- Machinery
- Operation
- Fuel

Per each technology/strategy the types of ship it can be applied to is reported (following a rough classification of Tankers, Containers, Ro-Ro, Ferries and Off-Shore Support Vessels, OSV), as well as the possibility for existing ships to adopt it, an indication of the payback time and an estimate of the connected potential fuel/emission reduction rate. In addition, among parentheses near the technology's name, it is also reported the main outcome of the technology (fuel consumption, pollutant abated).

Finally, where available, an estimate of the technology's cost/effectiveness is reported.

### **9.2.1 Ship design**

In this category all the possible strategies which relate to the design of a ship are included. Most of them can only be applied to new built vessels.

#### *Efficiency of scale (fuel consumption)*

Usually the bigger a ship is, the more efficient it results. This can be reflected on both the construction of new ships and the optimisation usage of the existing ones. Ports machineries

---

<sup>20</sup> <http://www.wartsila.com/>

and infrastructures need to be adapted. Optimising the ships size will result in a 4-5% transport efficiency.

This strategy can be applied to Tankers, Containers, Ro-Ro ships and Ferries and can be considered of short payback time after its implementation.

*Reduce ballast (fuel consumption)*

In order to increase the stability, a ship is usually provided with additional weight in the lowest part of the hull. This weight (usually obtained using water), named ballast, is stored in a particular tank of the ship. It causes a higher resistance to the ships displacement and thus a higher consumption. Reducing the ballast at the minimum feasible level can save up to 7% of fuel consumption. In addition, in new ships, a further ballast reduction can be adopted without losing in the ship stability by increasing the beam by 0.25m.

This strategy can be applied to all vessels categories and can be considered of short payback time.

*Lightweight construction (fuel consumption)*

An alternative strategy to reduce the weight of a ship is the use of lightweight structures. It can be applied only to new ships (of all the types) and should have a short payback time. A maximum 7% increase of efficiency is expected.

*Optimum main dimension (fuel consumption).*

A big impact on the ships resistance is also given by the hull fullness ratio (the ratio between the hull volume and the product of its maximum length, breadth and draft). Reducing this quantity will in turn result in a more efficient ship (up to 9% efficiency increase). It can be obtained by increasing the ship length. This strategy has usually a not really short payback time. According to the data presented in Sames (2009), the increase in efficiency of using e.g. a Baby Post-Panamax vessel would be of about 30% higher than the traditional Panamax one.

*Interceptor trim planes (fuel consumption)*

Interceptor trim planes can be applied to both new and existing ferries and ro-ro ships and consists in positioning a vertical metal plate on the transom of the ship covering most of its breadth. Due to the great pressure that usually exists in that area the interceptor has a great capability of stabilisation causing an increasing efficiency (up to 4%). Its payback time is typically short.

*Ducktail waterline extension (fuel consumption)*

This operates on a similar principle of the interceptor, it consists of lengthening the aft ship. The best results are obtained when coupled with the interceptor. It has been applied to containers, ro-ro ships and ferries. The interceptor has a short payback time. A 7% of efficiency increase is expected.

*Minimizing resistance of hull openings (fuel consumption)*

Openings on the ships’ hull are usually created as bow thrusters tunnels. Bow thrusters are very important to increase the maneuverability big vessels. However if the openings are not designed properly they can significantly contribute to motion resistance. Optimising their design will therefore turn in an increase efficiency. It can be applied to al kind of new and existing ships. The payback period is usually short.

IMO (2009) provides the following estimates (Annex IV, page 286).

**Table 5 Transverse thruster openings**

<i>Transverse thrusters openings (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-145	-140	10.7	0.90%
High reduction potential	-160	-160	53.1	4.20%

*Air lubrication (fuel consumption)*

Air pumped under the ships’ hull creates a carpet between the water and the ship itself with substantially reduced friction. The system is known as ACS (air cavity system) and is assumed to be 30-years lasting. Motion resistance is thus considerably reduced. Depending on the type of ship it turns in a different fuel consumption reduction. This reduction ranges from a minimum of 3.5% for ferries to a maximum of 15% for tankers. The payback period is quite short for most of the ships.

Since the minimal length of the vessels to apply this strategy is 225m, in IMO (2009), the following ship categories have been considered:

- Tankers (crude oil and bulk > 60,000 dwt, LPG > 50,000 m3 capacity and all LNG tankers)
- Containers Vessels > 2000 TEU

The analyses carried out in IMO (2009) consider half of the fuel reduction assumed by the technology suppliers (i.e. 5% for tankers and 3% for containers). Considering new ships costs

reported in UNCTAD (2008) (with a 0.7 correction factor) and that the ACS system should impact for the 2-3% of a new ship price the following cost efficiency table has been obtained (Annex IV, page 275):

**Table 6 Air Cavity System**

<i>Air Cavity System (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-115	-90	7.5	0.90%
High reduction potential	-150	-140	24.4	1.90%

It is worth noting that, according to IMO (2009), a big influence on the effectiveness of this measure is given by smoothness of the hull. This of course causes extra-costs due to maintenance. These costs have not taken into account in the preceding table.

*Tailoring machinery concept for operation (fuel consumption)*

For new built ferries and OSV an opportunity to strongly increase the ship efficiency is given by the opportunity of tailoring the machinery concept to the operation required. As an example the high propulsion efficiency of a single skeg hull form is combined with the manoeuvring performance of steerable thrusters. The concept is limited to new built ferries and OSV. It has a short payback time and has the possibility of increasing the ship efficiency up to 35%.

**9.2.2 Propulsion**

In this category are included all the possible strategies which relate to the propulsion system of a ship.

*Wing thrusters (fuel consumption)*

It represents an innovative propulsion concept able to increase the efficiency of 8-10%. It can be adopted only by new ro-ro ships, ferries and OSVs. It has a quite short payback period.

*CRP propulsion (fuel consumption)*

In this propulsion concept, a single propeller is substituted by a pair of propellers behind each other that rotate in opposite directions. It can be adopted by all new built types of ships. The efficiency gain is around 10-15%. The implementation costs seem to be quite higher than other solutions resulting in a longer payback time.

*Propeller design and monitoring (fuel consumption)*

The propeller(s) of a ship plays an important role in the consumption. Several strategies can be adopted to increase the efficiency: i) it is possible to optimise the interaction between propeller and hull, ii) propellers-rudders combinations, iii) advanced propeller blade section, iv) propeller tip winglets, v) propeller nozzle and vi) propeller monitoring. Almost all these strategies can be applied to both new and existing ships (all can be applied to tankers and containers, while the other ships types can adopt only some of them). The payback period is generally short. Overall these strategies can contribute to a 15% increasing of efficiency.

In IMO (2009) the cost effectiveness of propeller performance monitoring, propeller/rudder combination and upgrade and of propeller upgrade (with winglet, nozzle and boss cap fins) has been evaluated. The results are reported in the following tables (Annex IV, pages 279-280):

**Table 7 Propeller Performance monitoring**

<i>Propeller Performance monitoring (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-135	-130	5.4	0.40%
High reduction potential	-160	-160	42.5	3.40%

**Table 8 Propeller/rudder upgrade**

<i>Propeller/rudder upgrade (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	90	120	19.7	1.60%
High reduction potential	-80	-70	58.5	4.70%

**Table 9 Propeller upgrade (winglet/nozzle)**

<i>Propeller upgrade (winglet/nozzle) (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	530	600	1.3	0.10%
High reduction potential	-90	-80	11.2	0.90%

**Table 10 Propeller boss cap fins**

<i>Propeller boss cap fins (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-155	-150	42.9	3.40%
High reduction potential	-155	-155	53.1	4.20%

In particular this latter has been estimated assuming a capital cost of 20,000€ for 735kW engine and of 146,000€ for 22,050kw one (the cost varies linearly with the power between the two extreme values), a 10 years lifetime and the possibility to be used by all the vessels.

*Constant versus variable speed operation (fuel consumption)*

Reducing the number of revolutions of the propellers with the speed would save up to 5% of fuel.

*Wind Power (fuel consumption)*

A very promising option to increase vessels efficiency is to use energy coming from wind. Different opportunities exist. Sails installed on the deck or a kite attached to the bow of the ship represent an option (leading to an increase in efficiency up to 20% for all kind of ships apart from OSV), while another opportunity is to use vertical rotors able to convert wind power into thrust, exploiting the so-called Magnus effect (Magnus, 1852). The latter can be applied only to tanker and ro-ro ships with a 30% potential efficiency improvement. A medium payback time characterizes both the options. According to Faber et al. (2009) rotors placed on the ships' decks can contribute to reduce fuel consumption from 3.6% of crude oil tanker with deadweight (dwt) smaller than 200000 tonnes to 12.4% of bulk carrier with dwt < 99000 tonnes.

More specifically, for what concerns the opportunity of using a towing kite to use the wind energy, the optimal configuration is achievable with vessels having a minimum length of 30m and a minimum speed if 16 knots. For these reasons only tankers and bulk carriers are being considered as potential users (IMO, 2009). The IMO report (IMO, 2009) also attempts the evaluation of the 2020 cost efficiency of this kind of application. Starting from the available towing kites (up to 640 m<sup>2</sup>) and assuming that by 2020 there will be kites up to 50.000 m<sup>2</sup> to be used in the largest vessels the report provides the following table of Cost efficiency and abatement potential (Annex IV, page 272).

**Table 11 Towing Kyte**

<i>Towing Kyte</i> (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-85	-75	37.1	3.00%
High reduction potential	-135	-130	100.9	8.00%

In the table two scenarios are considering basing on the number of days at sea the kite can be used (33 or 67%).

#### *Pulling thruster (fuel consumption)*

Another technological option dedicated to new ferries, ro-ro and OSV ships is the pulling thruster. Different configurations can be chosen leading to a 10% potential consumption reduction. This option is characterized by a quite short payback period.

#### *Seawater Lubricated Stern Tube Bearing System (fuel consumption + oil waste reduction)*

Apart from atmospheric emissions, maritime transport also impacts on the environment for the discharge in sea of exhausted oil. A source of this oil is that contained in the stern tube. This oil is necessary to allow the seal of the propulsion system to work properly. The problem is that in some cases, a small damage to the system makes the oil flow directly into the sea. If we consider that typical stern tubes contain 1500 litres of oil, it is possible to image how significant the problem is. Recently, the possibility of substituting the oil with seawater has been evaluated (Carter, 2009). The first outcomes of this strategy are the environmental and economic benefits connected with avoiding oil usage. Furthermore, as shown Lavini *et al.* (2007), the use of seawater also allows an efficiency increase of around 2%.

### 9.2.3 Machinery

In this category are included all the possible strategies which relate to the ship's machinery. With respect to the other groups of options, in this case environmental benefits are not only connected to energy efficiency but also to other factors, such as the use of alternative sources of energy etc.

#### *Hybrid auxiliary power generation (fuel consumption)*

Using the electric energy produced by a fuel cell and stored in batteries a hybrid system is able to maximize the energy efficiency by balancing the loading of each component. Despite the

overall increasing efficiency is lower than 2%, the use of the fuel cell can lead to a reduction of NO<sub>x</sub> and particles higher than 60% and a reduction of CO<sub>2</sub> of about the 30%. It can be implemented on all types of new ships and has a short payback period.

In addition it would be advisable for ships when are in ports to use shore-side electricity instead of producing it. This is likely to generate considerable emissions reductions since the average efficiency of power station is much higher than that of ships' power generators. In Hall (2009) an analysis has been carried out with this purpose. In the following table a comparison between emission generated by the production of shore-side and on board electricity is reported for the UK case.

**Table 12 Potential emissions reduction with Shore-Side electricity**

Pollutant	Ships power generator emissions (g/kWhe)	Power station emissions (g/kWhe)	Reduction (%)
NO <sub>x</sub>	14.1	1.2	91.6
CO	0.9	0.2	75.6
SO <sub>2</sub>	2.2	1.2	45.8
CO <sub>2</sub>	718.6	542.6	24.5

Source: Hall (2009) Table I, page 3

The situation is not as positive everywhere. Indeed in China, Indonesia, Russia, and the United Arab Emirates there would be an increase of pollutant emissions. On the other hand there are countries such as Norway, France, Belgium and Brazil, but also Japan, Spain and Italy in which the situation is more favourable than in UK due to a more extensive use of renewable sources of energy.

Nevertheless, in Entec (2005a), an attempt of providing an estimation of the cost of using shore-side electricity has been provided. Results are reported in the following table.

**Table 13 Shore-Side electricity costs (€/tonne) (ENTEC, 2005A, Table 5.2, Page 39)**

Emission	Ship type	Small Vessel €/tonne	Medium Vessel €/tonne	Large Vessel €/tonne
NO <sub>x</sub>	New	9,662	5,371	3,847
	Retrofit	12,086	6,631	4,704
SO <sub>2</sub>	New	9,889	5,498	3,937
	Retrofit	12,370	6,788	4,815

Source: ENTEC (2005A), Table 5.2, Page 39

#### *Diesel electric machinery (fuel consumption)*

A similar concept can also be applied to the main engines of a ship. The use diesel electric machinery are used during normal operation can provide important benefits to the overall



ship's efficiency. The system can be applied to new built ro-ro ships, ferries and OSV. The payback period is relatively short. The situation would be even much better in case of a fully electric main engine (see Hansen, 2009). Fuel savings are estimated to be up to 20%.

#### *Internal Engine Modification (IEM) (NO<sub>x</sub>, VOC, PM)*

They involve changes to the combustion process within the engine and are oriented to optimise combustion, improve air charge characteristics or alter the fuel injection systems thanks to engine modification. Since many parameters influence the combustion efficiency and emission formation, many technological changes have been proposed. Large parts of them aim to cut NO<sub>x</sub> emissions reducing peak temperature and pressure in the cylinder. IEM can be divided in two main categories: Basic and the Advanced (Entec, 2005b).

Basic IEMs change the conventional fuel valves with low-NO<sub>x</sub> slide valves. The purpose is to optimize spray distribution in the combustion chamber without compromising on component temperatures and engine reliability. Currently, the Basic IEM is only applicable for slow-speed 2 stroke engines. Since all cylinders can be changed simultaneously, installation can take a day per engine and does not require being in dry dock. However, all new engines of this type are thought to have these valves fitted as standard. Slide valves provide a reduction in NO<sub>x</sub>, VOC and PM emissions (Aabo, 2003).

Advanced IEMs are instead optimised combinations of a number of IEMs developed for particular engine families. They include: retard injection (30% reduction estimation, EPA, 2003, but also risk of efficiency reduction), higher compression ratio (up to 35% NO<sub>x</sub> reduction, Wartsila 2004a), increased turbo efficiency, common rail injection, etc. The most common combination used is increased compression ratio, adapted fuel injection, valve timing and different nozzles (EPA, 2003). A reduction rate of 30-40% in NO<sub>x</sub> emissions is generally achieved. Wartsila, Caterpillar and FMC are the main manufacturers. However, advanced IEM for ships are generally still in the development phase (Wartsila Corporation, 2004).

#### *Water Injection (NO<sub>x</sub>)*

Water injection is used to reduce the combustion temperature. Using a valve, it cools the combustion chamber during or before combustion, by injecting water directly into the cylinder (Wartsila, 2004a). The engines with water injection are equipped with a combined injection valve and nozzle that allows injection of water and fuel oil into the cylinder. Since the water and the fuel system are separated, neither of the modes will affect the operation of the engine. However, separate pumps for the fuel and water are needed and storage and

bunkering of freshwater is necessary. Wartsila and Man B&W are the main producer of water Injection technologies. In order to achieve a 50-60% NO<sub>x</sub> reduction a 40-70% water/fuel ratio is required (Sarvi, 2004). Unfortunately, they increase the fuel consumption and smoke emissions and, considering the elevated costs, they have a short lifetime (Eilts and Borchsenius, 2001).

Alternatively, Humid Air Motor (HAM) can be considered. It uses seawater to add water vapour to the combustion air. Based on decrease of combustion temperature it reduces the NO<sub>x</sub> formation up to 80% (Eyring, et al., 2005). From an economic point of view, high initial costs have to be sustained to install the humidifier, which also require large surface and volume. However, the low consumption of fuel and lubricating oil consumption allows reducing the operating costs of the engine. The experience carried out on the Viking Line's MS Mariella has shown an emission reduction from 17 to between 2.2 and 2.6 g/k Wh and a fuel consumption decrease of 2-3% (Det Norske Veritas, 2005).

#### *Exhaust Gas Recirculation (EGR). (NO<sub>x</sub>)*

Exhaust Gas Recirculation (EGR). Thanks to recirculation process, a portion of exhaust gases is filter, cooled and circulated back to the engine charge air. Decreasing the peak cylinder temperature, it reduces the formation of NO<sub>x</sub> during the combustion process. A reduction of 35% in NO<sub>x</sub> emissions is expected (Entec, 2005b). On the contrary, smoke and PM tend to increase because of the reduced amount of oxygen and longer burning time. Moreover, since exhaust gases contain gaseous sulphur species, a corrosion problem from sulphuric acid formation is generated (EPA, 1999). For this reason it is difficult to use EGR for marine diesel engines using heavy fuel oils on a fully commercial scale. EGR can also be applied in combination with Water. In this case up to 70% reduction in NO<sub>x</sub> emissions below the IMO limit might be obtain.

#### *NO<sub>x</sub> control methods (NO<sub>x</sub>, fuel consumption, particulate matter)*

These methods are centred on treating the engine exhaust gas itself either by re-burning the exhaust gas or passing it through a catalyst or plasma system. Among them the following alternatives can be considered.

Re-burning reduces NO<sub>x</sub> emissions reintroducing the fuel into the exhaust gas. It is then re-heated in a boiler but at significant less temperature than the combustion within the diesel itself. The main drawbacks are that the thermal efficiency is reduced and that a significant increase in cost and space requirements occurs.

Selective Catalytic Reduction (SCR) uses catalyst to convert NO<sub>x</sub> emissions into nitrogen and water by reaction reducing agents such ammonia (NH<sub>3</sub>) or urea (CO(NH<sub>2</sub>)<sub>2</sub>). No limitations exist about the ships types and it allows reducing NO<sub>x</sub> emission up to 90-95%. To reach 90% NO<sub>x</sub> reduction 15 g of urea are approximately needed per kWh energy from the engine (EEB et al., 2004). Moreover, lower fuel consumption can be combined with low NO<sub>x</sub> emissions because the engine may be fuel-optimized. The most critical problems are the space requirement for the catalyst elements and storage of ammonia or urea and also the investment and operational costs are appreciable. Clean fuel will prolong the life of the catalyst and decrease the maintenance necessary. Once installed it is in most cases operating nearly 100% of the time (Trozzi and Vaccaro, 1998; Sorgard et al., 2001). Alternatively Selective Non-Catalytic Reduction (SNCR) can be used which works similarly to Selective Catalytic Reduction but without use of catalyst. A reducing agent (ammonia or urea) injected during the combustion process, transform the nitrogen oxides to nitrogen and water, reducing a 50% of NO<sub>x</sub> emissions (Sorgard et al., 2001; Marintek, 1999). The drawback of the system is that it is less efficient than the Selective Catalytic Reduction, because only 10-12% of ammonia react with NO<sub>x</sub>. Since the cost of ammonia is about the same as the cost of heavy fuel oil (Trozzi and Vaccaro, 1998) and since the system requires extensive modification to engine, the SNCR doesn't seem to be competitive.

Plasma Reduction Systems is based on the use of plasma. This is a partially ionized gas comprised of a charge of neutral mixture of atoms, molecules, free radicals, ions and electrons. Electrical power is converted into electron energy and the electrons create free radicals, which destruct pollutants in exhaust emissions. Experiments have shown that NO<sub>x</sub> can be reduced up to 97%. It seems to be flexible in terms of size and shape and should be relatively low cost. However, for marine use, it is still in development phase.

WiFE on Demand is a system that reduces NO<sub>x</sub> emissions providing water in fuel emulsion "on demand". It can be really effective in environmental and legislative hot spots. It is a fuel emulsion technology for marine vessels that recycles oily waste water from on board for safe use in the combustion process, eliminating the need for costly disposal of oily waste on shore. It can work with a variety of water to fuel ratios, from 0% to 50%, on the base of the water available on the vessel and in proportion that is appropriate to specific operating conditions. A 30% of water in fuel emulsion can reduce NO<sub>x</sub> emissions by 30% and particulate matter (PM) by 60-90%. It can be retrofitted to a variety of vessel types and fuel system. From an economic point of view, it seems to be a cost-effective pollution solution.

**Table 14 Scrubber Costs used in AEA (2009) (Table 6.4, page 33)**

Technologies	Ship type	Investment (k€)	Lifetime (Years)	Operation and Maintenance (k€)
Basic IEM	Retrofit	9	2.5	0
Advanced IEM	New	20	25	0
EGR+WIF	New	743	25	15
EGR+WIF	New	743	25	22
EGR+WIF	New	743	25	39
EGR+WIF	New	743	25	65
SCR	New	949	25	169

Source: AEA (2009) (Table 6.4, page 33)

In AEA (2009) the costs presented in Table 14 have been used for analyzing the cost-effectiveness of NOx reduction techniques.

In Table 15 the estimation of the cost/effectiveness of the previous technologies is reported as elaboration of the estimates provided in (Entec, 2005b, Rehai and Hefazi, 2006, Lovblad and Fridell, 2006 and IIASA, 2007).

**Table 15 Cost effectiveness of NOx reduction measures per €/tonne.**

Technologies	Ship type	Small Vessel €/tonne	Medium Vessel €/tonne	Large Vessel €/tonne
Basic IEM	New	11	9	9
Basic IEM	Retrofit	35	16	12
Advanced IEM	New	93	36	18
Direct water injection	New	391	353	328
Humid air motors	New	255	222	188
Humid air motors	Retrofit	291	274	250
SCR outside SO <sub>2</sub> ECA	New	704	558	501
SCR outside SO <sub>2</sub> ECA	Retrofit	770	607	543
SCR inside SO <sub>2</sub> ECA	New	517	419	379
SCR inside SO <sub>2</sub> ECA	Retrofit	583	469	422
SCR ships using MD	New	393	411	207
SCR ships using MD	Retrofit	460	473	341

Source: data are in accordance with what reported in EMTEC (2005b), Rahai and Hefazi (2006), Lovblad and Fridell (2006) and IIASA (2007). Notice that ECA stands for Emission Control Area and MD for marine distillates.

*SOx control methods (NOx, fuel consumption, particulate matter)*

Sulphur oxide is a pollutant emissions produced during the combustion process. Since it is directly proportional to the content of sulphur in fuel, the main method to reduce sulphur oxide emissions is to reduce the quantity of sulphur in fuel. In 2005, the European Commission established that, from January 2010, the marine fuels used at berth shall not exceed 0.1%

sulphur content. However, to reduce sulphur oxide emissions abatement technologies can also be used and literature documents several dozen of them (Rentz et al., 1996; Takeshita, 1995). Combustion modification represents a first option. It uses the addition of limestone (CaCO<sub>3</sub>) or dolomite (CaCO<sub>3</sub>\*MgCO<sub>3</sub>) into conventional boilers. Usually, the process injects limestone into pulverized coal-fired boiler, which achieves emission reduction rated from 50 to 60%. Another method is the Fluidized Bed Combustion (FBC) that removes SO<sub>x</sub> and NO<sub>x</sub> emissions with high efficiencies but is still expensive. One of the main problems of the combustion modification is the large amounts of waste that are produces. This can be a problem for the increasing difficulties with waste disposal and costs.

*Scrubbers (NO<sub>x</sub>, SO<sub>x</sub>, particulate matter)*

Scrubbers deserve a specific section since they are able to effectively abate different kind of pollutant. They use alkaline compounds to neutralize sulphur oxides in the scrubber and transfer them into the water in the form of sulphates (Trozzi and Vaccaro, 1998). They can reduce SO<sub>x</sub> by 99% and NO<sub>x</sub> and particulate by 85% without increasing the CO<sub>2</sub> production. Retrofitting the existing commercial fleet over 25000 dwt would take 5 years and would cost 250x10<sup>9</sup> \$, five time less and more rapidly than, for example, distilling the fuel. In Winkler (2009, page 87) are provided the prices for scrubbers reported in Table 16.

**Table 16 Indicative scrubber costs for different ships categories**

Vessel Type and average fuel usage per year (with total vessel power)	Indicative Scrubber Cost (\$)
Ferry 23,850 tons (34MW)	3,400,000
Tanker 28,000 tons (30MW)	2,400,000
Cruise 40,000 tons (40MW)	3,200,000

Source: Winkler, 2009, page 87

Two scrubbing methodologies exist: Sea Water Scrubbing and Fresh Water Scrubbing. Seawater is an ideal scrubbing agent because it has an adequate level of alkalinity and already contains 900mg per litre of sulphur as a natural constituent, thus it makes it perfect for removing acid gases from the exhaust emissions. After this process, the water is filtered to remove particulates and re-circulated back into the sea (EEB et al., 2004).

The solid particles removed from the gases are trapped in a settling or sludge tank and collected for disposal. On the other hand fresh water scrubbing uses a caustic soda (NaOH) solution for neutralizing the sulphur. This washing solution is pumped from the process tank

through a system cooler to the scrubber. From the scrubber the washing solution returns to the process tanks by gravity. Uncertainty exists about the effects of waste water on sea. It still remains to be demonstrated if this cleaning technology is environmentally suitable in all types of environment (shallow water, brackish waters and enclosed port areas).

Generally, the amount of sulphur discharged seems to be insignificant compared to the quantity of sulphate that the seawater naturally contains (Trozzi and Vaccaro, 1998). However, based on precautionary principle, the Annex VI of the MARPOL forbids discharging waste into estuaries and enclosed ports (EEB et al., 2004).

**Table 17 Scrubber Costs used in AEA (2009)**

Technologies	Ship type	Investment (k€)	Lifetime (Years)	Operation and Maintenance (k€)
Scrubber 1.5-open	New	1148	15	23
Scrubber 1.5-closed	New	2296	15	193
Scrubber 1.5-open	Retrofit	2296	12.5	23
Scrubber 1.5-closed	Retrofit	4592	12.5	193
Scrubber 0.5-open	New	1148	15	23
Scrubber 0.5-closed	New	2296	15	296
Scrubber 0.5-open	Retrofit	2296	12.5	23
Scrubber 0.5-closed	Retrofit	4592	12.5	296
Scrubber 0.1-open	New	1148	15	23
Scrubber 0.1-closed	New	2296	15	347
Scrubber 0.1-open	Retrofit	2296	12.5	23
Scrubber 0.1-closed	Retrofit	4592	12.5	347

Source: AEA (2009) (Table 6.4, page 33)

In AEA (2009) for the scrubbers cost/effectiveness evaluation it has been considered a cost of 0.2€<sub>2005</sub>/l for urea, 0.5€<sub>2005</sub>/l for NaOH and the following additional costs parameters.

In the following table the estimation of the cost/effectiveness of the previous technologies is reported as elaboration of the estimates provided in (Entec, 2005c, Rehai and Hefazi, 2006 and IIASA, 2007).

**Table 18 Cost effectiveness of SOx reduction measures per €/tonne abated**

Technologies	Ship type	Small Vessel €/ton	Medium Vessel €/ton	Large Vessel €/ton
Sea water scrubbing	New	370	340	310
Sea water scrubbing	Retrofit	550	520	490

Source: data are in accordance with what reported in EMTEC (2005b), Rahai and Hefazi (2006), Lovblad and Fridell (2006) and IIASA (2007). Notice that 2.7% S fuel is the sulphur concentration in the fuel.

In Wang et al. (2007), a cost-effectiveness analysis has been performed for assessing the introduction of SO<sub>2</sub> control strategies on U.S. commercial fleet. Results reported here show that the cost-effectiveness of all the ships adopting Low-sulphur marine fuel in all the SECAs is much more positive than the estimate reported in the previous table (1,330 \$/tonne is the estimated result which is more or less half of what reported here). This result is very useful since it focuses the attention on the necessity to carefully use this kind of estimates in similar evaluations.

*Waste heat recovery (fuel consumption)*

It is possible to recover the thermal energy from the exhaust gas and converts it into electrical energy for the other systems of the ship. The potential energy and emissions savings is between 10 and 20% (with the new systems). It can be applied to all new and existing ships (apart from OSV). The payback period seems to be quite short.

*Main Engine Tuning/Delta Tuning (fuel consumption)*

IMO (2009) provided the following estimates (Annex IV, page 285).

**Table 19 Main engine tuning**

<i>Main engine tuning (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	405	470	1	0.10%
High reduction potential	-90	-85	7.8	0.60%

*Common rail (fuel consumption, NO<sub>x</sub>)*

It is an advanced fuel injection technology which reduces emissions and improves engine performance by maintaining a high and constant injection pressure at all engine loads (Sarvi, 2004). Optimizing the fuel injection it allows reduces NO<sub>x</sub>, particulate and CO<sub>2</sub> leading to better atomization of the fuel. From an economic point of view, total costs can increase because stronger injection equipments, as fuel pumps, accumulators, injectors and control unit, are needed. IMO (2009) provided the following estimates (Annex IV, page 285).

**Table 20 Common rail upgrade**

<i>Common rail upgrade (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	25	45	1.1	0.10%
High reduction potential	-125	-120	5.3	0.40%

*Power management and automation (fuel consumption)*

A correct power management is a part of the operation of a ship which can contribute to a 5% of increasing efficiency. It can be applied to all the types of ship with a quite short payback period. The increasing efficiency can be also higher in the case it is perpetrated automatically.

Two possible strategies belonging to this category have been analyzed in IMO (2009), i.e. the shaft power meter and the fuel consumption meter. For the first the following assumption exists, cost estimated in the range 26,000\$ and 31,200\$ and constant for each ship type: 10 years of expected lifetime, reduction potential in the range 0.5-2% with the benefits due to optimization of ballast, load and trim. In the second case the same assumption holds except for the costs which are considered in the range 46,000-55,200\$. The analysis provides the following results (IMO, 2009, Annex IV, page 284, 286).

**Table 21 Shaft power meter**

<i>Shaft power meter (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	70	115	5.4	0.40%
High reduction potential	-105	-95	21.3	1.70%

**Table 22 Fuel consumption meter**

<i>Fuel consumption meter (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	245	330	5.4	0.40%
High reduction potential	-60	-40	21.3	1.70%

In addition, further reductions can be obtained by energy saving lighting and power management. In IMO (2009) the following estimates have been produced.



**Table 23 Low energy/Low-heat lighting**

<i>Low energy/Low-heat lighting (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	385	440	0.1	0.00%
High reduction potential	-95	-85	0.6	0.00%

**Table 24 Power management**

<i>Power management (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	100	130	0.1	0.00%
High reduction potential	-130	-125	0.7	0.10%

*Speed control pumps and fans (fuel consumption)*

The engine cooling water system contains a considerable number of pumps which are major energy consumer. Controlling their speed could turn in a considerable consumption reduction. It can be applied to all new and existing ships. In IMO (2009) the following estimates have been produced (Annex IV, page 286).

**Table 25 Speed control pumps and fans**

<i>Speed control pumps and fans (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	210	250	2.1	0.20%
High reduction potential	-90	-80	10.6	0.80%

*Solar power (fuel consumption)*

Depending on the available deck space, solar panel can contribute to reduce the energy consumption of a ship. The expected efficiency is of around the 4%. This strategy cannot be applied to containers and OSV. The payback period seems to be relatively short.

**9.2.4 Operation**

In this category are included all the possible strategies which relate exclusively to the ship's operation. Practically by definition, all the following strategies have a low payback time.

*Turnaround time in port (fuel consumption)*

All possible strategies aimed at reducing the port turnaround can have a big impact on the ships efficiency. In fact all the time saved can be used in a more lasting trip with a reduced speed. Strategies can be found for every type of new and existing ship. The expected efficiency is of around the 10%.

*Propeller surface finish/polishing (fuel consumption)*

Being always under the sea-level, propellers are usually a place of organic material growth and fouling. This strongly impact on the propellers' efficiency. Regular in-service polishing can therefore help at recovering energy efficiency. In addition, the use of divers can also avoid the service interruption.

In IMO (2009) two types of strategies are considered, namely propeller brushing and increased frequency of propeller brushing. For this latter case the following assumptions hold: the cost ranges in the interval 3000-4500\$ applied every 5 years; costs do not vary with the ship type (the measure can be applied to all the ship types) and finally the abatement potential ranges between 0.5 and 3%.

The results of the analyses carried out in IMO (2009) are reported hereafter (Annex IV, page 280):

**Table 26 Propeller brushing**

<i>Propeller brushing (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-75	-65	25.4	2.00%
High reduction potential	-125	-120	62.8	5.00%

**Table 27 Increased frequency of propeller brushing**

<i>Increased frequency of propeller brushing (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-160	-130	6.2	0.50%
High reduction potential	-160	-160	36.7	2.90%

*Hull cleaning and coating (fuel consumption)*

The growth of algae and organic material on the hull can significantly contribute at increasing the ship resistance. Decisive factors for hull performances are the age of the ship, the time spent in port, service speed, water temperature and the changes in draft and duration of loading conditions. Possibilities a ship owner has to increase the ship performance are, maintenance, surface pre-treatment, coating, repeated dry-dock interventions (Kane, 2009). Frequent cleaning can help improving efficiency of about 3%. In alternative modern coatings with smoother and harder hull surfaces are able to offer a lower resistance when clean but also less fouling resulting in a much better whole behaviour.

As anticipated the hull cleaning is important also for the performance of the ACS system. Coating can be used on purpose to prevent/reduce foaling. In IMO (2009) two types of coatings and three types of cleaning were considered.

For what concerns the coating, the first type is considered to have an approximate cost of 45,000\$ and second one of 250,000\$. To the first type of coating a fuel/CO<sub>2</sub> saving of 0.5-2% is estimated, while, for the other the percentage is estimated to be in the range 1-5% (depending on the ship type). Results of the cost efficiency estimation are reported in the following tables (IMO, 2009, Annex IV, page 278).

**Table 28 Hull Coating Type 1**

<i>Hull Coating Type 1</i> <i>(year 2020, price of bunker fuel</i> <i>500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-115	-105	6.6	0.50%
High reduction potential	-150	-150	26.1	2.10%

**Table 29 Hull Coating Type 2**

<i>Hull Coating Type 2</i> <i>(year 2020, price of bunker fuel</i> <i>500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-40	-15	13.2	1.10%
High reduction potential	-140	-130	65.3	5.20%

Hull cleaning can be done by means of an hull brushing, an underwater hull hydroblasting and a dry-dock full blast. In IMO (2009) their cost effectiveness has been evaluated as well. For the first type (brushing) the cost estimation ranges between 26,000 and 39,000\$ (to be repeated every 5 years). The same differences made for the coating has been made for differentiating the cost among the different ship types. A reduction potential range of 1-10% has been considered. For the second type (hydroblasting) the same hypotheses have been made apart from the costs assumed to range in the interval 33,000-50,000\$. For the third type (dry-dock full blast), the cost ranges between 68,000 and 81,500\$, has to be repeated every 25 years and the abatement potential is estimated to be in the interval 5-10%. As a consequence, the following tables derive (Annex IV, page 282, 283).

**Table 30 Hull brushing**

<i>Hull brushing</i> (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-95	-65	12.7	1.00%
High reduction potential	-155	-150	125.6	10.00%

**Table 31 Underwater hydroblasting**

<i>Underwater hydroblasting</i> (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-80	-35	12.7	1.00%
High reduction potential	-155	-150	125.6	10.00%

**Table 32 Dry-dock full blast**

<i>Dry-dock full blast</i> (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)	Cost efficiency (US\$/tonne of CO2)		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-155	-150	8.2	0.60%
High reduction potential	-160	-160	16.1	1.30%

In addition, a further methodology to increase the ship efficiency is based on the hull performance monitoring. In this case, the average cost estimated is about 45,000 each 5 years,

plus 5,000 each year. It can be applied to all ship types and the considered reduction potential should be in the interval 0.5-5%. The following estimates derive (Annex IV, page 281).

**Table 33 Hull performance monitoring**

<i>Hull performance monitoring (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-45	-45	6.2	0.50%
High reduction potential	-150	-150	61.2	4.90%

#### *Ship speed reduction (fuel consumption)*

Emission from a vessel are roughly related to the square of the vessel's speed. Thus reducing ship speed is an effective way to cut energy consumption and thus emissions. Keeping the same distance, reducing the speed of 1 kn will result in an 11% of increasing efficiency. According to Corbet et al. (2009), this strategy might be preferred by ship operators in case of introduction of a CO<sub>2</sub> trading schemes. Indeed, by halving the ships average speed, the CO<sub>2</sub> abatement rate would be of around 70%. The problem is the type of strategy adopted to preserve the scheduled frequency. In case the time lost will be recovered from a reduction of the in-port time, then the CO<sub>2</sub> abatement is likely to be even higher. On the other hand, in case additional ships have to be added the reduction will be less significant.

In IMO (2009) a cost efficiency evaluation was made considering that to a given speed reduction percentage ( $v_r$ ), corresponds a number of vessels to be purchased equal to  $\left(\frac{1}{1-v_r} - 1\right)$ . This analysis uses the vessels costs deduced from UNCTAD (2008) reduced by the 70% to account for the prices volatility. The operational costs were evaluated to be in the range 6000-8000\$/day without considering the fuel costs. In addition in the analysis, ferries and cruise vessels were not considered (being in a route/time scheme) as well as ro-ro and vehicles carriers, whose prices are uncertain. As a result the following table result for the other types of vessels (Annex IV, page 273).

**Table 34 10% Speed Reduction**

<i>10% Speed Reduction (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
The entire fleet	80	135	98.7	7.90%

*Weather routing (fuel consumption)*

Not always the shortest path is also the most convenient. Indeed with bad weather conditions a longer, but more quite path could result in a lower consumption. Planning the voyage in this way can give considerable benefits in terms of efficiency. In IMO (2009, Annex IV, page 285) a cost effectiveness analysis of this option has been performed with the following hypotheses: cost estimated in the range 800-1,600\$, reduction potential in the range 0.1-4% and applicability extended to all the vessels with route flexibility (no ferries and cruise ships).

**Table 35 Weather routing**

<i>Weather routing (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-130	-100	1.2	0.10%
High reduction potential	-165	-160	46	3.70%

*Vessel trim (fuel consumption)*

By regulating the sailing conditions in order to find the optimum trim, it is possible to increase the energy efficiency of about the 5%. Of course it is not always easy to find the optimum trim and thus this strategy is very complicated to rely on. payback period seems to be relatively short.

*Autopilot adjustment (fuel consumption)*

A better autopilot can help saving energy consumption since it offers an higher stability to the ship. IMO (2009) has provided the following estimations (Annex IV, page 285).

**Table 36 Autopilot upgrade/adjustment**

<i>Autopilot upgrade/adjustment (year 2020, price of bunker fuel 500\$/tonne, interest rate 4%)</i>	Cost efficiency (US\$/tonne of CO <sub>2</sub> )		Maximum abatement potential	
	Low cost estimate	High cost estimate	in Mt	% of total emissions
Low reduction potential	-140	-140	5.4	0.40%
High reduction potential	-160	-160	31.9	2.50%

#### *Energy saving operation awareness (fuel consumption)*

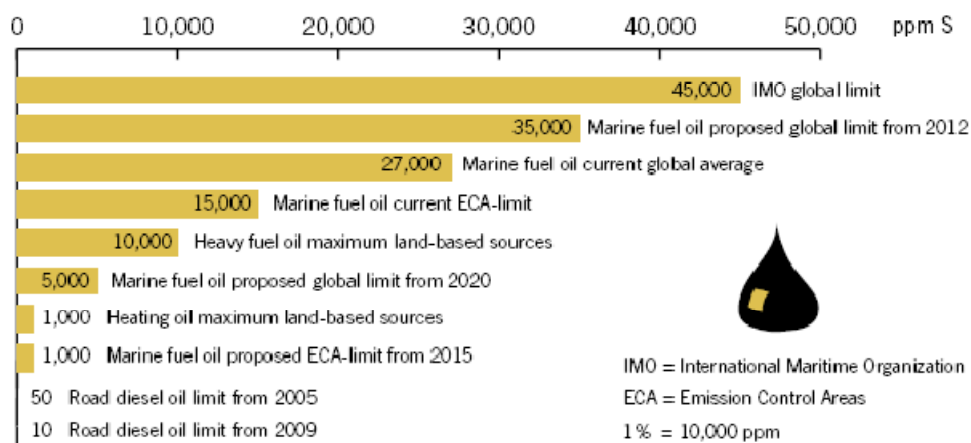
A culture of fuel saving supported by incentives or bonus to the crew of a ship can help the company to save a big percentage of energy consumption. Training and a measuring system are indispensable means to implement this strategy.

#### **9.2.5 Fuel Type**

Fuel used for vessels movement as well as the kind of processes which are performed on it have a big impact on the ships' pollutant emissions. For this reason it deserves a specific section in this chapter.

Generally, marine fuels are classified as fuel oil and distillate. Fuel oil refers to residual fuel oil manufactured at the "bottom end" of an oil refining process. The most commonly term used for this fuel is the heavy fuel oil (HFO). It is the heaviest of marine fuels and contains significant amounts of sulphur. Its average sulphur content is 2.7% mass, 90% higher than conventional diesel or petrol (Butt, 2007). However, for economical reason, it is the largest used (Endresen et al., 2003) The following figure shows as marine bunker is the fuel with the highest sulphur content. Distillate fuel can be divided into marine gas oil (MGO) and marine diesel oil (MDO). MGO is a light distillate fuel containing no residual components and light aromatic hydrocarbons. MDO can contain residual fuel oil and is a heavier distillate (Wilde et al., 2007).

Since the sulphur emissions are proportional to the sulphur content on the fuel, the easiest method for reducing sulphur oxide emissions is to use fuel with lower sulphur content. Three alternatives are available: the use of low-sulphur fuels, the use of ultra-low sulphur fuels and the use of alternative fuels. According to Wang et al. (2007) the choice of using low sulphur fuel would immediately cause a 44% reduction of SO<sub>x</sub>. However as lately proved by the same authors (see Lauer et al., 2009) reducing SO<sub>x</sub> without regulating also NO<sub>x</sub> might turn in an ineffective strategy since a decrease in SO<sub>4</sub> is likely to be compensated by an increase in NO<sub>3</sub>.



**Figure 11. Sulphur content of fuels**

Source: EEB (2008), page 6

### *Low Sulphur diesel fuel*

Low Sulphur diesel fuel is the fuel that contains fewer than 500 parts per million sulphur (0.5%). It reduces sulphur emissions and has a decreasing effect on particulate matter emissions (EEB et al., 2004). A study of Ritchie et al., (2005) shows that a switch from 2.7% to 1.5% sulphur content on fuel will reduce PM emissions by 18% and a switch to fuel with 0.5% sulphur content will decrease PM emissions by more than 20%. Currently, low sulphur marine gas oil (MGO), which possesses 0.2% sulphur content, is available. However, in order to use this fuel, a capital investment is required. The vessels have to be re-equipped with fuel storage and delivery systems and special controls must be incorporated into distribution schemes. In addition, the different fuel oil grades may require use a different lubricating oil grades and technical modification for fuels storage and handling system on board (Schmid and Weisser, 2005).

**Table 37**Cost for fuel shifting in 2020 both with respect to the tones of fuel and to the energy produced

Option (%S in fuel)	Low Cost (\$/tonne)	High Cost (\$/tonne)	Low Cost (k€ <sub>2005</sub> /PJ)	High Cost (k€ <sub>2005</sub> /PJ)
Fuel Shift (2.94→1.5)	20	20	359	359
Fuel Shift (2.94→1)	30	30	538	538
Fuel Shift (2.94→0.5)	120	170	2152	3049
Fuel Shift (2.94→0.1)	280	330	4510	5370
Fuel Shift (0.5→0.1)	160	160	2753	2753

Source AEA (2009), Table A6-2, page 32

In AEA (2009) costs for fuel shifting in 2020 are reported as an adaptation of the estimates provided in Purvitz&Gertz (2009). Such costs are reported in the following table. In the table



are reported also the costs with respect to the energy produced by the fuel (in Peta Joule, PJ,  $1PJ = 10^{15}J$ ).

In addition, in Table 8, the estimation of the cost/effectiveness for fuel switching is reported as elaboration of the estimates provided in (Entec, 2005c, Rehai and Hefazi, 2006 and IIASA, 2007).

**Table 38 Cost effectiveness of fuel switching for SO<sub>x</sub> reduction measures per €/tonne abated**

Technologies	Ship type	Small Vessel (€/ton)	Medium Vessel (€/ton)	Large Vessel (€/ton)
<b>Fuel switching: 2.7% S fuel to 1.5% S fuel</b>	New	1900	1900	1900
<b>Fuel switching: 2.7% S fuel to 1.5% S fuel</b>	Retrofit	1900	1900	1900
<b>Fuel switching: 2.7% S fuel to 0.5% S fuel</b>	New	1300	1300	1300
<b>Fuel switching: 2.7% S fuel to 0.5% S fuel</b>	Retrofit	1300	1300	1300

Source: data are in accordance with what reported in EMTEC (2005b), Rahai and Hefazi (2006), Lovblad and Fridell (2006) and IIASA (2007). Notice that 2.7% S fuel is the sulphur concentration in the fuel.

#### *Ultra-Low Sulphur diesel fuel*

Ultra-Low Sulphur diesel fuel is the fuel that contains fewer than 30 parts per million sulphur (0.03%). Also in this case, capital investments are needed to re-equip the vessel's fuel storage and the delivery system. Moreover, since the ultra low sulphur fuel doesn't contain enough sulphur to provide lubrication, a synthetic lubricant additive have to be mixed with the fuel prior to use (Schmid and Weisser, 2005).

#### *Alternative fuels*

They may be used in the place of diesel fuels. Biofuels, natural gas and hydrogen are some of them. Generally, for fuel switching techniques, vessels have the option of either entirely switching to alternative fuels or operating on dual-fuel mode, with separate fuel storage tanks for each fuel. The European Commission's White Paper (1997) on renewable energy sources estimated the bioenergy potential on EU15 in 2010 at 135 Mtoe compared to 55 Mtoe in 1998. The EU has set a goal of replacing 20% of the fuels used in transport with alternative fuels by 2020.

Biofuels are produced from animal or vegetable fat base (palm oil, coconut oil, etc...). Glycerol and fatty acids are removed during the refining process and the residue of methyl or ethyl ester is used as a combustion fuel source. Using biofuels many advantages can be reached. Beside to reduce the emissions of SO<sub>x</sub> and particulate matter (-50%) they allow reducing the dependence on fossil-based and non-renewable fuel sources. However, the level of NO<sub>x</sub>

content in exhaust gases seems increase (+10%). Moreover, the availability of this fuel is limited and the costs remain an issue (Karila et al., 2004).

Natural gas is generally methane. Since it burns slowly, its combustion in the diesel engines generate low levels of CO<sub>2</sub> and particulate emissions (Karila et al., 2004). Wartsila produce a dual-fuel four-stroke engine, which during operation can switch between natural gas and light fuel oil. Its energy consumption increases a bit, but the production of SO<sub>x</sub> and NO<sub>x</sub> is only a few per cent of the amount produced in a conventional two stroke engine (Wartsila, 2004).

The use of Liquefied Natural Gas (LNG) can give a considerable contribution in terms of energy efficiency and environmental sustainability of the maritime traffic. In particular for the latter aspect, it can contribute to reduce the CO<sub>2</sub> emissions of around the 25%, NO<sub>x</sub> of about 90% and it does not produce any sulphur emission. From an economical point of view, the increasing efficiency of this kind of fuel can allow to save around 4% of total energy with a consequent quite short payback period. It can be use in all type of new and existing ships. The problem of the LNG is mainly related the energy necessary for its production. The main problem is the storage that can compromise safety on board (Sudiro and Bertucco, 2008).

Hydrogen technology requires the application of fuel cells on ship. Few commercial installations for small ships (15 kW) already exist. However, for larger vessels with a big power demand (60 MW) the application of the fuel cells is still not possible. Moreover, a larger tankage volume to cover the same energy need provided by diesel fuels is needed (Eyring et al., 2005). From an economic point of view, the fuel cell application is still not competitive with the internal combustion engines (Keith et al., 2000).

#### *Distillate fuel (SO<sub>x</sub>, particulate matter)*

Distillates reduce SO<sub>x</sub> by 80% and particulate matters by 35%. It is estimated that the cost to introduce distillates in the market is 250x10<sup>9</sup> \$ and the time needed, about 20 years. This would cause the CO<sub>2</sub> rising of 20%.

#### *Emulsified fuel (NO<sub>x</sub>, CO, particulate matter)*

Fuel emulsification reduces pollutant emissions by adding water on fuel. Producing a more complete combustion with lower fuel consumption it cut the amount of NO<sub>x</sub>, CO and PM. It has been in use since 1984 on stationary low speed diesel engine plants. However, smaller ships could have spatial problem, because additional equipments are needed for generating the water/fuel mixture. Larger fuel pumps and water tank are some example. Moreover, since the water used for emulsification must be clean and without salts, a water distiller system is

needed (Sorgard et al., 2001). In theory, large reduction of NO<sub>x</sub> is possible, but the reduction rate is proportional to the amount of water added to the fuel. MAN B&W reports that for each 10% of water added a 10% NO<sub>x</sub> reduction can be achieved (MAN B&W, 2004).

## **10. The international framework to regulate CO<sub>2</sub> emissions from international maritime transport.**

The latest European Commission Communication towards Copenhagen COP15<sup>21</sup> allows pointing out the latest core legislative actions, which have been taken on a European scale in order to address emissions from maritime transport.

Within this document the Commission sets out concrete proposals to achieve successful results within international climate change negotiations at Copenhagen and beyond. In particular, this Communication identifies three core challenges, namely targets and actions, financing, and building of an effective global carbon market. Within the identification of new commitments and practical solutions in order to achieve them the Commission states that *“to have a reasonable chance of staying below the 2C threshold, global GHG emissions must be reduced to less than 50% of 1990 levels by 2050...Developed countries must lead in meeting this global goal and demonstrate that a low-carbon economy is possible and affordable”*.

Concerning emissions from international aviation and maritime transport the Commission is expecting a global settlement to be agreed in Copenhagen for reducing the climate impact of these sectors below 2005 levels by 2020 and consistently below 1990 levels by 2050. Market based measures, including emissions trading, are seen as a possible solution to ensure emission reduction. About the negotiation of such an agreement and global measures the Commission stresses the fact that both the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) would have had the responsibility to conclude the process by the end of 2010. The Commission agrees on the fact that, after this deadline with no agreement in ICAO and IMO *“emissions from international aviation and maritime transport will be counted towards national totals under the Copenhagen agreement which will ensure comparable action by all developed countries.”* The EU has included CO<sub>2</sub> emissions

---

<sup>21</sup> COM(2009) 39 final, Brussels, 28.1.2009, *“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”*.

from aviation within the EU ETS<sup>22</sup>. Regarding maritime transport within the communication the Commission asserts: “several market-based measures are currently being examined. If no effective global rules to reduce GHG emissions from this sector can be agreed upon, the EU should agree its own measures.”

The above mentioned Communication has been published on 28<sup>th</sup> of January 2009 and it followed the important approval of the EU Climate Change package, adopted by the European Parliament in December 2008. This package has been designed to achieve the EU's overall environmental target of a 20 % reduction in greenhouse gases and a 20 % share of renewable energy in the EU's total energy consumption by 2020. On 6 April 2009 the Council of Ministers issued a decision, under the ordinary legislative procedure, with substantial amendments to this package. This decision of the Council honors a first reading agreement between the European Parliament and the Council reached at the end of 2008. According to art. 294 of the Treaty on the functioning of European Union<sup>23</sup> when such an agreement is reached under ordinary procedure the European Parliament and the Council agree on a list of compromise amendments, which both institutions commit themselves to adopt<sup>24</sup>. The decision of the

---

<sup>22</sup> Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009, No L 140.

<sup>23</sup> Formerly Article 251 TEC pre-Lisbon Treaty.

<sup>24</sup> The ordinary legislative procedure, formerly known as Co-decision procedure, is the main legislative procedure by which directives and regulations are adopted. Article 294 outlines ordinary legislative procedure in the following manner. The Commission submits a legislative proposal to the Parliament and Council. At the first reading Parliament adopts its position. If the Council approves the Parliament's wording then the act is adopted. If not, it shall adopt its own position and pass it back to Parliament with explanations. The Commission also informs Parliament of its position on the matter. At the second reading, the act is adopted if Parliament approves the Council's text or fails to take a decision. The Parliament may reject the Council's text, leading to a failure of the law, or modify it and pass it back to the Council. The Commission gives its opinion once more. Where the Commission has rejected amendments in its opinion, the Council must act unanimously rather than by majority. If, within three months of receiving Parliament's new text the Council approves it, then it is adopted. If it does not then the Council President, with the agreement of the Parliament President, convenes the *Conciliation Committee* composed of the Council and an equal number of MEPs (with the attendance and moderate of the Commission). The committee draws up a joint text on the basis of the two positions. If within six weeks it fails to agree a common text, then the act has failed. If it succeeds and the committee approves

Council marks the final adoption of the major legislative package, which was proposed by the Commission in January 2008 and followed the endorsement of specific emissions reduction targets by the European Council in March 2007. While maintaining the initial objectives of the Commission's proposal and improving the functioning of the ETS by harmonizing the allocation of allowances at EU level, this compromise also took into consideration the important risks of carbon leakage and the impact of the package on EU competitiveness. This Climate Change package includes several legislative texts: a revision of the existing ETS Directive 2003/87/EC, a Directive on Renewable energies<sup>25</sup>, a Directive on Carbon Capture and Storage<sup>26</sup> and a Decision on shared efforts to reduce greenhouse gas emissions<sup>27</sup>.

Within the above mentioned Decision the European Parliament and the Council jointly stressed the fact that all sectors of the economy, including international maritime shipping and aviation, should make concrete efforts to achieving emission reductions. In particular paragraph (2) of Decision's Preamble rules that *"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 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."* This Decision, addressed by its article 16 to all Member States, sets legally binding shared efforts leaving the door open for a future necessary inclusion of maritime sector emissions into the Community reduction commitments. It has to be underlined that a decision, defined in Article 288 of the Treaty of the Union<sup>28</sup>, is binding on the person or entity to which it is addressed and may also

---

the text, then the Council and Parliament (acting by majority) must then approve said text. If either fails to do so, the act is not adopted.

<sup>25</sup> Directive 2009/28/EC of the European Parliament and of the Council.

<sup>26</sup> Directive 2009/31/EC of the European Parliament and of the Council.

<sup>27</sup> Decision 406/2009/EC adopted jointly by the European Parliament and the Council.

<sup>28</sup> Formerly Article 249 TEC.

be invoked by individuals before national courts due to its direct effect<sup>29</sup> which is recognized by case law.

By citing these Communication and Decision it clearly appears that European Commission and Parliament and the Council are waiting for a concrete step forward on maritime emissions reduction to be made by the international community through IMO or UNFCCC. Therefore a proposal for the inclusion of new commitments addressing those emissions within an existing or new EU legal framework cannot be reasonably expected earlier than 2011.

It has to be mentioned that a strategy to reduce and regulate atmospheric emissions from ships was already available in November 2002 and this covered both emissions leading to air pollution and climate change<sup>30</sup>. However just the strategy related to air pollution from ships turned into concrete action with, as for example, a directive regulating sulfur content of marine fuel, which came into force in August 2005<sup>31</sup>.

The IMO Marine Environment Protection Committee (MEPC) and its Member States have been discussing, within their last sessions, about the need for a mandatory instrument to address the issue of GHG emissions from shipping. This discussion has been pushed forward by the publication of the "Second IMO GHG Study 2009"<sup>32</sup> (update of the 2000 IMO GHG Study) which has been prepared on behalf of IMO by an international consortium led by MARTINEK. This study set out a comprehensive overview of policy options for reduction of emissions including

---

<sup>29</sup> Direct effect is a principle of European Union Law according to which certain pieces of European legislation are enforceable before the courts of Member States. Direct effect is not explicitly mentioned in any of the EU Treaties, but was established by the European Court of Justice in *Van Gend en Loos v. Nederlandse Administratie der Belastingen* (Case 26/62; [1963] ECR 1; [1970] CMLR 1), in which the court held that obligations imposed upon member states by the treaties could be enforced by individuals, in the form of individual legal rights, before national courts. The principle has subsequently been applied to legislation adopted under the treaties in the form of regulations and directives.

<sup>30</sup> <http://ec.europa.eu/environment/air/transport.htm#3>.

<sup>31</sup> EU (2005). Directive 2005/33/EC of the European Parliament and of the Council.

<sup>32</sup> MEPC 59/4/7

a Maritime Emissions Trading Scheme<sup>33</sup>, seen as “*cost-effective policy instruments with high environmental effectiveness*”<sup>34</sup>.

The discussion within last MEPC sessions concerned not only the feasibility of each policy options, but also the possible form a legal instrument could take in order to strongly express IMO’s Parties’ will to address the issue of GHG emissions from shipping<sup>35</sup>.

There are currently three main options which are under discussion:

- Inclusion of the addition measures to address GHG emissions to Annex VI of Marpol 73/78
- Development of an additional annex to MARPOL 73/78
- Development of a stand-alone legal instrument

MARPOL 73/78 Convention still represents the most relevant regulation on marine pollution. In 1997, air pollution was included in Annex VI. At the moment, greenhouse gases are included. In fact, Annex VI sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone-depleting substances. Regulations for the Prevention of Air Pollution from Ships entered into force on 19 May 2005, following the ratification by the Independent State of Samoa of Annex VI of the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78). The 1997 Protocol to the MARPOL Convention, which includes Annex VI, was supposed to enter into force 12 months after being accepted by 15 States with not less than 50% of world merchant shipping tonnage<sup>36</sup>. Samoa, the fifteenth

---

<sup>33</sup> Here’s the complete list of options analyzed in 2009 study: .1 A mandatory limit on the Energy Efficiency Design Index (EEDI) for new ships;.2 Mandatory or voluntary reporting of the EEDI for new ships;.3 Mandatory or voluntary reporting of the Energy Efficiency Operational Indicator (EEOI);.4 Mandatory or voluntary use of a Ship Efficiency Management Plan (SEMP);.5 Mandatory limit on the EEOI value, combined with a penalty for non-compliance;.6 A Maritime Emissions Trading Scheme (METS);.7 A so-called International Compensation Fund (ICF), to be financed by a levy on marine bunkers.

<sup>34</sup> MEPC 59/4/7

<sup>35</sup> MEPC 58/4/15

<sup>36</sup> According to amendment procedure set out in Article 16, paragraph (f)(ii).

State to ratify the instrument, deposited its ratification on 18 May 2004. Annex VI has now been ratified by States with 54.57% of world merchant shipping tonnage.

According to its article 16 technical Annexes of MARPOL Convention 73/78 can also be amended using the “tacit acceptance”<sup>37</sup>: amendments “*shall be deemed to have been accepted at the end of a period to be determined by the appropriate body at the time of its adoption...unless within that period an objection is communicated to the Organization by not less than one third of the Parties*”, representing the 50 per cent of the gross tonnage of the world’s merchant fleet<sup>38</sup>.

In practice, amendments are normally adopted within MEPC’s sessions or by a Conference of the Parties to MARPOL<sup>39</sup>.

Annex VI has been recently amended within MEPC 58<sup>40</sup> and it is expected to come into force by July 2010. The idea of including GHG emission reduction commitments by amending Annex VI of MARPOL 73/78 would certainly avoid the need to redefine basic concepts and obligations which are listed in Annex I of the Convention. On the other hand it would require reopening or further developing the debate on the current revision of the same Annex. That would probably cause a delay of the implementation of new SOx standards and NOx Technical Code, adopted at MEPC 58, which is seen by some of the Parties as a “*significant loss given the importance of these amendments for improving air quality*”<sup>41</sup>. Moreover GHG is not considered as a “pollutant” like other emissions currently regulated by Annex VI and it has a global rather than a regional impact.

The adoption of a new Annex to MARPOL 73/78 would then avoid the delay of the last negotiated amendments facilitating settlement of new measures without losing the core principles and obligation of the Convention. However even this option would leave some theoretical problems unsolved. MARPOL Annex VI does not aim to reduce aggregate emissions

---

<sup>37</sup> CICERO Report 2007:7, [www.cicero.uio.no](http://www.cicero.uio.no).

<sup>38</sup> Article 16, paragraph (f)(iii).

<sup>39</sup> Confer [http://www.imo.org/Conventions/contents.asp?doc\\_id=678&topic\\_id=258](http://www.imo.org/Conventions/contents.asp?doc_id=678&topic_id=258).

<sup>40</sup> MEPC 58/23/Add.1

<sup>41</sup> MEPC 58/4/15



of the shipping sector, but to address local/regional pollution on “per-ship” basis circumscribed to specific sources of pollution in specific areas and to specific accidents.

To include GHG emissions’ impact on global environment to MARPOL has been seen, by UK as an example, as an attempt to adapt “*a similar solution to a different problem*”<sup>42</sup>.

Therefore, the idea of stand-alone legal instrument seems, at present, to meet with larger approval within the Parties and IMO’s discussion. A new convention could be created *ex novo* with widespread consensus by defining concepts and obligations which could better fit to the purpose. However this might require stronger efforts from the Parties and longer negotiations.

In order to fully deliver its mandate as stipulated in Article 2.2 of the Kyoto Protocol to the UNFCCC<sup>43</sup> MEPC has also analyzed potential constraints of a new binding legal instrument addressing GHG emissions from international shipping. In particular the Committee showed concerns about the compatibility between Kyoto Protocol’s “common but differentiated responsibilities” approach according to which legally binding emissions reduction commitments should apply just to Annex I Parties, and Paris MOU’s “no more favorable treatment” concept due to which relevant legal instruments (conventions) should apply also to ships which fly the flag of a State which is not a Party to that convention<sup>44</sup>. To identify if there is a potential conflict between two different international treaties it has to be understood if they somehow regulate the same subject in a contradictory way. According to IMO Sub-Division for Legal Affairs of the Organization there is no potential treaty law conflict between the Kyoto Protocol and upcoming IMO provisions addressing GHG gases from international shipping.

Article 2.2 of the Kyoto Protocol should be not literally interpreted allowing instead IMO to adopt any measure in this context and to apply them across the board in the same way as

---

<sup>42</sup> *Ibidem*

<sup>43</sup> Art. 2.2 of the Kyoto Protocol to the UNFCCC: “*The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively*”.

<sup>44</sup> <http://www.parismou.org/upload/pdf/MOU,%20incl.%2031st%20%20Amendment%20editorial%20revised.pdf>.

other IMO's regulations<sup>45</sup>. By stating that the Parties included in Annex I "*shall pursue limitation or reduction of emissions of greenhouse gases...from marine bunker fuels, working through the International Maritime Organization*" the Conference of the Parties did not mean to restrict negotiation and adoption of GHG emissions reduction commitments in the marine sector just to those States which are listed in Kyoto Protocol Annex I. If so all Parties which fall out of that list should not take part to the ongoing discussion. Moreover IMO treaties such as MARPOL normally set technical requirements and regulations to be applied universally by all ships regardless of the flag they are flying. A new international treaty restricted just to certain countries would induce, for example, ship-owners to simply change the flag of their ships in order not to fall under its new onerous regulation. That would of course empty not only MARPOL and any other IMO treaty, but also Kyoto Protocol/UNFCCC of their meaning and objectives.

Therefore Kyoto Protocol's principle such as "*common but differentiated responsibilities and respective capabilities*"<sup>46</sup> can be an obstacle within a new IMO convention. The law of the sea and in particular international shipping trade rules, due to their complexity, have, by definition, to be applied to all commercial ships making appropriate distinguishes just based "*on factors such as their type, structure, manning and operational features, irrespective of the flag they are flying or the degree of industrial development of the flag State or the State of*

---

<sup>45</sup> MEPC 58/4/20, "*PREVENTION OF AIR POLLUTION FROM SHIPS, Legal Aspects of the Organization's Work on Greenhouse Gas Emissions in the Context of the Kyoto Protocol*".

<sup>46</sup> United Nations Conference on Environment and Development: Framework Convention on Climate Change, May 9, 1992, 31 I.L.M. 849 [hereinafter FCCC].

The "common but different responsibilities" principle (CBDR) is described succinctly in Principle 7 of the Rio Declaration on Environment and Development: "States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command."

On this topic see also Paul G. Harris, N.Y.U. Environmental Law Journal, Volume 7, 1999, p. 27-48, *Common but differentiated responsibility: the Kyoto Protocol and United States Policy*".

*nationality of the owner or the operator*<sup>47</sup>. A different approach would inevitably clash into the narrow interaction of private and public law related to ships registration as well as in the interaction between flag, port and coastal State jurisdiction without reaching any concrete result in terms of GHG emissions reductions.

Within the evaluation of the best possible IMO regulatory framework on GHG emissions from ships, in particular CO<sub>2</sub>, Parties already agreed on a list of principles to be accomplished:

1. Effective contribution to the reduction of total GHG;
2. Binding and equally applicable to all Flag States in order to avoid evasion;
3. Cost-effectiveness;
4. Limitation, or at least, effective minimization of competitive distortion;
5. Sustainable environmental development without penalizing global trade and growth;
6. Goal-based approach and not a prescriptive specific method;
7. Supportive of promoting and facilitating technical innovation and R&D in the entire shipping sector;
8. Accommodating to leading technologies in the field of energy efficiency;
9. Practical, transparent, fraud-free and easy to administer<sup>48</sup>.

In the view of some sponsoring States together with certain authors an ETS for shipping would fully comply with the above listed principles<sup>49</sup>. Moreover it would be a mechanism which has been already experienced in other sectors and regions and it could be adapted, *ad hoc*, to the shipping sector without creating any conflict with UNFCCC ongoing negotiations.

Regarding the enforcement of such a scheme it could be built upon the principles of Flag State obligations<sup>50</sup> and Port State control (PSC)<sup>51</sup> in conformity with UNCLOS provisions<sup>52</sup>. Flag States

---

<sup>47</sup> MEPC 58/4/20

<sup>48</sup> MEPC 57/WP.8

<sup>49</sup> In particular France, Germany and Norway have been promoting the advantages of an ETS for shipping. See MEPC 59/4/26.

<sup>50</sup> See A.Boyle, *World Politics and International Law*, 1985, p. 363ff.

<sup>51</sup> See P. Birnie, *International Law and the Environment*, 2009, p. 379ff. See also [www.imo.org](http://www.imo.org) : Port State Control (PSC) is the inspection of foreign ships in national ports to verify that the condition of the ship and its equipment comply with the requirements of international regulations and that the ship is

would have to control whether ships are compliant with the requirements of the scheme, namely to monitor their emissions, surrender allowances for each unit of emissions and report them annually to the flag State and the international body that administers the scheme<sup>53</sup>. In combination with Flag State obligation also Port State control should be applied. According to 1982 Paris MOU Port State have the right to inspect ships flying a foreign flag entering its port to ensure their compliance with major international maritime convention. Within an ETS established by a new legal IMO instrument, Port State could then control record books and documentation of allowances and be informed by the international administrative body about the ship's compliance status. PSC officers will verify whether the ships can provide documental evidence of the fact they have surrendered sufficient allowances<sup>54</sup>.

The MEPC has been invited by the Parties to take concrete action and to deliver its mandate, as stipulated in Article 2.2 of the Kyoto Protocol, preparing a legal framework to be adopted in the immediate future. However, the absence of new legally binding commitments within the outcomes of Copenhagen COP15 will probably prolong the above mentioned. For the same reason it is unlikely that an amendment of EU ETS for the inclusion of maritime transport will be approved before the Parties will have concluded an agreement within IMO.

---

manned and operated in compliance with these rules. Many of IMO's most important technical conventions contain provisions for ships to be inspected when they visit foreign ports to ensure that they meet IMO requirements. These inspections were originally intended to be a back up to flag State implementation, but experience has shown that they can be extremely effective, especially if organized on a regional basis. A ship going to a port in one country will normally visit other countries in the region before embarking on its return voyage and it is to everybody's advantage if inspections can be closely co-ordinated.

<sup>52</sup> UNCLOS Articles 217,218.

<sup>53</sup> MEPC 59/4/26 submitted by France, Germany and Norway. Regarding obligations of the ships sponsoring States propose what follows: *"The emission reports have to be verified by an independent verifier as part of the flag State control. If a ship has emitted more than it has acquired allowance for, it needs to buy extra allowances in the market...For Port State control purposes, the ship will also have to keep a record book and documentation of its emissions and surrendered allowances"*.

<sup>54</sup> *Ibidem*.

## **11. Regional approach to regulate CO2 emissions: the European Union Directive on Emission Trading**

In 2005 the Directive 2003/87/EC<sup>55</sup> has launched a market for trading permits to emit CO<sub>2</sub> (EU emission allowances or EUAs). The European market for emissions trading (EU ETS) represents a successfully example of the market mechanisms that in 1997 the Kyoto Protocol has proposed to involve the private sector to abate the global CO<sub>2</sub> emissions (the Joint Implementation (JI) and Clean Development Mechanisms (CD) are the Kyoto complementary mechanisms, which are active and interrelated with the EU ET market). The EU ET market was set with this purpose of forcing major polluters (energy, metals and minerals sectors indicated in the Directive) to abate their CO<sub>2</sub> emissions gradually over time, leaving to firms the choice of the best and cost effective way to achieve the target. In general terms, the goal of the emitters is from the economics literature and requires that the emitters who are able to efficiently decrease emissions can sell some of their permits on the market; emitters who cannot efficiently decrease emissions have to buy extra permits.

The legislation offers the opportunity to comply with the obligation by using CERs (Certified Emission Reduction carbon credit, derived from CDM projects) and ERUs (Emission Reduction Unit carbon credit, derived from JI projects) but within given proportions decided by each country.

The EU ET scheme has been organized in two phases with an increasing public commitment to respect the limits: Phase I in 2005-2007, Phase II in 2008-2012, and Phase III starting in 2013.

In 2005 major emitters were freely allocated an initial amount (larger than 2 billion) of permits. They were free to trade their permits in the market, knowing that they would have to hold an amount of permits corresponding to the amount of emissions of the previous year at certain verification times. Lacking this compliance, companies would have to pay sanctions (100 €/ton plus the purchase of the missing permits in Phase II and 40 €/ton plus the purchase of the missing permits in Phase I). An identical new supply was given every year to the same sources. The market involves both spot and futures contracts, but there exists an important difference between Phase I and Phase II as to the link between the spot and the futures market. In Phase I investors and firms could trade futures contracts with an expiry date beyond Phase I. According to the rules set by the Directive 2003/87/EC, permits released in Phase I could not

---

<sup>55</sup> Amended by Directive 2009/29/EC

be used in Phase II, a situation known as "lack of bankability". Emission permits are however bankable between Phase II and Phase III, as established by the new trading EU Directive (2009/89/EC). Considering the environmental performance of the EU ET scheme, during the Phase I, which was called 'pilot phase' as these years served mostly to create benefits by 'learning-by-doing', a modest amount of abatement occurred in line with the modest ambition of the cap imposed (Convery et al., 2008:17). Actually, the emissions in 2005 were 4.56% lower than the cap, and in 2006 they were about the cap size (Carbon Market Data, 2009).

To sum up, under the EU ETS the European carbon emissions have decreased until 6.2% below 1990 levels at the end of 2008. Apart from the economic slowdown in the second half of 2008, the restructuring of the German energy market, and the liberalization of the energy market in the United Kingdom, also firms' investment decisions have contributed to the decrease.

Since the beginning, the market has had to recognize substantial uncertainties about the level of supply. For example, even in Phase II, there were indecisions about the possibility to use CERs and ERUs to comply in Phase III. According to some proposals, any spare capacity in the use of CERs and ERUs could have been used in Phase III but limiting the future use of CERs and ERUs. Another source of uncertainty was the inclusion of new important sectors, for example the aviation industry.

Also relevant is the issue of the supply of new permits at the beginning of Phase III, which, given bankability, affects prices in Phase II. For example, EUA allocations were 2,270 million tonnes for 2005-2007 (versus actual emissions of about 2,000 million) and 2,080 in 2008-2012. The level of supply in Phase III will depend on the commitment of the European governments to reaching the target. Important is also technological uncertainty about the costs of CO<sub>2</sub> abatement and the development of alternative technologies. Finally, in Phase I there was uncertainty about the supply of permits in Phase II, and, initially, also about the relation between allowances demand and supply.

### **11.1 The Carbon Market**

With regard to the price of the allowances, they were affected by a high volatility. The question is what affects the price (i.e. the demand and supply, of allowances?). Demand is driven by anticipated emissions that depend on several variables such as the cost of abatement, economic growth, energy prices, the initial allocation of permits, and weather conditions (Christiansen et al., 2005). It must be taken into account that the allowance market is not dominated by compliance trading, but that, like in all trading markets, most trades are

motivated by financial considerations. For example, when a power company buys a future contract to hedge against the risk price volatility, it will sell it again before maturity. So typically, no real transfer of allowances takes place (Trotignon and Ellerman, 2008:3).



**Figure 12. The market price of allowances 2005 – 2007**

Source: Mission Climat of Caisse des Depots (2007), in: “The European Carbon Market in Action: Lessons from the First Trading Period”, Convery et al. (2008)

A main influence on demand is therefore expectations about future prices, and inherently, uncertainty. Initially, participants were not allowed to borrow or bank allowances from/to other periods, so the total supply was determined by the initial allocation of permits. In phase II, when it was recognized that this restrained the development of the price significantly, participants were allowed to bank allowances to the third period, so total supply in the following periods depends also on banked or borrowed allowances.

Figure 9 shows the real allowance market developments during the years 2005, 2006, and 2007. In this trading period, the carbon dioxide allowance market has suffered from high price volatility. At the beginning of the period prices have raised sharply, as participants started buying permits almost immediately and those who had an excess of permits were not willing to sell them. A scarce market was created, which translates to increased incentives to reduce emissions. In April 2006 the European Commission released valuable information about the market, namely that there was a 4% surplus of permits EU-wide. Not surprisingly, the market reacted quickly with a drop in prices, followed by a highly volatile price development. This highlights the markets’ sensitivity to information releases. In fact, incomplete information is one of the market failures of the EU ETS carbon dioxide market. The practical difficulty to

access reliable information has contributed highly to price instability (Convery et al, 2008:16). More specifically, on the 25<sup>th</sup> of April 2006 the Czech Republic and the Netherlands released the information that their national emissions were respectively 15% and 7% lower than the number of permits allocated. Immediately, allowance prices dropped by about 10% on the spot market. Later that week comparable announcements on the long positions from France and Belgium led to a closing spot price on Friday that was 54% lower than the price on the Monday before (Ellerman Buchner 2008:269). As a result of these information releases, the long-term price signal became disrupted and uncertain, participants were less willing to engage in emission reduction activities. The allowance surplus reflects into a price convergence towards 0, meaning that pollution becomes free. The market activity shifts towards phase II allowances, and phase I allowances become worthless (Convery et al., 2008:14-15). In phase II allowance banking reduces price spikes as it can be used to hedge against price uncertainty. It provides temporal flexibility between current actual marginal abatement cost and expected future marginal abatement cost, which is especially useful for firms facing large expenditures to abate pollution (Tietenberg, 2003:415). The result of this policy change is that for Phase II allowances, prices are also based on post-2012 expectations. However, as there is still high uncertainty about political agreements to be made for the post-Kyoto period, the long-term price signal depends on very uncertain future political events (Convery et al., 2008:15).

Where banking allows firms to hedge against low prices, price uncertainty for the high peaks can be addressed by a price cap or a safety-valve mechanism, where the government guarantees that it will allocate more allowances when the market price reaches a certain value (Jacoby and Ellerman, 2004). This could create a more stable investment climate. However, it also removes the relative certainty of the maximum level of emissions that was one of the benefits of a cap-and-trade policy and it requires additional administrative complexity (Gupta et al., 2007:758). To overcome the first problem, the government could pursue a policy where it would buy back the permits at a time where there is a long-position or abundance of allowances. In that way the price of allowances could remain relatively stable. This kind of policy could, however, disrupt transparent pricing, and therefore could be a treat for the development of a well-functioning carbon market.

The initial allocation of permits is another important determinant of the price of pollution and the incentives to innovate. A choice has to be made between grandfathering and auctioning. Experience tells that until now most emission trading policies have made use of the free



allocation of permits. A no-cost allocation was both with EU ETS and the US SO<sub>2</sub> program critical for political acceptance (Ellerman, 2005; Convery et al., 2008). Grandfathering permits has the advantage that it reduces the fear of the industry to get ‘competed away’ by firms outside the region under regulation. Allocating permits for free to current firms indirectly increases their market power as it creates entry barriers for new firms, who have to buy the permits on the market (European Commission, 2000:20).<sup>56</sup> Another benefit of auctioning is that it raises revenues that can be used for environmental purposes, or given back to the sector by means of a subsidy on lower-polluting technologies or infrastructure, for example. Goulder et al. (1999) find that this ‘revenue-recycling’ can be used to cut distortionary (labor) taxes and in that way give economy-wide efficiency benefits. The EU decided that in the first phase, no more than 5% of the allowances could be auctioned. At member state level, only four countries have auctioned their permits in the first phase, added up this accounted for 0.13% of total allocation (Convery et al., 2008:11). In the second phase, up till 10% of allowances may be auctioned.

## **11.2 Carbon leakage**

An important element of regional emission trading is ‘carbon leakage’, i.e. the situation where a stricter environmental policy in one region increases carbon emissions in other regions. It can work in two ways: 1) through the competitiveness channel: carbon-intensive activities get re-allocated towards areas with less stringent policies, or the industry outside the region gains in market share, and 2) through the fossil fuel price channel: the policy decreases the demand for fossil fuel, thereby lowering its price that triggers a higher fuel use and higher associated emissions in non-participating countries (Organization of Economics Co-operation and Development (OECD), 2009: 86). Carbon leakage occurs due to incomplete coverage in terms of countries, industries or greenhouse gasses. The OECD did simulation analysis on the magnitude of carbon leakage; the results are shown in the figure below.

The data show that leakage is a severe problem that can reduce environmental effectiveness by a magnitude up till 16% if the EU region implements CO<sub>2</sub>-only regulations. However, including more greenhouse gasses or more countries in policy reduces carbon leakage a lot. In

---

<sup>56</sup> The creation of entry barriers to polluting industries in the EU ETS is positive from an environmental viewpoint and beneficial for the current firms, but obviously a bad side-effect particularly for consumers, and when striving for a free and competitive market in general.

a situation where all Annex I countries and Brazil, India and China jointly implement a regulation to reduce all greenhouse gases with 2.7 Gt in 2050, the carbon leakage reduces to a negligible amount. The two channels work in opposite directions: the wider the country (or GHG) coverage, the lower the leakage from the competitiveness channel but the higher the leakage through the fossil fuel price channel. The magnitude of these effects depends predominantly on the degree of competitiveness on the market that the covered industries operate in, and on the elasticity of demand and supply of fossil fuel prices (OECD, 2009:86).

**Table 39 Carbon leakage rates**

Coverage		Leakage rates	
Region	GHG	2020	2050
EU	CO <sub>2</sub> only	13%	16%
	all GHG	6.30%	11.50%
Annex I	all GHG	0.70%	1.70%
Annex I + Brazil, India and China	all GHG	0.20%	0.20%

Source: OECD, 2009:87

Note: leakage rates are calculated by a reduction in emissions of 2.7Gt in 2050 with respect to 2005, corresponding to a 50% cut in EU emissions.

Related to competitiveness but positively affecting environmental effectiveness is that carbon pricing makes energy-intensive (or pollution-intensive) industries less competitive, causing these industries to lose market share to industries that place a lower burden on the environment. It is estimated that the output of energy-intensive industries drops by 13% when an emission reduction of 50% of 2005 levels by 2050 is agreed upon globally. Alternatively, if the same regulation is only implemented in the European Union, the world production of energy-intensive industries would decrease by less than 1% as the re-allocation of plants and the associated carbon leakage dominates. For industries *within* the EU, global action is much more attractive than a EU-only action as their projected output under these scenarios respectively increases by 2% (due to the slight competitive advantage of their energy efficiency) and decreases by 4%. The same industry outside the EU bears the cost of global action, as their production would drop by as much as 16%, compared to a production increase of 0.2% under EU-only policy (OECD, 2009:87-88.)

In discussing the expansion of the EU ETS, the Commission evaluates the risk of carbon leakage for the sector under consideration. Factors that are taken into account are the following: 1) the extent to which the sector is able to pass on the allowance price to consumers without loss of market share, 2) the effect that auctioning allowances has on the production cost, and 3) the market structure and the degree of competition the sector faces (DG Enterprise). For

sectors that are found to bear a significant risk of carbon leakage, grandfathering of permits can amount to 100% of total allocation. In this light, the usage of the term ‘carbon leakage’ is confusing as these three factors merely indicate that an industry loses market share to competing firms and not necessarily that firms are moving or that energy prices drop. A clear distinction has to be made between a loss of competitiveness and the true evasion effect. The first one is beneficial to environmental effectiveness, but is a main concern for the industries under consideration and for politics for national industry protection reasons. The evasion effect includes the abovementioned re-location of firms and the increasing demand of fossil fuels by other regions, being a main concern for policy-makers and environmentalists.

In the literature on environmental policy in relation to competitiveness, there has been a hypothesis that stringent policy in fact *increases* the competitiveness of the sector under consideration. Rationale behind it is that firms have numerous opportunities to innovate and only limited attention, and that strict regulations stimulate continuous innovation – creating early-mover advantages and innovation offsets (Porter and van der Linde, 1995). This so-called “Porter hypothesis” is nonetheless rejected by many, criticizing amongst others the assumption that a regulator can decide better than the firm itself which innovations are most attractive (Palmer et al., 1995). Preliminary results on industrial competitiveness are that the power industry had the power to pass through part of the carbon prices to consumers. As the sector has been grandfathered the permits, in fact the opportunity costs were reflected in higher prices. These so-called ‘windfall profits’ are also attributable to high fossil fuel prices during the trading period. Cement, refining, aluminum and steel sector were dealing with more fierce competition and could not pass on the price to consumers. There is to date no empirical evidence that these sectors had any market share loss due to carbon pricing (Convery et al., 2008:25).

### ***11.3 The inclusion of shipping into the EU ETS***

When deciding which sectors to include in the scheme, it would be reasonable to include sectors that are among the most heavily polluters. Currently, the EU ETS applies to about 11.500 installations from the electric power sector and other energy-intensive sectors like cement, refining, steel and aluminium, and with 45% of the EU’s total CO<sub>2</sub> emissions covered, it is the world’s largest tradable permits program (Gupta et al., 2007:757). For the maritime transport sector, the environmental record is mixed. On the one hand, shipping is relatively pollution-extensive per quantity of goods transported. On the other hand, the sector’s emission of GHG is significant in absolute terms (CE Delft et al, 2007:1). Transport covers about

one fifth of total GHG emissions in the EU-27, and that about 15% of that is caused by international marine shipping and domestic navigation (European Environmental Agency (EEA), 2009).<sup>57</sup> In line with the findings for the EU-27, global GHG emissions from maritime shipping are estimated to account for 1.8% to 3.4% of total emissions (CE Delft et al, 2007:181). Apart from being a heavy polluter, the shipping sector is expected to increase its GHG emissions significantly due to the increase in global goods traded (CE Delft et al, 2007:1). Inclusion of the maritime transport sector into the EU ETS can also provide Community-wide benefits. The more inclusive the trading scheme gets, the more cost reductions the member states face with respect to compliance with Kyoto targets. On beforehand, it is estimated that total cost savings of an EU ETS policy that includes all sectors are about €900 million more compared to a policy that includes only energy suppliers and energy-intensive industry (European Commission, 2000:11).

In theory, the carbon emission abatement should be done by the operators with lowest marginal abatement cost (MAC). The International Maritime Organization (IMO) (IMO, 2009) has researched the maritime transport sector's maximum abatement potential and related marginal cost. A rough conclusion that can be drawn is that the estimated MAC range from negative amounts to at maximum between €53,- (low estimate) and €93,- (high estimate) per ton of CO<sub>2</sub> avoided. (IMO, 2009:263).<sup>58</sup> Average MAC for all participating operators in the EU ETS were on beforehand estimated to be €20, and the average price of the permits has indeed varied around that value in the first trading period (Blok et al, 2001). Due to its relatively high MAC the maritime transport sector as a whole is expected to become a net-buyer of allowances, meaning that it would finance emission cuts elsewhere rather than to actually cut

---

<sup>57</sup> Road transport is responsible for emission of the major part of transport emissions. A main reason why not to consider the inclusion of road transport into the trading scheme is that allocating allowances, monitoring emissions and enforcing compliance of such small mobile emitters is too complex (European Commission, 2000:10). The EU did, however, establish a command-and-control regulation to regulate the carbon dioxide emissions from road transport, which enters into force in January 2012. The European Commission has an objective of limiting average CO<sub>2</sub> emissions from new passenger cars to 120 grams per km - a reduction of around 25% from current levels. By improving fuel efficiency, this is also expected to deliver substantial fuel savings for drivers. (Regulation EC 443/2009)

<sup>58</sup> The respectively \$80,- and \$140,- found by IMO converted with an exchange rate of 1.5 US\$ per Euro, on 21 October 2009 (ECB: <http://www.ecb.int/stats/exchange/eurofxref/html/eurofxref-graph-usd.en.html>)

emissions inside shipping (Kågeson, 2007:29). However, with a fair amount of emission reductions that are cost-efficient at the current price of allowances, the sector has certainly the capability to realize GHG abatement itself. Another finding of IMO was that there is even a range of measures with negative cost efficiency, meaning that they are even profitable when there is no price on CO<sub>2</sub> emissions. The estimated maximum abatement potential lies between 210 to 440 Mt of CO<sub>2</sub>. This is as much as 15–30% of the total emissions of the vessels taken into account (IMO, 2009:263).

The EU ETS has proven to realize emission reductions by making carbon dioxide emissions marketable and thereby creating incentives to abate GHG emissions. During the EU ETS, the European carbon emissions have decreased until 6.2% below 1990 levels at the end of 2008 (EEA, 2009b).<sup>59</sup> As the first years were characterized by relatively undemanding reduction goals, and these goals are expected to be more stringent in the following trading years, the environmental effectiveness of emission trading is likely to increase. In the end it is technological change that can drive the Community towards a low-carbon society, therefore this is the ultimate goal of the policy: “[...] as emissions trading will induce competition between companies to find cost-effective ways to reduce their emissions, an additional boost will be given to environmentally friendly technologies” (European Commission, 2000:8). Results of a survey among the majority of participating industries show that the firms are ‘pricing-in’ the value of CO<sub>2</sub> allowances in their short-term marginal cost decisions and that, for most industries, the EU ETS affects long-term decisions regarding the development of innovative technologies (McKinsey & Company and Ecofys, 2005:5). In order for the maritime transport sector to become more environmentally friendly, the flexible nature of the EU ETS provides a definite window of opportunity, without placing unnecessary high burden on the sector – as can be expected from traditional command-and-control measures.<sup>60</sup>

---

<sup>59</sup> A critical note made by the EEA is that the witnessed emission reduction in 2008 occurred for a major part due to changes that were outside the scope of the policy. First and foremost there was the economic slowdown after the financial crisis. Then, Germany and the United Kingdom, who are the two main polluters and who also dominate the downward trend in emissions, have had drastic market design changes: as a part of Germany’s Integrated Energy and Climate Program their energy market was made more energy efficient and reliant on renewable energy, and in the UK there was the liberalization of the energy market and the associated switch from oil and coal to gas (EEA, 2009b:17).

<sup>60</sup> A number of studies comparing market-based and command-and-control instruments for different pollutants found that in all cases, the cost of achieving the same reduction in pollution are between 1.72

### **11.4 Limits to include the maritime transport sector**

In contrast to the success potential of the EU ETS, the internal features of the maritime transport sector are not favourable to a regional trading policy. Ships vary considerably in size, type and even usage. This means that when deciding on the specific policy design, mainly with respect to the distribution of allowances, it will be a challenge to agree with all stakeholders and still end up with an ambitious policy. A choice needs to be made between i) grandfathering based on a historic approach, ii) grandfathering based on a benchmark approach, and iii) auctioning. If, for example, allowances would be grandfathered based on historical emissions, the ship activity in the base year is crucial. Tramp shipping is characterized by very irregular transport activity, making a historical approach rather unreliable. A ship travelling much more in the base year than in a trading year would realize large windfall profits, while a ship travelling relatively much in a trading year would be in problems. Moreover, grandfathering permits in this way distorts the competitive market for shipping due to high volatility in trading (CE Delft et al, 2006:232). Distributing allowances with a benchmark approach is shown to be difficult due to the broad range in ship types and sizes. It is not easy to design a benchmark that doesn't discriminate against one of the categories (Martinek, 2006). Auctioning permits places the responsibility for allocation with the sector itself, overcoming any discriminative problems. However, it needs to be assured that auctions take place frequently, corresponding to the high variability in some shipping industries. Another complication arises due to so-called "occasional sources"; ships that only occasionally enter the European seas or ports (Harrison et al, 2004:90). As a result to the above, the design of the permits allocation creates a basis for disagreement among the industry itself.

In order to include maritime transport as a trading sector in the EU ETS, the participating countries need to decide on an allocation method of ship emissions to countries, which will be the major bottleneck for implementation. An allocation method needs to be chosen, as under the framework of EU ETS the member states are responsible for the emissions of their national installations (under the Burden Sharing agreement). For over 10 years, the topic of allocation of shipping emissions to Parties has been discussed under the framework of UNFCCC, with the intention to pursue limitation of emissions from the sector on a global scale. These discussions have led to the selection of eight allocation options (FCCC/SBSTA/1996/9/Add.2: 19-22), and in

---

and 22 times higher for command-and-control instruments (Tietenberg, 1990). The previous chapter provides a thorough comparison of market-based and command-and-control policy instruments.

1997 the UNFCCC Subsidiary Body for Scientific and Technological Advice (SBSTA) selected 5 options for further consideration by the Conference of Parties (COP):<sup>61</sup>

1. No allocation.<sup>62</sup>
2. Allocation to Parties according to the country where the bunker fuel is sold.
3. Allocation to Parties according to the nationality of the transporting company, the country where the vessel is registered, or the country of the operator.
4. Allocation to Parties according to the country of departure or destination of the vessel, or shared between departure and destination.
5. Allocation to Parties according to the country of departure or destination of the passenger or cargo, or shared between the countries of departure or destination.

Since the selection of the five allocation options in 1997, no progress has been towards agreement upon the allocation of emissions. Progress on choosing the best allocation method has been slow due to the fact that whatever option is selected, some member state finds itself disadvantaged (Haïtes, 2009:417). The five are also applicable to a European allocation of emissions. Although they are selected for further consideration, they all have their own disadvantages. Allocation to the country where the fuel is sold is highly sensitive to evasion as tankers could easily get their fuel from outside the region. To allocate emissions according to the flag of the ship is difficult as ships tend to change flags regularly. The last two options could lead to ships avoiding the countries or ports that are participating in the system, which could cause evasion. Alternatively, in a dissertation about how to include the maritime shipping sector into the EU ETS, Kågeson (2007) proposed to make the ship (independent of the flag) the liable entity (which would be as much as 'no allocation'). It would mean that the ship could only enter a port included in the EU emission trading scheme, if participates in the EU ETS (Kågeson, 2007:12-16). Another option would be to allocate total emissions to countries on the basis of the share of freight tones loaded (European Commission and Entec UK Limited,

---

<sup>61</sup> They are selected by the Subsidiary Body for Scientific and Technological Advice (SBSTA), a body of the UNFCCC that counsils the Conference of Parties on various topics including climate, the environment, and technology. The three other options are ruled out because of unfair treatment of land-locked countries, the requirement of too much data availability and therefore high administrative cost, and the exclusion of the high seas (CE Delft et al, 2006: 235).

<sup>62</sup> If the goal is still to reduce emissions under the Kyoto Protocol, the sector has to be regarded as a single Party and included in the regulation accordingly.

2005). As the amount of emissions allocated to EU member states differs significantly with the allocation options, it is a very complex task to agree on the method with all stakeholders.

A practicality that is helpful for inclusion of maritime transport in the EU ETS is that, according to Regulation 18 of MARPOL Annex VI, all ships larger than 400GT are required to hold so-called 'bunker delivery notes'. These notes cover information about port of bunkering, fuel suppliers, sulphur content of the fuel, and more. To be useful for the Emission Trading Scheme, additional information about the carbon content of the fuel needs to be added (Kågeson, 2007:17). The national monitoring institution can use the notes to calculate emissions and it can verify if the ships have covered them with permits or have ceased to do so. In case the vessel is the liable entity, this information could even be shared with participating ports, which could in turn reject services to non-complying ships (Kågeson, 2007:17). Denial of services could be used as an additional non-monetary penalty to provide incentives to comply with the regulation.

For legal feasibility it has to be underlined that the inclusion of shipping in the existing EU ETS would appear to be consistent with UNCLOS provisions and customary international law, but it would also probably be jurisdictionally opposed by non-EU states and industry bodies<sup>63</sup>

In fact, according to Article 2 UNCLOS<sup>64</sup> the European Union has the power to issue rules and regulations requiring ships to report their emissions from their entire journey even if most of

---

<sup>63</sup> The International Chamber of Shipping (ICS) already showed its interest and concerns regarding the inclusion of the shipping sector into an ETS. In its 2005 "Position Paper , MARPOL VI" ICS stated: "*ICS is interested to learn of emission trading schemes and mechanisms where they serve to facilitate compliance with international regulations. It is recognized that regional environmental characteristics may require local emission measures that exceed international requirements but also that they should operate within an enabling international framework. Regional legislation is discouraged since it is likely to militate against free and fair international trade.*"

<http://www.marisec.org/icsorange/icspositionpapers/MARPOL%20Annex%20VI%20%20Jul%202005.pdf>

<sup>64</sup> UNCLOS Article 2: "*1. The sovereignty of a coastal State extends, beyond its land territory and internal waters and, in the case of an archipelagic State, its archipelagic waters, to an adjacent belt of sea, described as the territorial sea. 2. This sovereignty extends to the air space over the territorial sea as well as to its bed and subsoil. 3. The sovereignty over the territorial sea is exercised subject to this Convention and to other rules of international law.*"



them had occurred out of the EU waters. To do so EU could argue that such a request would come within its jurisdiction over its territorial sea, unless ships would be required to surrender allowances only at entry to an EU port and not anywhere out of EU territorial waters. That would raise the risk of evasion of the scheme. Vessels may in indeed decide not to call at EU ports, but to choose non-EU ports closely located to EU waters, but still out of them (e.g. Gibraltar or Ukraine). This option would inevitably block EU from exercising its jurisdiction over those vessels and that would undermine the effectiveness of the whole scheme.

Another issue related to the legal feasibility of including the shipping sector into the EU ETS is the choice between route and time based shipping ETS. Both approaches, to be effective, require the scheme to be operative also extraterritorially, which means out of EU waters. As mentioned above EU cannot impose rules or restrictions outside its area of sovereignty and jurisdiction. The only argument EU could use to avoid non-EU states complaints is that, within the EU ETS, there would not be any attempt to exercise jurisdiction out of its territorial waters, but simply a settlement of conditions to be respected by vessels willing to enter EU ports.

It is indeed allowed by UNCLOS and GATT to adopt regional measures in order to protect the environment. However it has to be stresses the fact that nor UNCLOS or other IMO Conventions currently provide the EU with a strong legal instruments to protect the extraterritorial effectiveness of its laws and regulations.

Going back to the brief analysis a of a route based scheme it may induce vessels sailing from far non-EU countries, e.g. New Zealand, to stop by closer non-EU ports, e.g located in Egypt, turning the voyage to EU ports, for carbon purposes, much shorter. That would allow them to report and surrender much less CO2 emissions, somehow hiding the real entity of the trip.

On the other hand a time based scheme, working back over a fixed period of time before and after visiting EU ports to determine the total amount of emissions from ships, may include periods when ships were trading between non-EU ports or just stopping there. This would inevitably cause problems in terms of extraterritorial effectiveness of the scheme. Moreover during any period of time the ownership of vessels may change even more than once causing obstacles in terms of enforcing compliance.

### **11.5 Some risks**

Besides a limited feasibility of inclusion of maritime transport in the EU ETS, due to the above mentioned administrative- and distributional difficulties, there is also a chance of failure of the policy. Ships are per definition easily movable, and can therefore reduce production cost

simply by avoiding the European ports, seas or gasoline sellers as much as possible, which leads to carbon leakage and a policy that is incapable to reduce emissions from maritime transport. On top of that, European maritime transport companies risk losing market share to companies that are outside the regulation. Although there are currently no estimates on the expected carbon leakage as a result of inclusion of shipping in the EU ETS, something can be said about how the industry is likely to respond. The geographical scope of the scheme is important. If all emissions from ships arriving or departing from a European port would be included, it would create an incentive for non-participating ports to try to establish themselves as a hub for intercontinental ships. At the hub, the cargo could be transferred to special boats that move between EU ports and the hub, and in that case the largest part of the intercontinental carbon emissions would not require allowances (Kågeson, 2007:25). It depends on the specific allocation of emissions how exactly this system would work, but basically ships would avoid the European waters or ports – thereby reducing the impact of the policy on emission reductions. If only emissions on voyages between EU ports are included in the scheme, it would make sense to make an extra call at a port outside the EU, without transferring the cargo to another ship. It could in this case be profitable for EU ships to make an extra stop in the Mediterranean (in a port in a North African or the Middle Eastern country) or in the Baltic Sea (in a Russian port) (CE Delft et al, 2007:233).

Another source of failure of the policy lies in the dynamics of the carbon market. First, incomplete information is a general concern as it can disrupt the long-term price signal making participants less willing to engage in emission reduction activities. In 2006, a practical difficulty to access reliable market information has contributed highly to price instability (Convery et al, 2008:16) More specifically, on the 25<sup>th</sup> of April 2006 the Czech Republic and the Netherlands released the information that their national emissions were respectively 15% and 7% lower than the number of permits allocated. Immediately, allowance prices dropped by about 10% on the spot market. Later that week comparable announcements on the long positions from France and Belgium led to a closing spot price on Friday that was 54% lower than the price on the Monday before (Ellerman Buchner 2008:269) (see line 2 in figure 4). It is clear that another problem underlying the following price drop is that the information released confirmed the beliefs that the initial allocation of permits was too generous, which needs to be a lesson for future policy-makers. In the second phase of the EU ETS, allowance banking has reduced price spikes as it can be used to hedge against price uncertainty. It provides temporal flexibility between current actual marginal abatement cost and expected future marginal abatement cost, which is especially useful for firms facing large expenditures to abate pollution, like the

maritime transport sector (Tietenberg, 2003:415). A second concern with a cap-and-trade policy is high transaction cost (related to trading, monitoring, enforcement, and verification). In the presence of high transaction cost, the efficient equilibrium where emissions are reduced at lowest cost society-wide might not be reached. The volume of allowances traded will decrease as a result of the cost associated with trading (Stavins, 1995), creating another source of disruption of the long-term price signal.

### **11.6 Conclusion**

Reducing GHG emissions from the maritime transport sector by means of inclusion into the EU ETS is mainly interesting because of the opportunities that the policy creates to reduce emissions from the regarded sector, while allowing for flexibility in how to achieve that. It has to be taken into account that trading and other transaction cost could place a large burden on small emitters, making trading inefficient. Another threat to the working of the EU ETS is incomplete information or insecurity about future policy decisions, causing volatility and investment risk in the carbon market. A treat for the maritime sector when included into the policy is loss of competitiveness to companies that don't fall under the regulation.

Opposite to the conclusions drawn from the external features (of the EU ETS), the internal features of the maritime shipping sector are not specifically favorable to inclusion into the policy. Although the sector has a significant abatement potential meaning that environmental gains can be realized, and that large ships are already obliged to hold bunker notes with information about bunker fuel sold, there are some challenges that need to be overcome in order to make the policy a success. First and foremost, the participating countries need to decide on an allocation method, which will be politically difficult and has been the major bottleneck for over a decennium in the international debate. The mobile nature of the sector creates a risk of carbon leakage, which is a major concern for the environmental effectiveness of the policy and needs to be addressed with great care. Apart from that, there are administrative difficulties due to the fact that the ships vary considerably in size, type and even use. This means that when deciding on the specific design, mainly with respect to the distribution of allowances (grandfathering based on historic or benchmark approach, or auctioning), it will be a challenge to agree with all stakeholders and still end up with an ambitious policy.

## **12. International mechanisms to reduce maritime transport emissions**

When analyzing the inclusion of the maritime transport sector in the EU ETS it became clear that the main challenges to make such a regional approach work are: 1) to decide on how to allocate shipping emissions to countries, and 2) to avoid the threat of carbon leakage and thereby evasion of the policy's effectiveness. Theoretically, the first two problems could be solved when the maritime transport sector is involved in a global mechanism to reduce the sector's CO<sub>2</sub> emissions: in a global system there would be no need for emission allocation to Parties (UNFCCC SBTA option 1: no allocation) and due to global coverage there is no room for ships to avoid regions that impose stricter regulations. Apart from that, there are administrative difficulties related to the great variety in ship type, size and usage within the sector that can be addressed by using fuel consumption as the basis for emission calculations. Various options exist when designing a global regulation for maritime shipping. For all non-voluntary options it holds that the shipping sector (or practically: the IMO) could be included as a separate Party in the Kyoto protocol in order to be held accountable for the achievement of its abatement targets. This chapter will analyze several mechanisms for a global policy on maritime CO<sub>2</sub> emissions.

### ***12.1 Common but differentiated responsibilities***

The most important principle in international negotiations on the fight against climate change is that of common but differentiated responsibilities, like it was the central topic on COP15 in Copenhagen last December. The initial text comes from the Rio Summit in 1992: "In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command" (DESA, 1992). For maritime transport the basic principle is, on the contrary, equal treatment of ships. In the Copenhagen discussions the conflict of these two principles was highlighted. In a statement by the Executive Secretary of the UNFCCC Secretariat, Mr. Yvo de Boer, a solution was mentioned on how to do this: "[...] A global cap on bunker fuels would be in line with the "equal treatment" principle of the IMO. Using the obtained revenues to assist developing countries in addressing climate change would be in line with the provisions of the climate change Convention. The amounts that could be generated by maritime transport in reducing its carbon footprint are substantial with estimates over four billion US dollars per

year.” (IMO, 2009). A second way to combine both principles is to differentiate commitments for Annex I and non-Annex I countries, without relying on the nationality of ships as the flag can change easily. A solution could be to differentiate responsibilities according to the route of the vessels or ship size (Faber and Rensema, 2008:36). A justification for differentiated responsibilities in a maritime policy is that the policy should not interfere with the growth potential of developing countries. As some countries are dependent on maritime transport for their exports, and countries are thought to develop by periods of export-led economic growth, global coverage of the described policies could namely lead to lower economic growth (Faber and Rensema, 2008:36). Kågeson (2008:2) highlights that it may not be possible to achieve complete global coverage of an international maritime emission trading scheme, as support from developing countries might be limited. He therefore envisages three possible stages of implementation: First the set-up of a scheme by the IMO and the UNFCCC that is open for voluntary participation by states and ports, then a scheme that covers all traffic on ports in Annex I countries, which can be later extended to a scheme covering all maritime traffic on a global level. The same could be applied on a tax or a levy system, although careful analysis of the effects is needed as a major threat to the environmental effectiveness of these systems is carbon leakage by incomplete coverage. For the voluntary sectoral crediting option, this is not an issue.

## ***12.2 Maritime Emission Trading Scheme (METS)***

A Maritime Emission Trading Scheme (METS) is a global cap-and-trade system for the maritime transport sector only. The IMO could set the desired cap and create a commission to take care of frequent auctions of the pollution permits, as well as make sure that the policy is adequately monitored. The revenues from auctioning could for example be returned to the sector by means of subsidies on green technologies, or used for a technology fund to assist (companies in) developing countries in their mitigation efforts (Kågeson, 2008:4). Like under the EU ETS, permit allocation could also be done by grandfathering, either based on a historical or a benchmark approach. This would, however, be associated with the same difficulties related to the great variety of ships and usage as discussed in the previous chapter.

In a closed system, for the maritime transport sector only, there is no interaction with other (regional) emission trading markets. In an open system, the METS would be linked to other markets, which allows for trade with other sectors that may face a lower marginal abatement cost than the shipping sector, favouring cost-effectiveness. The volume of allowances and the number of potential participants would also be much greater in an open system, which

benefits market transparency and trade, but could create more uncertainty (Kågeson, 2008:2). In a METS with global coverage there would be no carbon leakage caused by ships avoiding regions that have implemented a (regional) emission trading scheme. If enforcement occurs through Port State Control (PSC), the ultimate penalty is the detention of the ship or a ban of the ship that doesn't comply. In case only a few ports don't enforce the METS, ships could choose to evade the policy by calling at those ports. However, this would decrease their limits and increase their costs considerably (Faber and Rensema, 2008: 26). Carbon leakage gets more and more a treat when the number of ports enforcing the regulations falls. With global coverage, the total of CO2 emissions per ship can be calculated as a factor of the total fuel bought, without risking carbon leakage by ships bunkering in places outside the regulation. In sum, a global METS that is open to other sectors and that allocates permits by means of auctioning would generate the benefits of a cap-and-trade system without facing the problems related to emissions allocation to Parties and carbon leakage.

### **12.3 Maritime Sectoral Crediting Mechanism (MSCM)**

A Sectoral Crediting Mechanism (SCM) sets baselines of emissions for an entire sector, and a reduction of emissions below that baseline generates tradable credits for the sector as a whole. Inside the sector there would be national authorities or special institutes to distribute credits to individual sources (Baron and Ellis, 2006:8). It is fairly similar to a cap-and-trade approach, which can be thought of as ex-ante crediting. SCM is voluntary in nature: no penalties are imposed on firms or ships that are not reaching emission reductions. This is why it is also referred to as 'no-loose' sectoral crediting. For the same reason, the IMO needs to redirect incentives to individual sources to avoid non-cooperation and free-riding behaviour. The IMO could simply pass on the credits to sources that show improved performance, or it could set overachievement goals as a baseline for internal allocation of credits as a safety net in case some individual sources realize no or only disappointing emission reduction. Generally, this mechanism is envisaged to encourage particularly developing countries to participate in GHG reduction. The generated credits can be sold on the financial market at the prevailing carbon credit price, or directly to governments and firms of Annex I countries that use them to offset national emissions or to reduce the cost of compliance to their abatement targets. As SCM is voluntary, the future supply of credits from this system is highly unpredictable. Given that demand is relatively stable and predictable, an unforeseen large credit supply reduces the carbon price and could therefore have far fetching effects on the incentives to mitigate GHG emissions (Baron et al, 2009:9). Low prices as well as price volatility make investments in low-

carbon technologies less profitable and more insecure. The system can only be implemented as complementary to cap-and-trade systems already in place as those systems are to guarantee the demand for the offsetting credits. The downside of such a no-loose approach is that it could be a source of competitiveness concerns. Complementing a regional trading system like the EU ETS with a MSCM increases incentives for participating companies to move to MSCM hosting countries or outside the scope of the regional system, which could thus threaten the competitiveness of European ports or ships. This critical note only holds when the sector is already included in a regional regulation, which is not the case for maritime transport yet.

#### ***12.4 Maritime Emission Reduction Scheme (MERS)***

At the MEPC 56, Norway proposed an international Maritime Emission Reduction Scheme (MERS) to tackle CO<sub>2</sub> emissions from international shipping. The proposal differs significantly from the abovementioned market-based instruments as it is a hybrid system combining the taxing of emissions with a cap on total emissions. The idea is that the IMO sets a cap on total CO<sub>2</sub> emissions from international maritime transport, and that all CO<sub>2</sub> emissions are taxed simultaneously. The revenue of these taxes are paid to a fund that will be used for three goals: 1) technical and operational industry improvements to increase the sectors abatement potential, 2) purchase of offset credits in the emission trading markets to make sure the sector stays below the predefined cap, and 3) climate change adaptation in developing countries (Stochniol, 2007:2). In accordance with an international emission trading scheme, enforcement will take place in participating ports as the emission charges have to be paid there. Monitoring takes place at the central level where ship owners need to submit monthly a fuel use record to the scheme database. The proposal suggests a emission charge of 40% of the market price of CO<sub>2</sub> allowances (set annually), and an emission cap that is until 2050 set at 2005 emission levels, and that decreases with 1% a year after 2050. It is calculated that with a charge of \$10 and coverage of more than 2/3 of total maritime transport emissions, the fund would consist of \$3 billion annually. This is translated into total environmental benefits in terms of lower abatement of 15GtCO<sub>2</sub> before 2050: 7GtCO<sub>2</sub> due to the technical and operational industry improvements and 8GtCO<sub>2</sub> due to emission offsets (Stochniol, 2007:6).<sup>65</sup> A benefit of this system compared to an international maritime emission trading scheme is that it avoids set-up

---

<sup>65</sup> It is calculated that after 2050 the proposal results in a total of 31GtCO<sub>2</sub> lower emissions, split up between 21 GtCO<sub>2</sub> from industry improvements and 10GtCO<sub>2</sub> from offsets.

cost of a global trade system and transaction cost related to trading. Because it doesn't require any permit allocation the system is relatively easy to construct – like for emission trading with full auctioning of permits.

A similar proposal was made by Denmark to MEPC 57. It suggests a flat bunker levy set at a fixed cost level per ton of fuel bunkered, and also proposes a cap on total emissions. Revenues are collected into an international maritime greenhouse gas emission fund that is to be used primarily for offsetting emissions above the cap by the acquisition of CO<sub>2</sub> emission credits in other sectors. As the levy is paid together with the fuel, the system could be subject to evasion as ships go bunkering in non-participating ports or offshore (Kågeson, 2008: 7). In the proposal it is suggested to link the levy to the cost related to offsetting to the levy, causing the levy to rise with non-compliance of ships – and vice versa.

### **12.5 Conclusion**

Reducing GHG emissions from the maritime transport sector by means of inclusion into the EU ETS is mainly interesting because of the opportunities that the policy creates to reduce emissions from the regarded sector, while allowing for flexibility in how to achieve that. Although the sector has a significant abatement potential meaning that environmental gains can be realized, and that large ships are already obliged to hold bunker notes with information about bunker fuel sold, there are some challenges that need to be overcome in order to make such a regional policy successful. These challenges include deciding on a method to allocate ship emissions to countries, diminishing the risk of carbon leakage, and designing a policy that is administratively and politically feasible with respect to allowance distribution and treatment of the great variety in ship type, size and usage. A global policy could overcome most of the abovementioned challenges, but will be a success only when the 'equal treatment of ships' principle of the IMO can be streamlined with the 'common but differentiated responsibilities' principle of the UNFCCC. The design of a global regulation to address emissions from maritime transport can be either a global maritime emissions trading scheme, a cap-and-tax system, or a voluntary sectoral crediting policy. For the non-voluntary options it holds that the shipping sector (or practically: the IMO) could be included as a separate Party in the Kyoto Protocol in order to be held accountable for the achievement of its abatement targets. They require ship operators being responsible balancing its carbon credits, while enforcement takes place through Port State Control. The benefits of respectively permit auctions, taxes or (fuel) levies can be used for a fund directed at supporting emission reductions from developing countries. Alternatively, the voluntary sectoral crediting is a low-cost and easy accessible approach that



benefits by stimulating developing countries to strive for emission reductions, but risks low or volatile market carbon price due to high and uncertain credit supply.

### **13. Conclusion and future research directions.**

Besides the increasing awareness of the need for policy interventions in this sector, a comprehensive analytical framework to give some insights on how to apply policy instruments, which should be informed by efficiency and equity principles, is still lacking. In addition, the international regulatory system of the international maritime transport make complex the application of policy measures to abate air emissions from the sector.

Our analysis has sketched the state of the art concerning the main methodological aspects to design policy measures to regulate air emissions from maritime transport, air pollutants and green house gases (namely, estimation of emissions caused by maritime activities; identification of technological and policy options to abate air emissions from ships), application of marketable instruments at European and/or international level). Our first results show that, because of the high uncertainty in air emissions estimations, and the several legal and economic constraints for regional and international environmental policy strategy for air emissions of maritime transport, further research is needed in the fields of air emissions estimation and policy options.

With regard to the air emissions estimation, a scientific debate is nowadays open on which would be the most proper way to accomplish this issue. Indeed, the scarce or limited availability of data concerning maritime transportation activities has caused during the last decades the widespread of different calculation methodologies. In addition the application of recently available new technologies for more detailed traffic data acquisition is further questioning the usefulness of methodologies proposed so far.

In particular, first approaches proposed in the last decade started their analysis from the technical features (e.g. installed power, weight, and so on) of the vessels included in one of the available ships' databases (e.g. Lloyd's Register Fairplay Database) and making some assumptions on their activities (average number of hours at sea, average engine load factor) they were able to give an estimate of the total emissions from ships. These first studies reported very different results in case they were trying to resemble the total fuel sales or not. This opened a strong debate which has finally led to the conclusion that previous estimates totally relying upon maritime fuel sales, considerably underestimate emissions from the maritime sector. This important step forward in the emissions evaluation has been followed by

other attempts which tried to refine the evaluation considering more reliable information on the ships' activities. The 2009 IMO report (Prevention of Air Pollution from ships – Second IMO GHG Study 2009. MEPC 59/INF.10) has followed this path, considering ships activities retrieved in real time for the whole 2007 from the Automated Identification System (AIS<sup>66</sup>) network. It is estimated the AIS is available on about 40.000 ships throughout the world (from December 2004 it is now required to all international voyaging ships with gross tonnage of 300 or more tons and all passenger ships regardless of size to have this system aboard), that is to say, approximately a half of the total fleet. The use of these data (even if aggregated per ships category) allowed the definition of a “consensus” estimate of the global pollution from international shipping (all the most important researchers in the field participated to the work).

Research however is moving fast towards the use of AIS data to directly evaluate instantaneous emissions coming from each single ship. In this way their geographical characterization is immediate and more accurate. The challenge is to find a way to cover all the ships which have not yet this system working aboard. This would be possible, for example trying to crossing AIS data with data concerning maritime traffic and coming from different data sources (Eurostat, port calls, etc.).

Finally, with regard to the policy option to abate CO<sub>2</sub> emissions from international maritime transport, we would like to highlight the relations between international maritime transport and the level of the international trade, which is strong importance in the actual global economy. Designing policy options to include CO<sub>2</sub> emissions embodied in international trade of manufactured goods (including also emissions from their transport) will allow the regulation of CO<sub>2</sub> emissions from maritime transport as well. This approach is focused on the role of consumers, which can affect the global emissions, they should be conscious of the ecological effects of their choices. In recent literature it has been advocated to shift from the current production-based quantification of CO<sub>2</sub> emissions to consumption-based quantification in order to benefit the design of a more equitable, more effective and participatory future climate policy (see Atkinson et al, 2010; Helm et al, 2007; Munksgaard et al, 2009; Peters and

---

<sup>66</sup> The Automatic Identification System (AIS) is a system used by ships and Vessel Traffic Services (VTS) principally for identification and locating vessels. AIS provides a means for ships to electronically exchange ship data including: identification, position, course, and speed, with other nearby ships and VTS stations.

Hertwich, 2008a). With production-based CO<sub>2</sub> emission quantification the country where the goods are produced is allocated the related pollution, for which it is responsible in environmental regulations. Moreover, it has the tendency to shift responsibilities as countries can virtually export their CO<sub>2</sub> emissions in order to comply with (inter)national climate change agreements. Consumption-based CO<sub>2</sub> quantification on the other hand does include emissions from international transport, as it allocates the total of emissions based on the country where the goods are consumed

## References

- Aabo, K. (2009). Exhaust Gas Emission Control Today and Tomorrow. In proceedings of the 31<sup>st</sup> propulsion and emission conference. Motorship. Copenhagen
- Aabo, K. (2003). Emission Control – 2stroke engines. Presented at the “EU Stakeholders Workshop on low-.emission shipping” 4 and 5 September 2003.
- AEA – Bosh, P., Coenen, P., Fridell, E., Palmer, T., Holland, M. (2009) Cost Benefit Analysis to Supporting the Impact Assessment accompanying the revision of Directive 1999/32/EC on the Sulphur Content of Certain Liquid Fuels, Issue 1
- AMVER (2004) Global Ship Observations for a full year.  
<http://www.amver.com/statarchive.htm>
- Andreoni, V., Miola, A., Perujo, A., (2008) Cost Effectiveness Analysis of the Emission Abatement in the Shipping Sector” ISSN 1018-5593 - ISBN 978-92-79-11280-5
- Bang, H.S. (April 2009) “Port State Jurisdiction and Article 218 of the UN Convention on the Law of the Sea”, *Journal of Maritime law and Commerce*, Vol. 40, No. 2
- Baron, R., B. Buchner, and J. Ellis, (2009), “Sectoral approaches and the carbon market”. Organization of Economic Co-operation and Development (OECD) and the the Environment Directorate of International Energy Agency (IEA), (June 2009) Paris.
- Baron, R., and J. Ellis, (2006), “Sectoral crediting mechanisms for greenhouse gas mitigation: institutional and operational issues”. Organization of Economic Co-operation and Development (OECD) and the Environment Directorate of International Energy Agency (IEA). (May 2006) Paris
- Birnie, P., Boyle, A. and C. Redgwell (2009), “International Law and the Environment”, Oxford University Press.
- Blok, K. D. de Jager, and C. Hendriks, (2001). Economic evaluation of sectoral emission reduction objectives for climate change. (March 2001).
- Boyle, A. (1985), “World Politics and International Law”, Duke University Press
- Butt, N. (2007). The impact of cruise ship generated waste on home ports and ports of call: A study of Southampton. *Marine Policy* 31, 591-598.
- Carbon Market Data (2009). World ETS database. [online]. [Accessed 10 September 2009]. Available at: [http://carbonmarketdata.com/pages/wd\\_info.php](http://carbonmarketdata.com/pages/wd_info.php)

- Carter, C. (2009). Elimination of a Ship Source Pollutant – STOP (Stern Tube Oil Pollutant). In proceedings of the 31<sup>st</sup> propulsion and emission conference. Motorship. Copenhagen
- CE Delft, Germanischer Lloyd, MARTINEK, and Det Norske Veritas (2006), “Greenhouse gas emissions for shipping and implementation guidance for the marine fuel sulphur directive”, Delft, (2006)
- Cofala J., Amann M., Heyes C., Wagner F., Klimont Z., Posch M., Schöpp W., Tarasson, Jan Eiof Jonson, Whall L.C., Stavrakaki A. (2007). *Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive*. Final Report. IIASA Contract No. 06-107
- COM (2009) 39 final, Brussels, 28.1.2009, “*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*”.
- CONCAWE (2004) The contribution of sulphur dioxide emission from ships to coastal deposition and air quality in the channel and southern North Sea area. *Rep. 2/94*, Brussels
- Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft (1972), 932 UNTS 3; UKTS 119 (1975), Cmnd. 6228; 11 ILM 262 (1972). In force 7 April 1974, Oslo
- Convention for the Protection of the Black sea Against Pollution (1992), with protocols on Pollution from Land-based Sources, Combating Pollution in Emergency Situations, and Pollution by Dumbing, 32 ILM (1993), 1110. All in force 15 January 1994, Bucharest
- Convention for the protection of the marine Environment of the N.E. Atlantic (1992), 3 YbIEL (1992) 759; 32 ILM (1993), 1072. In force 25 March 1998, Paris
- Convention for the Protection of the marine Environment of the Baltic sea Area (1992). In force 17 January 2000, Helsinki
- Convention for the Protection of the Mediterranean Sea Against Pollution (1976); Protocol Concerning Cooperation in Combating Pollution of the Mediterranean Sea by Oil and Other Harmful Substances in Cases of Emergency; Protocol for the Prevention of Pollution of the Mediterranean Sea by Dumping from Ships and Aircraft, 15 ILM (1976), 290. All in force 12 February 1978. 1980 and 1982 Protocols (q.v.). Revised convention and protocols 1995/6 q.v., Barcelona

- Convention on Fishing and Conservation of the Living Resources of the High Seas (1958), 559 *UNTS* 285; *UNKTS* 39 (1966), Cmnd. 3028; 17 *UST* 138, *TIAS* 5669. In force 20 March 1966
- Convention on the High Seas (1958, Geneva), 450 *UNTS* 82; *UKTS* 5 (1963), Cmnd. 1929; 13 *UST* 2312, *TIAS* 5200. In force 30 September 1962, Geneva
- Convention on the Territorial Sea and Contiguous Zone (1958), 516 *UNTS* 205; 15 *UST* 1606, *TIAS* 5639; *UKTS* 3 (1965), Cmnd. 2511. In force 10 September 1964, Geneva
- Convery, F., D. Ellerman, and C. de Perthuis (2008), "The European Carbon Market in Action: Lessons from the First Trading Period", Interim Report, (March 2008). Available at <http://www.aprec.net/>
- Cooper, D.A. (2003) Exhaust emissions from ships at berth. *Atmospheric Environment*, Vol. 37(27), pp. 3817-3830
- Copeland, C. (2008) "CRS Report for Congress, Cruise Ship Control: Background, Laws and Regulation and Key Issues"
- Corbett, J.J., Fischbeck, P.S. (1997) Emissions from ship. *Science*, 278(5339), 823-824
- Corbett, J., Fischbeck, P., Pandis, S., (1999). Global nitrogen and sulphur inventories for oceangoing ships. *Journal of Geophysical Research* 104, pp 3457-3470.
- Corbett, J.J., Koehler, H.W. (2003) Updated emissions from ocean shipping. *Journal of Geophysical Research*, Vol. 108(D20)
- Corbett, J.J., Koehler, H.W. (2004) Considering alternative input parameters in an activity-based ship fuel consumption and emission model: Reply to comment by Oyvind Endresen et al. on "Updated emissions from ocean shipping". *Journal of Geophysical Research*, Vol. 109(D23303)
- Corbett, J.J., Wang, H., Winebrake, J.J. (2009) The effectiveness and costs of speed reduction on emissions from international shipping. *Transportation Research Part D*, Vol. 14(8)
- Dalsoren, S.B., Eide, M.S., Endresen, O., Mjelde, A., Gravr, G., Isaksen, I.S.A. (2008) Update on emissions and environmental impacts from the international fleet of ships. The contribution from major ship types and ports. *Atmospheric Chemistry and Physics Discussions*, Vol. 8, pp. 18323-18384

- Deakin, E., (2001). *Sustainable development and sustainable transportation: Strategies for economic prosperity, environmental quality and equity*. Working paper, University of California at Berkeley, Institute of Urban and Regional Development..
- Decision 406/2009/EC adopted jointly by the European Parliament and the Council.
- Declaration of the UN Conference on the Human Environment (1972, Stockholm), UN Doc. A/CONF/48/14/REV.1
- Declaration of the UN Conference on Environment and Development (1992, New York), UN Doc. A/CONF.151/26/Rev.1, *Report of the UNCED*, vol. 1
- Det Norske Veritas, (2005). Technical Report in Norwegian for the Norwegian Department of the Environment “Reduksjoner av NOx iFartøyer – Tiltaksanalyse. Report Nr 2005-1095.
- Directive 2005/33/EC of the European Parliament and of the Council
- Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009, No L 140
- Directive 2009/28/EC of the European Parliament and of the Council.
- Directive 2009/31/EC of the European Parliament and of the Council.
- Emissions Database for Global Atmospheric Research, EDGAR (2009)  
<http://edgar.jrc.ec.europa.eu/index.php>
- EEB, (2004). *Air pollution from ships. A briefing document by: The European Environmental Bureau (EEB), The European Federation for Transport and Environment (T&E), Seas At Risk (SAR), The Swedish NGO Secretariat on Acid Rain.*
- EEB (2008) Air Pollution from Ships. Available online at <http://www.eeb.org/index.cfm/library/index.cfm?month=0&year=0&Air=1>
- Eilts, P., Borchsenius, J., (2001). Available NOx emissions reduction techniques – costs, benefits and field experience. In 23rd CIMAC World Congress on Combustion Engine Technology. Hamburg, Germany.
- Ellerman, A.D. and B.K. Buchner (2008). “Over-allocation or abatement? A preliminary analysis of the EU ETS based on the 2005-2006 emissions data”, *Environmental and resource economics*, 41, (2), 267-278
- EMEP/CORINAIR, (2002). *“EMEP/CORINAIR Emission Inventory Guidebook—3rd edition October 2002 UPDATE, Technical Report No 30, Shipping Activities—Sub sector 0804*

- European Environment Agency, Copenhagen, Denmark, 2002, web site: <http://reports.eea.eu.int/EMEP CORIN AIR3/en/B842vs3.4.pdf>, visited 2003.
- Endresen Ø., Bakke J., Sjørgard E., T. Flatlandsmo Berglen, P. Holmvang, (2005). Improved modelling of ship SO<sub>2</sub> emissions a fuel-based approach *Atmospheric Environment* 39: 3621.3628.
- Endresen, Ø., Mjelde, A., Sverud, T., Sjørgard, E., (1999). *Data and models for quantification of ship pollution*. Det Norske Veritas, Rep. 98-20
- Endresen, O., Sorgard, E., Bakke, J., Isaksen, I.S.A. (2004). Substantiation of a lower estimate for the bunker inventory: Comment on “Updated emissions from ocean shipping” by James J. Corbett and Horst W. Koehler. *Journal of Geophysical Research*, Vol. 109(D23302)
- Endresen, O., Sorgard, E., Sundet, J.K., Dalsoren, S.B., Isaksen, I.S.A., Berglen, T.F., Gravir, G. (2003). Emission from international sea transportation and environmental impact. *Journal of Geophysical Research*, Vol. 108(D17)
- Entec UK Ltd, (2002). *Quantification of emissions from ships associated with ship movements between ports in the European Community*
- Entec UK Ltd, (2005). *Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. General Report*.
- Entec UK Ltd, (2005a). Report “Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. Task 2a - Shore-Side Electricity” for the European Commission, DG Environment.
- Entec UK Ltd, (2005b). Report “Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments, Task 2b – NO<sub>x</sub> Abatement” for the European Commission, DG Environment.
- Entec, UK Ltd, (2005c). Report “Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments, Task 2c - SO<sub>2</sub> Abatement” for the European Commission, DG Environment.
- EPA (2003). Final Regulatory Support Document: Control of Emissions from New Marine Compression-Ignition Engines at or above 30 Liters per Cylinder. U.S. Environmental Protection Agency.



- European Commission (1997). Energy for the Future: Renewable Sources of Energy. White Paper for a Community Strategy and Action Plan, COM(97) 599 final URL: [http://europa.eu.int/comm/energy/library/599fi\\_en.pdf](http://europa.eu.int/comm/energy/library/599fi_en.pdf)
- European Commission (2000), "Green Paper on greenhouse gas emissions trading within the European Union", Commission of the European Communities (COM) 2000/0078, (March 2000)
- European Commission (2001). Communication "*The Clean Air For Europe (CAFÉ) Program: Toward a Thematic Strategy for Air Quality*" COM (2001)245
- European Commission and ENTEC (2002). Quantification of Emissions from Ships associated with ship movements between ports in the European Community. Dg ENV.C1, Eur. Comm., Brussels
- European Commission, McKinsey & Company and Ecofys, (2005). Review of the EU emissions trading scheme: highlights. Brussels and Utrecht. November 2005.
- European Environmental Agency, EEA (2002). *Annual European community CLRTAP emission inventory 1990–2000*. Technical Report 91. [http://reports.eea.eu.int/technical\\_report\\_2002\\_73/en](http://reports.eea.eu.int/technical_report_2002_73/en).
- European Environmental Agency, EEA (2009). Annual European Community greenhouse gas inventory 1990-2007 and inventory report 2009. Submission to the UNFCCC Secretariat. Technical Report NO 04/2009, Copenhagen (May 2009)
- European Environmental Agency, EEA (2009b). New estimates confirm the declining trend in EU greenhouse gas emissions. Press release, issued 31-08-2009. [online] [accessed on 28-09-2009]. Available from: <http://www.eea.europa.eu/highlights/new-estimates-confirm-the-declining-trend-in-eu-greenhouse-gas-emissions>
- EUROSTAT (2000). Transport and Environment – statistics for the transport and environment reporting mechanism (TERM) for the European Union. Luxembourg.
- Eyring, V., Koehler, H.W., van Aardenne, J., Lauer, A. (2005). Emission from International Shipping: 1. The last 50 years. *Journal of Geophysical Research*, Vol. 110(D17305)
- Eyring, V., Kohler, H., Lauer, A., Lemper, B. (2005). Emissions from international shipping: 2. Impact of future technologies on scenarios until 2050. *Journal of geophysical research*, 110.

- Faber, J., Markowska, A., Nelissen, D., Davidson, M., Eyring, V., Cionni, I., Selstad, E., Kågeson, P., Lee, D., Buhaug, Ø, Lindtsad, H., Roche, P., Humpries, E., Graichen, J., Cames, M., Schwarz, W. (2009). Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport. Tender DG ENV.C3/ATA/2008/0016. Delft, CE Delft,
- Faber, J., and K. Rensema (2008). "Left on the high seas". Global Climate Policies for International Transport. CE Delft. (Oktober 2008) Delft.
- Fagerli, H., Simpson, D. and Tsyro, S. (2004). *Unified EMEP model: Updates, in: Transboundary Acidification and Eutrophication and Ground Level Ozone in Europe*. EMEP/MSC-W Status Report 1.
- Farrell, A.E., Keith, D.W., Corbett, J.J. (2003). A strategy for introducing hydrogen into transportation, *Energy Policy* 31(13), 1357-1367.
- Georgakaki, A., Coffey, R.A., Lock, G., Sorenson S.C. (2005). Transport and Environment Database System (TRENDS): Maritime air pollutant emission modelling. *Atmospheric Environment*, Vol. 39, pp. 2357-2365
- Gupta, S., D. A. Tirpak, N. Burger, J. Gupta, N. Höhne, A. I. Boncheva, G. M. Kanoan, C. Kolstad, J. A. Kruger, A. Michaelowa, S. Murase, J. Pershing, T. Saijo, A. Sari (2007). Policies, Instruments and Co-operative Arrangements. In *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Haites, E. (2009). "Linking emissions trading schemes for international aviation and shipping emissions", *Climate Policy*, (9), p.515-430
- Hall W.J., 2009. Assessment of CO2 and priority pollutant reduction by installation of shoreside power. *Resources Conservation and Recycling*, doi:10.1016/j.resconrec.2009.10.002
- Hammingh P., J.M.M. Aben, W.F. Blom, B.A. Jimmink, W.J. de Vries, M. Visser (2007). *Effectiveness of international emission control measures for North Sea shipping on Dutch air quality*, (MNP Report 500092004/2007), Netherlands Environmental Assessment Agency (MNP), Bilthoven, September 2007. Available at <http://www.mnp.nl/bibliotheek/rapporten/500092004.pdf>

- Hansen, J.F. (2009). Fuel efficient LNGC Propulsion using variable Speed Electric Drives. In proceedings of the 31<sup>st</sup> propulsion and emission conference. Motorship. Copenhagen
- Harris, P.G. (1999). "Common but differentiated responsibility: the Kyoto Protocol and United States Policy", N.Y.U. Environmental Law Journal, Volume 7
- Harrison, D., D. Radov, and J. Patchett (2004). "Evaluation of the feasibility of alternative market-based mechanisms to promote low-emission shipping in the European Union sea areas", NERA economic consulting, London, (March 2004)
- Hayman B., Dogliani M., Kvale I., Fet A.M. (2000). Technologies for reduced environmental impact from ships: ship building, maintenance and dismantling aspects *Conference Proceedings, ENSUS 2000 Marine Science and Technology for Environmental Sustainability Department of Marine Technology and Science and Coastal Management*. University of Newcastle upon Tyne 2 - 12 Newcastle, UK 2000. ENSUS 2000. 4.-6.09.00
- Hoffmann S. and Krupnick A. J. (2004). *Valuing Risk To Health. Children are not little adults*. RFF- Resources, Washington DC. <http://www.rff.org/Publications/Resources/Documents/154/RFF-Resources-154-child.pdf>
- Holland et al. (2002). *Economic Assessment of Crop Yield Losses from Ozone Exposure. Report for the Contract EPG 1/3/170* The UNECE International Cooperative Programme on Vegetation. [http://www.airquality.co.uk/archive/reports/cat10/final\\_ozone\\_econ\\_report\\_ver2.pdf](http://www.airquality.co.uk/archive/reports/cat10/final_ozone_econ_report_ver2.pdf)
- Holland, M., Watkiss, P. (2002a). *Benefits table database: estimates of the marginal external costs of air pollution in Europe*. <http://ec.europa.eu/environment/enveco/air/pdf/betaec02aforprinting.pdf>
- Holland M, Hunt A., Hurley F., Navrud S., Watkiss P. (2005b). *Methodology for the Cost-Benefit Analysis for CAFE. Volume 1: Overview of the methodology*. Available on line : <http://ec.europa.eu/environment/archives/air/cafec/activities/cba.htm>
- Hurley F., Hunt A., Cowie H., Holland M., Miller B., Pye S. Watkiss P. (2005). *Methodology for the Cost-Benefit Analysis for CAFE. Volume 2 : Health Impact Assessment*. Available on line: <http://ec.europa.eu/environment/archives/air/cafec/activities/cba.html> APH, (2007). *Tool Box for Port Clean Air Programs. Improving Air Quality While Promoting Business Development*
- ICOADS, the International Comprehensive Ocean-Atmosphere data-set. <http://dss.ucar.edu/pub/coads/>

IIASA (2007). *Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive*. Final Report, Contract No. 06/107. Luxemburg, Austria

IMO Marine Environment Committee, 57<sup>th</sup> Session MEPC 57/WP.8

IMO Marine Environment Committee, 58<sup>th</sup> Session MEPC 58/4/15

IMO Marine Environment Committee, 58<sup>th</sup> Session MEPC 58/4/20, "*Prevention of Air Pollution from Ships, Legal Aspects of the Organization's Work on Greenhouse Gas Emissions in the Context of the Kyoto Protocol*".

IMO Marine Environment Committee, 58<sup>th</sup> Session MEPC 58/23/Add.1

IMO Marine Environment Committee, 59<sup>th</sup> Session MEPC 59/4/7

IMO Marine Environment Committee, 59<sup>th</sup> Session MEPC 59/4/26

IMO (2000). *Study of Greenhouse Gas Emissions from Ships*, Issue no. 2 - 31 March 2000  
[http://unfccc.int/files/methods\\_and\\_science/emissions\\_from\\_intl\\_transport/application/pdf/imoghmain.pdf](http://unfccc.int/files/methods_and_science/emissions_from_intl_transport/application/pdf/imoghmain.pdf)

IMO (2007). Report on the outcome of the comprehensive study undertaken by the informal cross government/industry scientific group of experts established to evaluate the effects of the different fuel option proposed under the revision of MARPOL ANNEX VI. BLG 12/6/1

IMO (2009). "Second IMO GHG study 2009; Prevention of air pollution from ships" International Maritime Organization (IMO) London, UK, Buhaug, Ø.; Corbett, J.J.; Endresen, Ø.; Eyring, V.; Faber, J.; Hanayama, S.; Lee, D.S.; Lee, D.; Lindstad, H.; Markowska, A.Z.; Mjelde, A.; Nelissen, D.; Nilsen, J.; Pålsson, C.; Winebrake, J.J.; Wu, W.Q.; Yoshida, K. [http://www.imo.org/includes/blastDataOnly.asp/data\\_id%3D26047/INF-10.pdf](http://www.imo.org/includes/blastDataOnly.asp/data_id%3D26047/INF-10.pdf)

IMO, (2009). "Control of greenhouse gas emissions from ships engaged in international trade in a post-2012 regime". Informational note by the international maritime organization. [Available \_\_\_\_\_ at [http://www.imo.org/includes/blastDataOnly.asp/data\\_id%3D27014/IMOinforonotefinal-CMP5.pdf](http://www.imo.org/includes/blastDataOnly.asp/data_id%3D27014/IMOinforonotefinal-CMP5.pdf)]

- International Convention for the Prevention of Pollution from Ships (MARPOL) (1973). *UKTS 27* (1983), Cmnd. 8924; 12 *ILM* (1973), 1319. Amended by Protocol of 1978 (q.v.) before entry into force, London
- IPCC (2006). Guidelines for National Greenhouse Gas Inventories (<http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html>)
- Jalkanen, J.-P., Brink, A., Kalli, J., Pettersson, H., Kukkonen, J., Stipa, T. (2009). A modelling system for the exhaust emissions of marine traffic and its application in the Baltic Sea area. *Atmospheric Chemistry and Physics Discussions*, Vo. 9, pp. 15339-15373
- Jonson, J.E., Simpson, D., Fagerli, H. and Solberg, S. (2006). Can we explain the trends in European ozone levels? *Atmos. Chem. Phys*, 6, pp 1–16.
- Kågeson, P. (2007). “Linking CO2 emissions from international shipping to the EU ETS”, Report Commissioned by the Federal Environment Agency, Germany (July 2007)
- Kågeson, P. (2008). “The Maritime Emissions Trading Scheme (METS)”, Nature Associates (May 2008) Stockholm
- Kane, D. (2009). Quantitative and qualitative analysis of vessel performance. In proceedings of the 31<sup>st</sup> propulsion and emission conference. Motorship. Copenhagen
- Karila, K., Karkkainen, T., Larmi, M., Niemi, S., Sandstrom, C.-E., Tamminen, J., Tiainen, J., (2004). Production of particulate emissions in compression ignition engines. Otamedia, Espoo, Finland.
- Keith, D., Farrell, A., Corbett, J. (2000). True zero-emission vehicles in a single step: hydrogen fueled ships with carbon management. In: Fifth International Conference of greenhouse Gas Control Technologies, Cairns, Australia.
- Lauer, A., Eyring, V., Corbett, J.J., Whang, C., Winebrake, J.J. (2009). Assessment of Near-Future Policy Instruments for Oceangoing Shipping: Impact on Atmospheric Aerosol Burdens and the Earth’s Radiation Budget. *Environmental Science and Technology*, n.43 (15), pp. 5592-5598.
- Lavini, G., Pedone, L. (2007). Improvement on Hydrodynamic Performance of Conventional Passenger Ship Hulls Through RANSE codes application. Presented at RINA’s Design and Operation of Passenger Ships, Cruise and Ferry Conference, London.
- Lloyd’s Maritime Information System (2002). The Lloyd’s Maritime Database. Lloyd’s Register – Fairplay Ltd, London

Lloyd's MIU (2004). Extract from the vessel movement database. Lloyd's Maritime Information Unit

Lloyd's Register of Shipping (1996). World Fleet Statistic, 1996, Lloyd's Regist. Eng. Serv., London

Lloyd's Register of Shipping (2000). World Fleet Statistic, 2000, Lloyd's Regist. Eng. Serv., London

Lloyd's Register of Shipping (2005). World Fleet Statistic, 2005, Lloyd's Regist. Eng. Serv., London

Lövblad, G., Fridell, E. (2006). Experiences from use of some techniques to reduce emissions from ships (<http://www.profu.se>).

Magnus, G. (1852). "Über die Abweichung der Geschosse," Abhandlungen der Königlichen Akademie der Wissenschaften zu Berlin, pages 1-23. See also: Gustav Magnus (1853) "Über die Abweichung der Geschosse, und: Über eine abfallende Erscheinung bei rotierenden Körpern" (On the deviation of projectiles, and: On a sinking phenomenon among rotating bodies), *Annalen der Physik*, vol. 164, no. 1, pages 1-29.

MAN B&W (2004). Emissions Control MAN B&W Two-stroke Diesel Engines. MAN B&W Diesel, Copenhagen Denmark.

MARIN (2008). Report. Available at <http://www.marin.nl/web/file?uuid=b7937e4c-c23c-46e0-a042-1cf0063d152f&owner=873c4345-f55e-4d84-8f96-058b54e8a911>

Marintek (1999). MarPower, Concepts of Advanced Marine Machinery Systems with Low Pollution and High Efficiency. State of the art report no. 2, European Commission, DG XII., Rep. 220724.01. Norwegian Marine Technology Research Institute, Trondheim, Norway (<http://www.marintek.sintef.no/MarPower/>).

Miola, A., Paccagnan, V., Mannino, I., Massarutto, A., Perujo, A., Turvani, M. (2009). External Costs of Transportation Case study: maritime transport. EU-Report, Scientific and Technical Research series. ISSN 1018-5593. Luxembourg

Motorship (2009). Emissions: 2009: Shipping goes green through the side door. *Motor Ship* (90), 1056, pp. 38,40,41.

Olesen, H.R., Winther, M., Ellermann, T., Christensen, J., Plejdrup, M. (2009). Ship Emissions and air pollution in Denmark. Present situation and future scenarios. Danish Ministry of the Environment. Environmental project n. 1306.

- Olivier, J.G.J. et al. (1996). Description of EDGAR Version 2.0 : a set of global emission inventories of greenhouse gases and ozone depleting substances for all anthropogenic and most natural sources on a per country basis of 1x1 degree grid. *RIVM Rep. 7710600002*. National Institute of public health and the environment, Bilthoven, Netherlands.
- Olivier, J.G.J., Berdowski, J.J.M. (2001). Global emissions sources and sinks. In: Berdowski, J., Guicherit, R., Heij, B.J. (Eds.), *The Climate System*. A.A. Balkema Publishers/ Swets & Zeitlinger Publishers, Lisse, The Netherlands, pp. 33–78.
- Oonk, H., Hulskotte, J., Koch, R., Kuipers, G., Van Ling, J. (2003). Emissiefactoren voor de binnenscheepvaart. TNO
- Ou, Z., Zhe, J. (2008). AIS Database Powered by GIS Technology for Maritime Safety and security. *The Journal of Navigation*, Vol. 61, pp. 655-665
- Paxian, A., Eyring, V., Beer, W., Sausen R., Wright, C. (2010). Present-Day and Future Global Bottom-Up Ship Emission Inventories Including Polar Routes. *Environmental Science and Technology*, Vol. 44, n. 4, pp. 1333-1339
- Perman, R.J., Ma, Y., McGilvray, J., Common, M. (2003) *Environmental and Natural Resource Economics*, 3rd ed. London: Addison Wesley Longman.
- Protocol for the protection of the Mediterranean Sea against Pollution from Land-Based Sources (1980). 19 *ILM*. In force 17 June 1983, Athens
- Protocol Relating to the Convention for the Prevention of Pollution from Ships, MARPOL (1978). 17 *ILM* (1978), Current texts in IMO, *Consolidated Edition*
- Purple Finder (2001). Purple Finder Database. <http://www.purplefinder.com>
- Purvin & Gertz – Avis, M.J., Birch, C.H. (2009). Impacts on the EU refining Industry & Markets of IMO Specification changes & other measures to reduce the sulphur content of certain fuels.
- Rahai, H.R., Hefazi, H. (2006). Emission control technologies for ocean going vessels. Center for Energy and Environmental Research and Services (CEERS), California State University, US.
- Rainer F. (2004). New elements for the assessment of External Costs from Energy Technologies – Final Report – OER European Commission. <http://www.ier.uni-stuttgart.de/forschung/projektwebsites/newext/>

- Rentz, O., Schleef, H-J., Dorn, R., Sasse, H., Karl, U. (1996). Emission control at stationary sources in the Federal Republic of Germany. Vol.1: Sulphur oxide and nitrogen oxide emission control. Karlsruhe, Germany, French-German Institute for Environmental Research, 588 pp (Aug 1996).
- Ritchie, A., de Jonge, E., Hugi, C., Cooper, D. (2005). Service Contract on ship Emissions: Assignment, Abatement and Market-based Instruments, Task 2c – SO<sub>2</sub> Abatement. Final Report, Entec UK Limited, Northwick, England.
- Sarvi, A., (2004). Smoke and particulate matter emissions from large diesel engines. Licentiate's thesis. Helsinki University of Technology, Department of Mechanical Engineering, Espoo, Finland.
- Schmid, H., Weisser, G. (2005). Marine Technologies for Reduced Emissions, In 2nd annual conference on green ship technology. Amsterdam, the Netherlands.
- Schreier M., Kokhanovsky A.A., Eyring V., Bugliaro L., Mannstein H., Mayer B., Bovensmann H., Burrows J.P. (2006). Impact of ship emissions on the microphysical, optical and radiative properties of marine stratus: a case study *Atmos. Chem. Phys.* 6: 4925-4942.
- Schrooten, L., De Vlieger, I., Int Panis, L., Chiffi, C., Pastori, E. (2009). Emissions of maritime transport: A European reference system. *Science of the Total Environment*, Vol. 408, pp. 318-323
- Simpson, D., Fagerli, H., Jonson, J.E., Tsyro, S., Wind, P. And Tuovinen, J.P. (2003). *Transboundary Acidification and Eutrophication and Ground Level Ozone in Europe. Unified EMEP Model Description*. EMEP/MSC-W Status Report 1, Part I.
- Skjølsvik, K. O., Andersen, A.B., Corbett, J.J., Skjelvik, J.M. (2000). *Study of greenhouse gas emissions from ships (report to International Maritime Organization on the outcome of the IMO Study on Greenhouse Gas Emissions from Ships)*, MEPC 45/8, MARINTEK Sintef Group/Carnegie Mellon Univ., Center for Economic Analysis/Det Norske Veritas, Trondheim, Norway.
- SOLAS (1974). International Convention for the Safety of Life at Sea [http://www.imo.org/Conventions/contents.asp?topic\\_id=257&doc\\_id=647](http://www.imo.org/Conventions/contents.asp?topic_id=257&doc_id=647)
- Sorgard, E., Mjelde, A., Sverud, T., Endresen, O. (2001). Technologies for reduction of pollution from ships. Report No. 99-2033. Det Norske Veritas, Norwegian research council, Norway.



- Stavins, R.N. (1995). Transaction cost and tradable permits. *Journal of Environmental Economics and Management*, 29, 122-148.
- Stochniol, A. (2007). "A new market-based CO2 emission reduction scheme". SD2: Supporting Document #2 for discussion of MEPC 56/4/9 (July 2007) London.
- Stopford, M. (2009). "Maritime Economics", Routledge
- Sudiro, M., Bertuccio, A. (2008). Production of synthetic gasoline and diesel fuels by alternative processes using natural gas, coal and biomass: process simulation and economic analysis. *International Journal of Alternative Propulsion* 2, 15-25. UNCTAD (2008), *Review of Maritime Transport*
- Takeshita, M. (1995). *Air Pollution Control Costs for Coal-Fired Power Stations*, IEAPER/17, IEA Coal Research, London, UK.
- Tan, A.K. (2006). *Vessel-source Marine Pollution: The Law And Politics Of International Regulation* (Cambridge Studies In International And Comparative Law), Cambridge University Press
- Thomas, R., Lauretis, R.D., Fontelle, J.P., Hill, N., Kilde, N., Rypdal, K. (2002). Shipping activities, Chapter B842, in *EMEP/CORINAIR Emission Inventory Guidebook*, edited by Lavender, K., Reynolds, G., Webster, A., Rypdal, K. European Environment Agency, Copenhagen, Denmark
- Tietenberg, T. (2003). "The tradable permits approach to protecting the commons: Lessons for Climate Change" *Oxford Review of Economic Policy*, 19, (3), 400-419
- Trozzi C. (2003). Environmental impact of port activities *1th International Scientific Symposium Environment and Transport* 19-20 June 2003 Avignon (France). 2000. Technical Report 91. [http://reports.eea.eu.int/technical report 2002 73/en](http://reports.eea.eu.int/technical%20report%202002%2073/en).
- Trozzi, C. Vaccaro, R., (1998). Methodologies for estimating future air pollutant emissions from ships. Techne report MEET RF98. Techne srl.
- United Nations Convention on the Law of the Sea (1982), Misc 11 (1983), Cmnd. 8941; 21 *ILM*, 1261. In force 16 November 1994, Montego Bay
- United Nations Conference on Environment and Development Framework Convention on Climate Change, 31 *ILM* (1992), 851; *B&B Docs*, 252. In force 21 March 1994

- United Nations Department of Economic and Social Affairs (DESA) (1992). "United Nations Report of the United Nations conference on environment and development". Annex I Rio Declaration of environment and development. A/CONF.151/26 (Vol. I), (June 1992) Rio de Janeiro. [Available at <http://www.un.org/documents/ga/conf151/aconf15126-1annex1.htm> on 14/01/2010] United Nations Publications (2004), "The law of the sea: obligations of states parties under the United Nations Convention on the law of the sea and complementary instruments"
- U.S. Coast Guard (2003). AMVER Database, <http://www.amver.com>
- U.S. Army Corps of Engineering (2004). Vessel Entrances and Clearances. Waterborne Commerce Statistic Centre, New Orleans. [www.iwr.usace.army.mil/ndc/data/dataclen.htm](http://www.iwr.usace.army.mil/ndc/data/dataclen.htm)
- Wang, C., Corbett, J.J. (2005). Geographical Characterization of Ship Traffic and Emissions. *Transportation Research Record*, Vol. 1909
- Wang, C., Corbett, J.J. (2007). The costs and benefits of reducing SO<sub>2</sub> emissions from ships in the US West Coastal waters. *Transportation Research Part D*, Vol. 12, pp. 577-588
- Wang, C., Corbett, J.J., Firestone, J. (2007a). Modeling Energy Use and Emissions from North American Shipping: Application of the Ship Traffic, Energy, and Environmental Model. *Environmental Science & Technology*, Vol. 41(9), pp. 3226-3232
- Wang, C., Corbett, J.J., Winebrake, J.J. (2007b). Cost-Effectiveness of reducing Sulfur Emission from Ships. *Environmental Science & Technology*, Vol. 41(24), pp. 8233-8239
- Wang, C., Corbett, J.J., Firestone, J. (2008). Improving Spatial Representation of Global Ship Emissions Inventories. *Environmental Science & Technology*, Vol. 42(1), pp. 193-199
- Wang, H. (2010). The comparisons of Speed Reduction with other policy instruments in GHG mitigation from containership. In *Proceedings of the 89<sup>th</sup> TRB Annual Meeting*. Washington DC
- Wang, H., Wang, C., Zhang, L. (2010). Evaluating the Economic Reasons of China's Stance on Ship-based GHG reduction negotiations. In *Proceedings of the 89<sup>th</sup> TRB Annual Meeting*. Washington DC
- Wartsila Corporation (2004). Marine Technologies for Reduced Emissions: [http://www.wartsila.com/Wartsila/docs/en/ship\\_power/media\\_publications/technical\\_papers/sulzer/marine\\_technologies\\_for\\_reduced\\_emissions.pdf](http://www.wartsila.com/Wartsila/docs/en/ship_power/media_publications/technical_papers/sulzer/marine_technologies_for_reduced_emissions.pdf)

- Wartsila Corporation (2004a). Lifetime Responsibility, Annual Report 2004, Sustainability Report.
- Wartsila Corporation, 2009. Energy Efficiency Catalogue. Accessed September, 20<sup>th</sup>, 2009 at the following link: [http://www.wartsila.com/Wartsila/global/docs/en/ship\\_power/energy-efficiency/boosting-energy-efficiency-presentation.pdf](http://www.wartsila.com/Wartsila/global/docs/en/ship_power/energy-efficiency/boosting-energy-efficiency-presentation.pdf)
- Wilde, H.P.J., Kroon, P., Mozaffarian, M., Sterker, T. (2007). Quick Scan of the Economic Consequences of Prohibiting Residual Fuels in Shipping. ENC-E-07-051.
- Winebrake, J.J., Corbett, J.J., Green, E.H., Lauer, A., Eyring, V. (2009) .Mitigating the Health Impacts of Pollution from Oceangoing shipping: an assessment of low-sulfur fuel mandates. *Environmental Science & Technology*, Vol. 43(13), pp. 4776-4782
- Winkler, J. (2009). Efficient Ship designs can regulate CO2 now. In proceedings of the 31<sup>st</sup> propulsion and emission conference. Motorship. Copenhagen
- Winther, M. (2008). New national emission inventory for navigation in Denmark. *Atmospheric Environment*. Vol. 42, pp. 4632-4655
- Woodruff, S.D., Diaz, H.F., Elms, J.D., Worley, S.J. (1998). COADS Release 2 Data and Metadata enhancements for improvements of marine surface flux fields. *Physics, Chemistry, and Earth Sciences*, Vol. 23, No. 5-6

European Commission

**EUR 24297 EN – Joint Research Centre – Institute for Environment and Sustainability**

Title: Analytical framework to regulate air emissions from maritime transport

Author(s): Miola, A., Ciuffo, B., Marra, M., Giovine, E.

Luxembourg: Office for Official Publications of the European Communities

2010 – 134 pp. – 21 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1018-5593

ISBN 978-92-79-15308-2

DOI 10.2788/78254

**Abstract**

*Maritime transport activity is becoming one of the most important topics on sustainability debate. Indeed, a part from industrial activity and energy production, maritime transport is the largest contributors to air pollution and the increasing rate of trade make the problem even more worrying. Aim of the report is to design a methodological framework to appraise the policy strategy to regulate air emissions from the ships (air pollutants and green house gases) giving some insights on how to design and to apply policy instruments that should be informed by efficiency and equity principles. The report outlines the state of the art on data, methodologies, air emissions estimations, technological and policy options to design a sectorial environmental policy strategy to regulate air emissions from ships. It gives an overview of the main methods to estimate the air emissions deriving from shipping activities and compares their results to define a reference framework. Particularly attention is done to cost effectiveness analysis of technological and policy options to abate GHG emissions from international maritime transport taking into account the legal regulatory system of this sector, and the main legal and economic constraints to implement a sectorial policy to abate CO<sub>2</sub> emissions. The report identifies some future research directions for the methods to estimate air emissions from ships and to design additional policy options applying consumption-based CO<sub>2</sub> quantification.*

### **How to obtain EU publications**

Our priced publications are available from EU Bookshop (<http://bookshop.europa.eu>), where you can place an order with the sales agent of your choice.

The Publications Office has a worldwide network of sales agents. You can obtain their contact details by sending a fax to (352) 29 29-42758.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

LB-NA-24297-EN-C



ISBN 978-92-79-15308-2



9 789279 153082