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IMO

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MEPC 59/4/7
9 April 2009
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PREVENTION OF AIR POLLUTION FROM SHIPS

Second IMO GHG Study 2009

Update of the 2000 IMO GHG Study

Executive Summary

Note by the Secretariat

SUMMARY

Executive summary:	The annex to this document provides the executive summary of the report (Phase 1 and Phase 2) on the updated 2000 IMO GHG Study on greenhouse gas emissions from ships, titled: "Second IMO GHG Study 2009". The full report can be found in document MEPC 59/INF.10
Strategic direction:	7.3
High-level action:	7.3.1
Planned output:	7.3.1.3
Action to be taken:	Paragraph 6
Related documents:	MEPC 45/8; MEPC 55/23; MEPC 56/23; MEPC 57/4/18 and Add.1, MEPC 57/21; MEPC 58/4/2 and MEPC 58/INF.6; MEPC 59/4/4 and MEPC 59/INF.10

Background

1 The first IMO study on emission of greenhouse gases from international shipping was commissioned following a request by the Diplomatic Conference on Air Pollution that was held at the IMO Headquarters in September 1997. The conference was convened by the Organization to consider air pollution issues related to international shipping and, more specifically, to adopt the 1997 Protocol to the MARPOL Convention (Annex VI – Regulations for the prevention of air pollution from ships). The first IMO study of greenhouse gas emissions from ships used figures for 1996 and was published in the year 2000 as document MEPC 45/8.

For reasons of economy, this document is printed in a limited number. Delegates are kindly asked to bring their copies to meetings and not to request additional copies.

CLIMATE CHANGE: A CHALLENGE FOR IMO TOO!

Update of the 2000 IMO GHG Study

2 MEPC 55 agreed that the 2000 IMO GHG Study should undergo a general update and MEPC 56 agreed on Terms of Reference for this work. Progress reports on the updating have been provided to MEPC 57 (MEPC 57/4/18 and Add.1) and MEPC 58 (MEPC 58/4/2). A final status report on the updating may be found in document MEPC 59/4/4.

3 The Committee will recall that the outcome of Phase 1 was reported to its fifty-eighth session. MEPC 58 noted with appreciation the introduction given by the coordinator of the international Consortium contracted to undertake the update of the Study, Dr. Buhaug of MARINTEK, who provided a summary of the main findings in documents MEPC 58/4/4 (executive summary) and MEPC 58/INF.6 (full report) (paragraph 4.23 of document MEPC 58/23).

4 The Steering Committee established in connection with the update agreed that the updated 2000 IMO GHG Study should be titled: **Second IMO GHG Study 2009.**

5 The executive summary of the final report covering both Phase 1 and Phase 2 of the Second IMO GHG Study 2009 is set out as annex to this document. The full report may be found in document MEPC 59/INF.10.

Action requested of the Committee

6 The Committee is invited to consider the attached executive summary of the Second IMO GHG Study 2009 as a basis of further consideration on the issue of greenhouse gas emissions from ships and take action as appropriate.

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ANNEX

Second IMO GHG study 2009

Executive summary

9 April 2009

Prepared for the International Maritime Organization (IMO) by:

- MARINTEK, Norway
- CE Delft, The Netherlands
- Dalian Maritime University, China
- Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Germany
- DNV, Norway
- Energy and Environmental Research Associates (EERA), USA
- Lloyd's Register – Fairplay Research, Sweden
- Manchester Metropolitan University, UK
- Mokpo National Maritime University (MNMU), Korea
- National Maritime Research Institute (NMRI), Japan
- Ocean Policy Research Foundation (OPRF), Japan

Preface

This study of greenhouse gas emissions from ships was commissioned as an update of International Maritime Organization's (IMO) *Study of Greenhouse Gas Emissions from Ships* which was delivered in 2000. The updated study been prepared on behalf of the IMO by an international consortium led by MARINTEK. The study was carried out in partnership with the following institutions:

> CE Delft, Dalian Maritime University, Deutsches Zentrum für Luft- und Raumfahrt e.V., DNV, Energy and Environmental Research Associates (EERA), Lloyd's Register – Fairplay, Manchester Metropolitan University, Mokpo National Maritime University (MNMU), National Maritime Research Institute (Japan), Ocean Policy Research Foundation (OPRF).

The following individuals were the main contributors to the report:

> Øyvind Buhaug (Coordinator), James J. Corbett (Task leader, Emissions and Scenarios), Veronika Eyring (Task leader, Climate Impacts), Øyvind Endresen, Jasper Faber, Shinichi Hanayama, David S. Lee, Donchool Lee, Håkon Lindstad, Agnieszka Z. Markowska, Alvar Mjelde, Dagmar Nelissen, Jørgen Nilsen, Christopher Pålsson, Wu Wanquing, James J. Winebrake, Koichi Yoshida.

In the course of their efforts, the research team has gratefully received input and comments from the International Energy Agency (IEA), the Baltic and International Maritime Council (BIMCO), the International Association of Independent Tanker Owners (INTERTANKO), the Government of Australia, the Government of Greece and the IMO secretariat.

The main objectives of the study were to assess: (i) present and future emissions from international shipping; (ii) the potential for reduction of these emissions through technology and policy; and (iii) impacts on climate from these emissions.

The work has been conducted in two phases. Results from the first phase, covering only part of the scope, was presented in MEPC 58/INF.6. This report covers the full scope of work, hence updates and supersedes the report on the first phase.

The views and conclusions drawn in this work are those of the scientists writing the report.

Recommended citation: *Second IMO GHG study 2009*; International Maritime Organization (IMO) London, UK, April 2009; 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.

List of abbreviations

ACS	Air cavity system
AGWP	Absolute global warming potential
AIS	Automatic identification system
AFFF	Aqueous film-forming foams
AMVER	Automated Mutual-assistance Vessel Rescue system
BC	Black carbon
CBA	Cost–benefit analysis
CDM	Clean development mechanism
CFC	Chlorofluorocarbons
CFD	Computational fluid dynamics
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
COADS	Comprehensive Ocean–Atmosphere Data Set
CORINAIR	Core Inventory of Air Emissions – Programme to establish an inventory of emissions of air pollutants in Europe
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EJ	Exajoule (10^{19} joules)
EIA	United States Energy Information Administration
EGR	Exhaust gas recirculation (NO_x reduction technology)
EU ETS	European Union Emissions Trading Scheme
FAME	Fatty Acid Methyl Ester (a type of bio-diesel)
FTD	Fischer–Tropsch diesel (a type of synthetic diesel)
GCM	Global climate model
GDP	Gross domestic product
GHG	Greenhouse gas
GT	Gross tonnage
GTP	Global temperature change potential
GWP	Global warming potential
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
HFO	Heavy fuel oil
HVAC	Heat, ventilation and air conditioning
ICF	International Compensation Fund for GHG emisssions from ships
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LNG	Liquefied natural gas
LRFPR	Lloyd's Register – Fairplay Research
LRIT	Long range identification and tracking system
MARPOL	International Convention for the Prevention of Pollution from Ships
MCFC	Molten carbonate fuel cell
MCR	Maximum continuous rating
MDO	Marine diesel oil (distillate marine fuel with possible residual fuel traces)
MEPC	Marine Environment Protection Committee
METS	Maritime emissions trading scheme
MGO	Marine gas oil (distillate marine fuel)
MSD	Medium speed diesel
NO_x	Nitrogen oxides

NMVOC	Non-methane volatile organic compounds
NSV	Net standard volume
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
OPRF	Ocean Policy Research Foundation
PAC	Polycyclic aromatic hydrocarbons
PFOS	Perfluorooctane sulphonates
PM	Particulate matter/material
PM_{10}	Particulate matter/material with aerodynamic diameter 10 micrometres or less
POM	Particulate organic matter/material
RF	Radiative forcing
RPM	Revolutions per minute
RTOC	Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee
SCR	Selective catalytic reduction
SECA	SO_x Emission Control Area
SEMP	Ship efficiency management plan
SF_6	Sulphur hexafluoride
SFOC	Specific fuel oil consumption
SO_x	Sulphur oxides
SOFC	Solid oxide fuel cell
SRES	Special Report on Emissions Scenarios (IPCC)
SSD	Slow speed diesel
TDC	Top dead centre
TEU	Twenty foot equivalent unit
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile organic compounds

Definitions

International shipping	Shipping between ports of different countries, as opposed to *domestic shipping*. International shipping excludes military and fishing vessels. By this definition, the same ship may frequently be engaged in both international and domestic shipping operations. This is consistent with IPCC 2006 Guidelines.
Domestic shipping	Shipping between ports of the same country, as opposed to *international shipping*. Domestic shipping excludes military and fishing vessels. By this definition, the same ship may frequently be engaged in both international and domestic shipping operations. This definition is consistent with IPCC 2006 Guidelines.
Coastwise shipping	Coastwise shipping is freight movements and other shipping activities that are predominantly along coastlines or regionally bound (e.g., passenger vessels, ferries, offshore vessels) as opposed to ocean-going shipping. The distinction is made for the purpose of scenario modelling and is based on ship types, i.e. a ship is either a coastwise or an ocean-going ship.
Ocean-going shipping	This is a term used for scenario modelling. It refers to large cargo-carrying ships engaged in ocean-crossing trade.
Total shipping	This is defined in this report as international and domestic shipping plus fishing. It excludes military vessels.

Chapter 1

Executive summary

Conclusions

- Shipping is estimated to have emitted 1,046 million tonnes of CO_2 in 2007, which corresponds to 3.3% of the global emissions during 2007. International shipping is estimated to have emitted 870 million tonnes, or about 2.7% of the global emissions of CO_2 in 2007.

- Exhaust gases are the primary source of emissions from ships. Carbon dioxide is the most important GHG emitted by ships. Both in terms of quantity and of global warming potential, other GHG emissions from ships are less important.

- Mid-range emissions scenarios show that, by 2050, in the absence of policies, ship emissions may grow by 150% to 250% (compared to the emissions in 2007) as a result of the growth in shipping.

- A significant potential for reduction of GHG through technical and operational measures has been identified. Together, if implemented, these measures could increase efficiency and reduce the emissions rate by 25% to 75% below the current levels. Many of these measures appear to be cost-effective, although non-financial barriers may discourage their implementation, as discussed in chapter 5.

- A number of policies to reduce GHG emissions from ships are conceivable. This report analyses options that are relevant to the current IMO debate. The report finds that market-based instruments are cost-effective policy instruments with a high environmental effectiveness. These instruments capture the largest amount of emissions under the scope, allow both technical and operational measures in the shipping sector to be used, and can offset emissions in other sectors. A mandatory limit on the Energy Efficiency Design Index for new ships is a cost-effective solution that can provide an incentive to improve the design efficiency of new ships. However, its environmental effect is limited because it only applies to new ships and because it only incentivizes design improvements and not improvements in operations.

- Shipping has been shown, in general, to be an energy-efficient means of transportation compared to other modes. However, not all forms of shipping are more efficient than all other forms of transport.

- The emissions of CO_2 from shipping lead to positive "radiative forcing" (a metric of climate change) and to long-lasting global warming. In the shorter term, the global mean radiative forcing from shipping is negative and implies cooling; however, regional temperature responses and other manifestations of climate change may nevertheless occur. In the longer term, emissions from shipping will result in a warming response as the long-lasting effect of CO_2 will overwhelm any shorter-term cooling effects.

- If a climate is to be stabilized at no more than 2°C warming over pre-industrial levels by 2100 and emissions from shipping continue as projected in the scenarios that are given in this report, then they would constitute between 12% and 18% of the global total CO_2 emissions in 2050 that would be required to achieve stabilization (by 2100) with a 50% probability of success.

Background

1.1 The 1997 MARPOL Conference (September 1997) convened by the IMO adopted resolution 8 on "CO_2 emissions from ships". This resolution invited, *inter alia*, the IMO to undertake a study of emissions of GHG from ships for the purpose of establishing the amount and relative percentage of GHG emissions from ships as part of the global inventory of GHG emissions. As a follow-up to the above resolution, the IMO Study of Greenhouse Gas Emissions from Ships was completed and presented to the forty-fifth session of the MEPC (MEPC 45) in June 2000, as document MEPC 45/8.

1.2 MEPC 55 (October 2006) agreed to update the "IMO Study of Greenhouse Gas Emissions from Ships" from 2000 to provide a better foundation for future decisions and to assist in the follow-up to resolution A.963(23). MEPC 56 (July 2007) adopted the Terms of Reference for the updating of the study, which has been given the title "Second IMO GHG Study 2009". This report has been prepared by an international consortium, as set out in the preface to this report.

Scope and structure

1.3 As set out in the terms of reference, this study provides estimates of present and future emissions from international shipping. "International shipping" has been defined in accordance with guidelines developed by The Intergovernmental Panel on Climate Change (IPCC). These guidelines divide emissions from water-borne navigation into two primary categories: domestic and international, where "international waterborne navigation" is defined as navigation between ports of different countries. Total estimates that include emissions from domestic shipping and emissions from fishing are also included in this report.

1.4 The study addresses greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) and other relevant substances (NO_x, NMVOC, CO, PM, SO_x) that are defined in the terms of reference for this study.

1.5 The report has been organized into the following main parts:

.1 Annual inventories of emissions of greenhouse gases and other relevant emissions from shipping from 1990 to 2007 (chapter 3);

.2 Analysis of the progress in reducing emissions from shipping through implementation of MARPOL Annex VI (chapter 4);

.3 Analysis of technical and operational measures to reduce emissions (chapter 5);

.4 Analysis of policy options to reduce emissions (chapter 6);

.5 Scenarios for future emissions from international shipping (chapter 7);

.6 Analysis of the effect of emissions from shipping on the global climate (chapter 8); and

.7 A comparison of the energy efficiency and CO_2 efficiency of shipping compared to other modes of transport (chapter 9).

Emissions 1990-2007

1.6 The analysis in this report shows that exhaust gas is the dominating source of emissions from shipping. Additionally, emissions originating from leaks of refrigerant and release of volatile organic compounds in conjunction with the transport of crude oil are quantified in this study. Other emissions include diverse sources, such as emissions from testing and maintenance of fire-fighting equipment. These are not considered significant and are not quantified in this report.

1.7 Emissions of exhaust gases from international shipping are estimated in this study, based on a methodology where the total fuel consumption of international shipping is first determined. Emissions are subsequently calculated by multiplying fuel consumption with an emission factor for the pollutant in question.

1.8 Fuel consumption for the year 2007 was estimated by an activity-based methodology. This is a change in methodology compared to the first IMO study on greenhouse gas emissions from ships, published in 2000, which relied on fuel statistics. The investigations that are presented in this study suggest that international fuel statistics would under-report fuel consumption. The difference between the fuel statistics and the activity-based estimate is about 30%.

1.9 Guidebook emission factors from CORINAIR and IPCC were used for all emissions except for NO_x, where adjustments were made to accommodate the effect of the NO_x regulations in MARPOL Annex VI. Estimates of emissions of refrigerants were retrieved from the 2006 United Nations Environmental Programme (UNEP) assessment of refrigerant emissions from transport. The emissions of VOC from crude oil were assessed on the basis of several data sources.

1.10 An estimate of the share of the total emissions of exhaust gases from ships that can be attributed to international shipping was made on the basis of the estimate for total fuel consumption by shipping and statistics for fuel consumption by domestic shipping in 2007. An emissions series from 1990 to 2007 was generated by assuming that ship activity was proportional to data on seaborne transport published by Fearnresearch. The estimate of GHG emissions for 2007 is presented in table 1-1. Emissions of SF_6 and PFC are considered negligible and are not quantified. Emissions of CO_2 from shipping are compared with global total emissions in figure 1-1.

Table 1-1 – Summary of GHG emissions from shipping* during 2007

	International shipping	Total shipping	
	million tonnes	million tonnes	CO_2 equivalent
CO_2	870	1046	1046
CH_4	Not determined*	0.24	6
N_2O	0.02	0.03	9
HFC	Not determined*	0.0004	≤ 6

* A split into domestic and international emissions is not possible

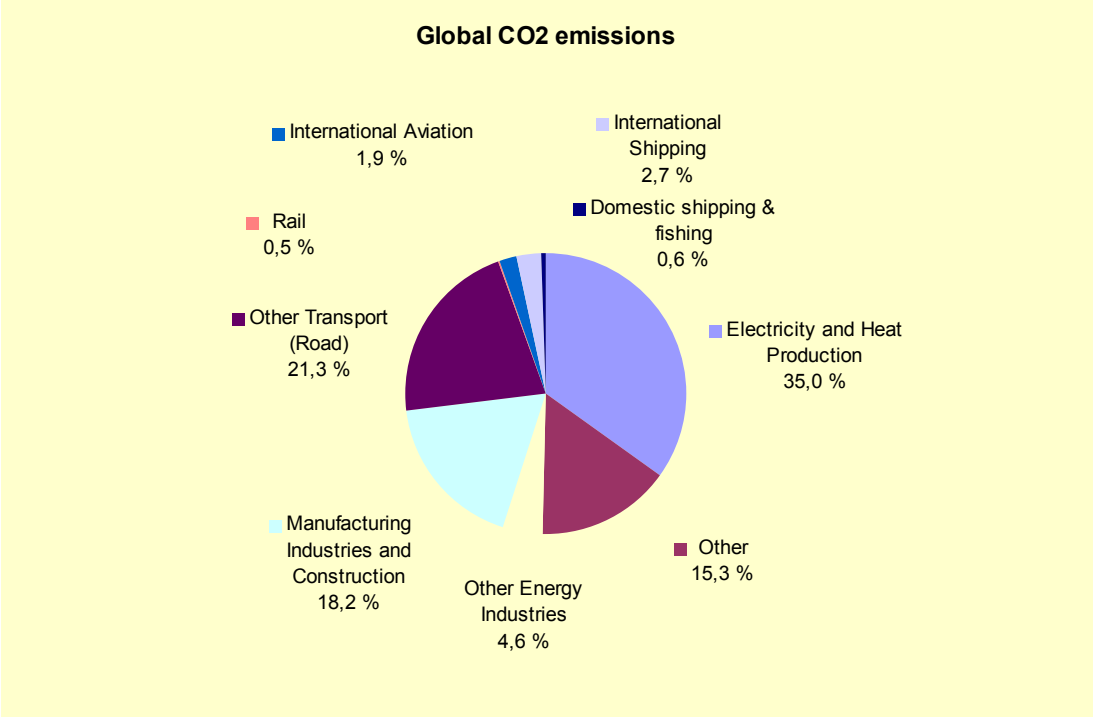

Figure 1-1 – Emissions of CO_2 from shipping compared with global total emissions

Emission reductions achieved by implementation of MARPOL Annex VI

1.11 Progress to date in reducing emissions was assessed by analysing the reductions in the emissions that are regulated in MARPOL Annex VI.

1.12 Reductions in emissions of ozone-depleting substances (ODSs) from ships have been achieved as a result of several international agreements, including the Montreal Protocol and MARPOL Annex VI. Reductions in these emissions have been estimated on the basis of figures in the 1998 and 2006 reports published by the UNEP Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC). The base year for the 2006 RTOC report is 2003; however, a base year is not available in the 1998 report. Nevertheless, these data indicate the following:

.1 CFC – 735 tonnes reduction (98%);

.2 HCFC – 10,900 tonnes reduction (78%); and

.3 HFC – 415 tonnes increase (315%).

1.13 Emissions of HFC have increased, because HFC are used as a substitute for CFC and HCFC.

1.14 Where emissions of NO_x are concerned, a reduction in emissions of about 12–14% per tonne of fuel consumed has been identified for regulated (Tier I) engines as compared to pre-regulation (Tier 0) engines. In 2007, about 40% of the installed engine power of the world fleet had been built since 1 January 2000 and was thus assumed to be Tier I-compliant. The net reduction in international emissions of NO_x from shipping in 2007 was thus about 6% compared to a no-regulation baseline. However, NO_x emissions from international shipping are estimated to have increased from 16 million tonnes in 2000 to 20 million tonnes in 2007.

1.15 Reductions in SO_x emissions have been estimated for 2008, since this is the first year in which both of the sulphur emission control areas (SECAs) have been fully in force. Based on a set of assumptions, including an average content of sulphur in the fuel that is used in SECAs, in the hypothetical unregulated scenario it is estimated that emissions of sulphur oxides from shipping in the SECA areas had been reduced by about 42%.

1.16 A reduction in emissions of VOC has not been quantified. The most tangible result of implementing regulation 15 in MARPOL Annex VI is the introduction of standardized VOC return pipes, through which tankers can discharge VOC to shore during loading. Most tankers now have this capability, although the frequency of their use is variable.

Technological and operational options for reduction of emissions

1.17 A wide range of options for increasing the energy efficiency and reducing emissions by changing ship design and ship operation has been identified. An overall assessment of the potential of these options to achieve a reduction of CO_2 emissions is shown in table 1-2. Since the primary gateway to reduction of CO_2 emissions is increased energy efficiency, these reduction potentials generally apply to all emissions of exhaust gases from ships.

Table 1-2 – Assessment of potential reductions of CO_2 emissions from shipping by using known technology and practices

<table>
<tr><th>DESIGN (New ships)</th><th>Saving of CO_2/tonne-mile</th><th>Combined</th><th>Combined</th></tr>
<tr><td>Concept, speed and capability</td><td>2% to 50%+</td><td rowspan="6">10% to 50%+</td><td rowspan="9">25% to 75%+</td></tr>
<tr><td>Hull and superstructure</td><td>2% to 20%</td></tr>
<tr><td>Power and propulsion systems</td><td>5% to 15%</td></tr>
<tr><td>Low-carbon fuels</td><td>5% to 15%*</td></tr>
<tr><td>Renewable energy</td><td>1% to 10%</td></tr>
<tr><td>Exhaust gas CO_2 reduction</td><td>0%</td></tr>
<tr><td>OPERATION (All ships)</td><td></td><td></td></tr>
<tr><td>Fleet management, logistics and incentives</td><td>5% to 50%+</td><td rowspan="3">10% to 50%+</td></tr>
<tr><td>Voyage optimization</td><td>1% to 10%</td></tr>
<tr><td>Energy management</td><td>1% to 10%</td></tr>
</table>

+ Reductions at this level would require reductions of operational speed.
* CO_2 equivalent, based on the use of LNG.

1.18 A considerable proportion of the potential abatement appears to be cost-effective at present. However, non-financial barriers may currently limit the adoption of certain measures, as discussed in chapter 5.

1.19 Renewable energy, in the form of electric power generated by solar cells and thrust generated by wind, is technically feasible only as a partial source of replacement power, due to the variable intensity and the peak power of wind and sunlight.

1.20 Carbon dioxide is the most important GHG emission from shipping, and the potential benefits from reducing emissions of the other GHG are small in comparison.

1.21 Fuels with lower life-cycle CO_2 emissions include biofuels and liquefied natural gas (LNG). The use of biofuels on board ships is technically possible; however, use of first-generation biofuels poses some technical challenges and could also increase the risk of losing power (e.g., due to plugging of filters). These challenges are, nevertheless, overshadowed by limited availability and unattractive prices that make this option appear unlikely to be implemented on a large scale in the near future. However, it is believed that LNG will become economically attractive, principally for ships in regional trades within ECAs where LNG is available.

1.22 Emissions of other relevant substances (NO_x, SO_x, PM, CO and NMVOC) as exhaust gas pollutants will be reduced as the energy efficiency of shipping is improved. Long-term reductions in emissions that are mandated or expected from implementation of the revised Annex VI are shown in table 1-3. Significant reductions in emissions can be achieved by increasing numbers or extending the coverage of Emission Control Areas.

Table 1-3 – Long-term reductions in emissions in the revised MARPOL Annex VI

	Global	ECA
NO_x (g/kW·h)	15–20%	80%
SO_x* (g/kW·h)	80%	96%
PM (mass)† (g/kW·h)	73%	83%

* Reduction relative to fuel that contains 2.7% sulphur.

† Expected PM reduction arising from change of composition of fuel.

1.23 Future (sulphur) emission control areas ((S)ECAs) will limit the maximum sulphur content of the fuels that are used within these areas to 0.1%. This is a radical improvement from the present-day average of 2.7% of sulphur in residual fuel, although it will still be 100-times higher than the levels of sulphur in automotive diesel fuels (10 ppm, 0.001%). Reductions in emission levels that are significantly beyond the ECA levels indicated in table 1-3 would create a need for stricter fuel-quality requirements.

Policy options for reduction of emissions

1.24 Many technical and operational measures that may be used to reduce GHG emissions from ships have been identified; however, these measures may not be implemented unless policies are established to support their implementation. A number of policies to reduce GHG emissions from ships are conceivable. This report sets out to identify a comprehensive overview of options. The options that are relevant to the current IMO debate are analysed in detail. These options are:

.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); and

.7 A so-called International Compensation Fund (ICF), to be financed by a levy on marine bunkers.

1.25 The analysis of the options is based on the criteria for a coherent and comprehensive future IMO regulatory framework on GHG emissions from ships, developed by MEPC 57. Based on these criteria, the following qualitative conclusions can be drawn with respect to options being discussed within IMO at present:

.1 A mandatory limit on Energy Efficiency Design Index (EEDI) for new ships appears to be a cost-effective solution that can provide a strong incentive to improve the design efficiency of new ships. The main limitation of the EEDI is that it only addresses ship design; operational measures are not considered. This limits the environmental effectiveness. The effect is also limited, in the sense that it applies only to new ships;

.2 Mandatory and/or voluntary reporting of either the EEDI or the EEOI would have no environmental effect in itself. Rather, environmental effectiveness and cost-effectiveness would depend on incentive schemes being set up to make use of the information. The assessment of the large number of conceivable incentive schemes was beyond the scope of this report;

.3 The Ship Efficiency Management Plan (SEMP) appears to be a feasible approach to increase awareness of cost-effective measures to reduce emissions. However, since this instrument does not require a reduction of emissions, its effectiveness will depend on the availability of cost-effective measures to reduce emissions (i.e. measures for which the fuel savings exceed the capital and operational expenditures). Likewise, it will not incentivize innovation and R & D beyond the situation of "business as usual";

.4 A mandatory limit on EEOI appears to be a cost-effective solution that can provide a strong incentive to reduce emissions from all ships that are engaged in transport work. It incentivizes both technical and operational measures. However, this option is technically very challenging, due to the difficulties in establishing and updating baselines for operational efficiency and in setting targets;

.5 Both the Maritime Emission Trading Scheme (METS) and the International Compensation Fund for GHG Emissions from Ships (ICF) are cost-effective policy instruments with high environmental effectiveness. They have the largest amount of emissions within their scope, allow all measures in the shipping sector to be used and can offset emissions in other sectors. These instruments provide strong incentives to technological change, both in operational technologies and in ship design; and

.6 The environmental effect of the METS is an integral part of its design and will therefore be met. In contrast, part of the environmental effect of the ICF depends on decisions about the share of funds that will be spent on buying emission allowances from other sectors. With regard to cost-effectiveness, incentives to technological change and feasibility of implementation, both policy instruments seem to be quite similar.

Scenarios for future emissions from international shipping

1.26 Future emissions of CO_2 from international shipping were estimated on the basis of a relatively simple model, which was developed in accordance with well-established scenario practice and methodology. The model incorporates a limited number of key driving parameters, as shown in table 1-4.

Table 1-4 – Driving variables used for scenario analysis

Category	Variable	Related elements
Economy	Shipping transport demand (tonne-miles/year)	Population, global and regional economic growth, modal shifts, shifts in sectoral demand
Transport efficiency	Transport efficiency (MJ/tonne-mile) – depends on fleet composition, ship technology and operation	Ship design, advances in propulsion, vessel speed, regulations aimed at achieving other objectives but that have consequences for emissions of GHG
Energy	Carbon fraction of the fuel that is used by shipping (g of C/MJ of fuel energy)	Cost and availability of fuels (e.g., use of residual fuel, distillates, biofuels, or other fuels)

1.27 In this study, carbon emissions are explicitly modelled as a parameter of the scenario. Other levels of pollutant emissions are calculated on the basis of energy consumption and MARPOL regulations. Scenarios are based on the framework for global development and storylines that have been developed by the Intergovernmental Panel on Climate Change (IPCC) in the Special Report on Emission Scenarios (SRES).

1.28 A hybrid approach, considering both historic correlations between economic growth and trade as well as analysis considering regional shifts in trade, increased recycling, and new transport corridors, has been employed, *inter alia,* to derive the projections of future demand for transport.

1.29 No regulations regarding CO_2 or fuel efficiency have been assumed, and the improvement in efficiency over time reflects improvements that would be cost-effective in the various scenarios rather than the ultimate technological potential.

1.30 Assumptions about future use of fuel reflect that the availability of energy in the SRES scenarios would permit the continued use of oil-based fuels until 2050 for shipping. Therefore, in these scenarios, in which there is non-regulation of GHG emissions, the move from oil-derived fuels would have to be motivated by economic factors. The effect of MARPOL Annex VI on the fuel that is used is considered.

1.31 Scenarios are modelled from 2007 to 2050. The main scenarios are named A1FI, A1B, A1T, A2, B1 and B2, according to terminology from the IPCC Special Report on Emission Scenarios (SRES). These scenarios are characterized by global differences in population, economy, land-use and agriculture which are evaluated against two major tendencies: (1) globalization versus regionalization and (2) environmental values versus economic values. The background for these scenarios is discussed in chapter 7 of this report.

1.32 Annual increases of CO_2 emissions, in the range of 1.9–2.7%, are found in base scenarios, with extreme scenarios indicating increases of 5.2% and −0.8%, respectively. The increase in emissions is driven by the expected growth in seaborne transport. The scenarios with the lowest emissions show reductions in CO_2 emissions in 2050 compared to emissions during 2007. Results from the scenarios are shown in figure 1-2.

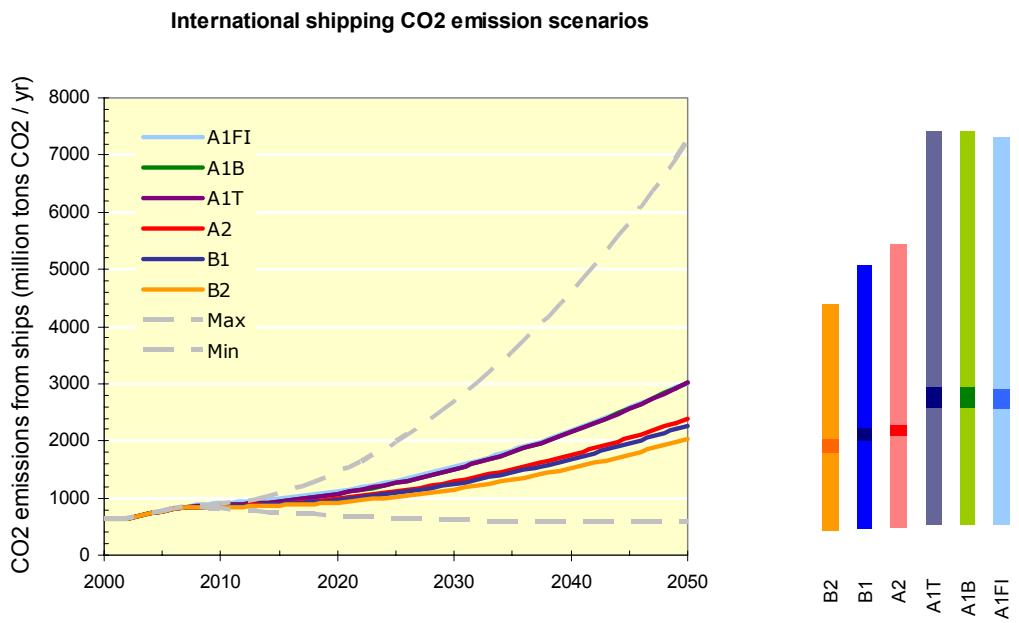

Figure 1-2 – Trajectories of the emissions from international shipping. Columns on the right-hand side indicate the range of results for the scenarios within individual families of scenario

Climate impact

1.33 A detailed analysis of the climate impacts of emissions from ships was performed, using state-of-the-art modelling and references to and comparison with other relevant research. Emissions from international shipping produce significant impacts on atmospheric composition, human health and climate; these are summarized below:

.1 Increases in well-mixed GHGs, such as CO_2, lead to positive "radiative forcing[1]" (RF) and to long-lasting global warming;

.2 For 2007, the RF from CO_2 from shipping was calculated to be 49 mW m^{-2}, contributing approximately 2.8% of total RF from anthropogenic CO_2 in 2005;

.3 For a range of 2050 scenarios, the RF of CO_2 from shipping was calculated to be between 99 and 122 mW m^{-2}, bounded by a minimum/maximum uncertainty range (from the scenarios) of 68 mW m^{-2} and 152 mW m^{-2};

.4 The total RF for 2007 from shipping was estimated to be −110 mW m^{-2}, dominated by a rather uncertain estimate of the indirect effect (−116 mW m^{-2}) and not including the possible positive RF from the interaction of black carbon with snow, which has not yet been calculated for ship emissions. We also emphasize that CO_2 remains in the atmosphere for a long time and will continue to have a warming effect long after it was emitted. This has been demonstrated here by showing how the residual effects of emissions from shipping prior to 2007 turn from a negative effect on temperature to a positive effect. By contrast, sulphate has a residence time in the atmosphere of approximately 10 days, and the duration of response of the climate to sulphate is of the order of decades, whilst that of CO_2 is of the order of centuries to millennia;

.5 Simple calculations of global means have been presented here for RF and temperature response, and are in agreement with other studies in the literature. As highlighted by others, global mean temperature response is only a first-order indicator of climate change. Calculations presented here show that the radiative forcing from shipping has a complex spatial structure, and there is evidence from other, more general, studies of indirect cloud-forcing effects that significant changes in precipitation patterns may result from localized negative RFs, even if the localized temperature response is not so variable. Such alterations in precipitation, even from negative forcing, constitute climate change. This is a complex subject, and more work on this aspect is needed;

.6 While the control of emissions of NO_x, SO_2 and particles from ships will have beneficial impacts on air quality, acidification and eutrophication, reductions of emissions of CO_2 from all sources (including ships and other freight modes) will be required to reduce global warming. Moreover, a shift to cleaner combustion and cleaner fuels may be enhanced by a shift to technologies that lower the emissions of CO_2; and

.7 Climate stabilization will require significant reductions in future global emissions of CO_2. The projected emissions from shipping for 2050 that have been developed for this work – which are based on SRES non-climate intervention policy assumptions – constitute 12% to 18% of the WRE450 stabilization scenario,

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[1] A common metric to quantify impacts on climate from different sources is "radiative forcing" (RF), in units of W/m^2, since there is an approximately linear relationship between global mean radiative forcing and change in global mean surface temperature. RF refers to the change in the Earth–atmosphere energy balance since the pre-industrial period. If the atmosphere is subject to a positive RF from, for example, the addition of a greenhouse gas such as CO_2, the atmosphere attempts to re-establish a radiative equilibrium, resulting in a warming of the atmosphere.

which corresponds to the total permissible global emissions of CO_2 in 2050 if the increase in global average temperature is to be limited to 2°C with a probability greater than 50%.

Comparison of emissions of CO_2 from ships with emissions from other modes of transport

1.34 The ranges of CO_2 efficiency of various forms of transport were estimated, using actual operating data, transport statistics and other information. The efficiency of ships is compared with that of other modes of transport in figure 1-3. Efficiency is expressed as mass of CO_2 per tonne-kilometre, where the mass of CO_2 expresses the total emissions from the activity and "tonne-kilometre" expresses the total transport work that is done. The ranges that have been plotted in the figure show the typical average range for each of them. The figure does not indicate the maximum (or minimum) efficiency that may be observed.

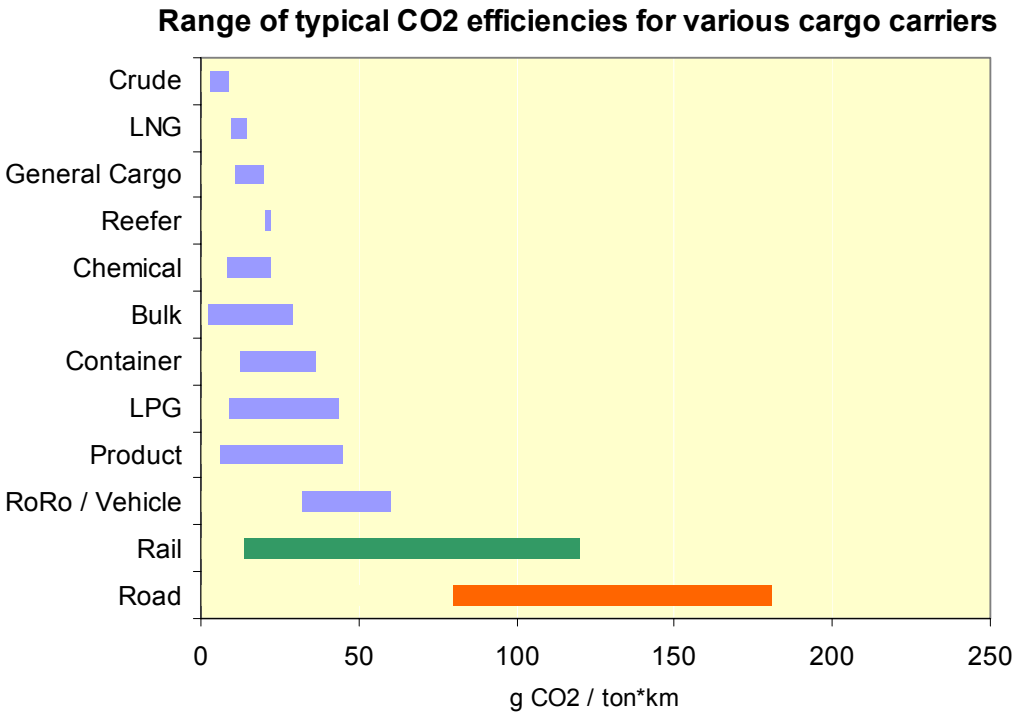

Figure 1-3 – Typical ranges of CO_2 efficiencies of ships compared with rail and road transport