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IMO

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Agenda item 4

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PREVENTION OF AIR POLLUTION FROM SHIPS

Assessment of IMO energy efficiency measures for the control of GHG emissions from ships

Note by the Secretariat

SUMMARY

Executive summary:	This document presents a Study carried out by Lloyd's Register and DNV on the projected emissions reduction associated with the technical and operational measures agreed at MEPC 59
Strategic direction:	7.3
High-level action:	7.3.1
Planned output:	7.3.1.3
Action to be taken:	Paragraph 7
Related documents:	MEPC 59/INF.10 and MEPC 59/24

Background

1 At MEPC 59, the Committee noted the recommendation of the Steering Committee which had overseen the production of the Second IMO GHG Study 2009 (MEPC 59/INF.10), that Member States and observers should be encouraged to make financial contributions to the follow-up work of the Study, for example, through a comprehensive cost-benefit analysis, feasibility and impact assessments of the measures proposed, or other activities as agreed by the Committee or initiated by the Secretary-General.

2 To facilitate further progress and as part of IMO's efforts to maintain its leading position, and recognizing its responsibility for the control of GHG emissions from the international maritime sector, the Secretariat, in furtherance of the above recommendation, commissioned Lloyd's Register in partnership with Det Norske Veritas to undertake the attached Study on assessment of IMO's energy efficiency measures agreed at MEPC 59.

Study on assessment of IMO energy efficiency measures

3 The Study provides an assessment of the projected emissions reduction associated with the technical and operational measures agreed at MEPC 59 (EEDI, EEOI and SEEMP) and is intended as a means to facilitate further progress on the issue through adequate scientifically-based information to assist the Committee in its consideration of a control regime for GHG emissions from international shipping and to facilitate the decision-making process.

4 The Study analyses the reduction potential from the package of technical and operational measures and provides an estimation of the expected level of reduction in CO_2 emissions from international shipping by the years 2020 and 2050 resulting from the agreed measures.

5 A comprehensive assessment of the potential reduction, both total and relative (tonnes-miles), resulting from implementation of the EEDI for new ships is also provided, as well as an analysis of the effects for different ship segments and for the aggregate emissions. The required level of reductions for different ship segments is based on sound science and realistic, although ambitious, assumptions.

6 The Study also presents an assessment of potential reduction, both total and relative, resulting from implementation of the Ship Energy Efficiency Management Plan (SEEMP).

Action requested of the Committee

7 The Committee is invited to note the attached Study on assessment of IMO energy efficiency measures as a basis for further consideration of the issue of greenhouse gas emissions from ships.

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ANNEX

ASSESSMENT OF IMO ENERGY EFFICIENCY MEASURES

Projected emissions reduction associated with the technical and operational measures agreed at MEPC 59

Lloyd's Register

DNV

EXECUTIVE SUMMARY

1.1 This Study was commissioned by the International Maritime Organization (IMO) to analyse the reduction potential from the package of energy-efficiency measures finalised at the International Maritime Organization's Marine Environment Protection Committee's fifty-ninth session in July 2009 (MEPC 59).

1.2 The Study was undertaken by Lloyd's Register in partnership with DNV and builds on the work undertaken in the Second IMO GHG study 2009 [1]. For consistency, base data from the Second IMO GHG study 2009 was used where possible, supplemented by data, modelling capability, methodology development and professional expertise pre-existing within both organizations.

MEPC 59 energy efficiency measures

1.3 The energy efficiency measures finalised at MEPC 59 included:

- Interim Guidelines on the method of calculation and (separately) the voluntary verification of the Energy Efficiency Design Index (EEDI) for new ships [2,3];
- Guidance for the Development of a Ship Energy Efficiency Management Plan (SEEMP) [4];
- Guidelines for voluntary use of the Energy Efficiency Operational Indicator (EEOI) [5];

Of these measures, the EEDI for new ships and the SEEMP for ships in service were considered to have the greatest potential impact on future ship energy-efficiency.

CO_2 emissions reduction measures

1.4 The principal ways of reducing CO_2 emissions from international shipping during the period to 2050 are considered to be a mix of operational measures, technology developments and use of alternative lower carbon fuels.

1.5 Technical measures are mainly applicable to new build ships; whilst operational measures are applicable to all ships in service. Although theoretically applicable to new and existing ships, use of alternative fuels (such as LNG) tends to involve significant changes to existing vessels and is therefore primarily considered as an option for new ships.

1.6 Assessment of the potential for the various measures to contribute to CO_2 reduction indicated emission reduction potentials of 10-50% for both operational and technical measures by 2050. CO_2 emission reduction potential due to use of alternative fuels was found to be low throughout this period.

Future emissions forecasts

1.7 A simulation model was used to predict likely CO_2 emissions to 2050. The Intergovernmental Panel on Climate Change (IPCC) scenarios A1B and B1 provided fleet and emission growth projections upon which different projections for the impact of technical and operational measures and the use of alternative fuels could be overlaid.

1.8 The likely uptake of measures by international shipping was categorised as: 'low' representing the minimum uptake of measures; 'attainable' with moderate support from market-based drivers; and 'optimistic' driven by very high fuel prices, substantial regulatory actions and/or other or market-based drivers.

Emission projections

1.9 The results for the various fleet growth and technology uptake scenarios evaluated, demonstrated that operational measures are likely to have an effect quickly (5-20 years). Technical measures take longer to show a significant impact (20-30 years), primarily because these measures are applicable only to new build ships. The contribution of alternative fuels to CO_2 reduction in the years to 2050 appears low (Figure S1).

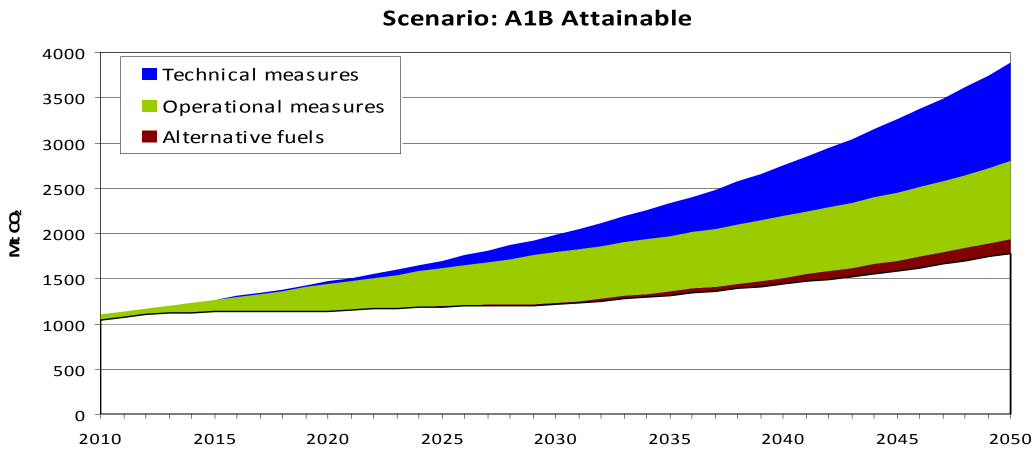


Figure S1 Potential impact of technical and operational measures and use of alternative fuels on CO_2 emissions (A1B 'Attainable' scenario) on international shipping

1.10 Examining emission reductions by ship category predicted significant growth in CO_2 emissions from container ships between 2020 and 2050. An overall reduction in CO_2 emissions for the world fleet with respect to the 2007 level was apparent only in the most optimistic scenario examined.

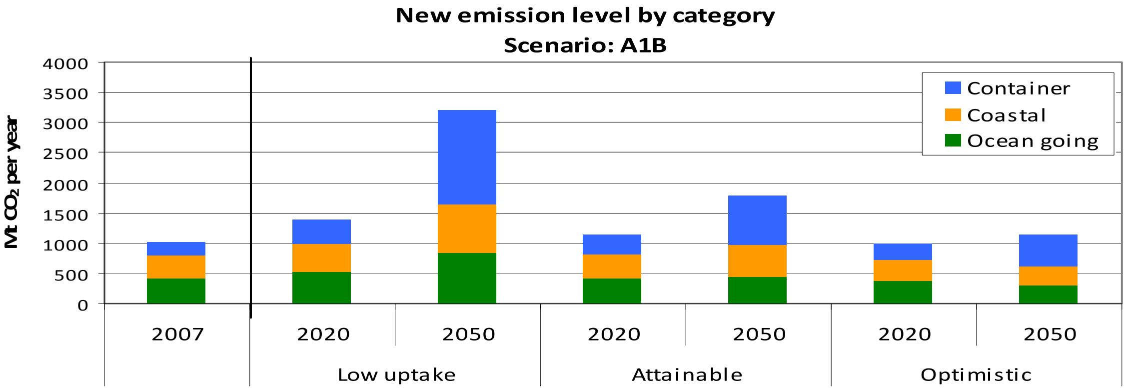


Figure S2 Emission level by ship category in 2020 and 2050 (A1B scenario)

Transport efficiency

1.11 Transport efficiency associated with the different technology uptake scenarios demonstrated improved efficiency for all scenarios in 2020 with respect to 2007 with further efficiencies to 2050 (Table S1). Tanker and bulk carriers were consistently more energy-efficient than container ships due to lower speed and larger average size. As expected, smaller coastal vessels tended to be least efficient due to economy of scale.

		Low uptake		**'Attainable'**		**'Optimistic'**	
	2007	2020	2050	2020	2050	2020	2050
Coastal	38.0	36.0	33.0	30.2	23.2	26.3	15.5
Container	29.0	27.3	23.7	21.9	12.1	19.4	7.7
Bulk (ocean-going)	10.0	9.4	8.3	7.9	4.4	6.8	2.8
Tanker (ocean-going)	13.0	12.3	10.7	10.2	5.7	8.8	3.6

Table S1 Transport efficiency (in g CO_2/tonne-mile) associated with the different uptake scenarios for the energy efficiency measures

The role of the EEDI in driving technological development

1.12 In order to realise the energy-efficiency and CO_2 emission reduction potential associated with technical innovation and the use of lower or no carbon fuels in new ships, it was assumed that a mandatory limit on the EEDI for new ships would be required to drive uptake of new technologies. A methodology was thus developed to determine the EEDI limit required for each ship category in order to achieve the projected emission reductions.

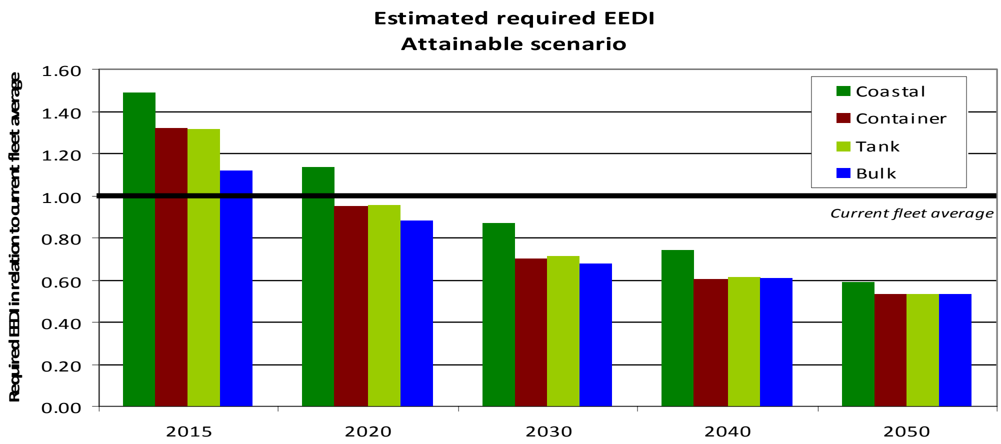


Figure S3 Required EEDI for ships built 2015-2050 to realise CO_2 emission reduction potential of technological developments and use of alternative fuels ('Attainable' scenario)

1.13 The values calculated (Figure S3) are relative to the current fleet average value (or 'baseline'). A value above 1 indicates an EEDI value above the current fleet average value; a value below 1 indicates an EEDI level below the current fleet average.

1.14 The results for the technology uptake scenarios assessed suggest introduction of a relatively moderate EEDI limit in 2015. After 2015, the EEDI will need to decrease gradually to 2050 with the indices for the different ship categories tending to converge around 40%-60% lower in 2050 than the current fleet average values.

The role of the SEEMP and EEOI in driving operational improvements

1.15 Management plans are well established tools within the marine industry for providing a non-prescriptive approach to managing operational issues. By providing advice and recommendations on measures that can have a positive impact on reducing vessel emissions, it is expected that the SEEMP will facilitate enhanced uptake of operational energy efficiency measures by ships. The EEOI enables continuous assessment of vessel transportation efficiency for individual ships. It can thus provide a quantitative yardstick for the impact on efficiency of the SEEMP and other measures.

1.16 Although the uptake of operational efficiency enhancing measures can generally be expected to be cost effective to implement, experience shows that additional drivers, such as environmental regulations, mandatory implementation of SEEMP and/or market-based instruments and measures, may be required to stimulate uptake of the range of possible operational measures.

1.17 Uptake of the full range of efficiency enhancing measures cannot be achieved without close cooperation throughout the supply chain and with ports. A broad regulatory regime encompassing, for example, port development, logistic chains and charter party agreements, is likely to be required to realise the full potential of the operational efficiency measures.

Conclusions

1.18 Significant potential for reduction of CO_2 emissions from ships due to operational and technical measures is apparent to 2050. 'Attainable' CO_2 emission reductions of around 1 billion tonnes are associated with technical measures (A1B 'Attainable' scenario) whilst operational measures have the potential to achieve a reduction of around 850 million tonnes CO_2 under the equivalent scenario in 2050. Alternative fuels appear unlikely to deliver a significant reduction unless a sustainably produced low or no carbon fuel suitable for widespread use by ships, emerges during the period to 2050.

1.19 Improved transport efficiency relative to 2007 levels is apparent over the period to 2050. Transport efficiency values (in gCO_2/tonne-mile) are reduced to 76-80% of 2007 levels in 2020 with further reductions to 42-61% of 2007 levels in 2050 under a scenario of stretching but attainable uptake of energy efficiency measures.

1.20 Emission reductions due to operational measures are likely to be realised more rapidly than that for technical measures on account of the time lag before the impact of more energy efficient new ships to becomes apparent.

1.21 To drive more energy-efficient ship design and realise the energy efficiency and CO_2 emission reduction potential associated with technical innovation and the use of lower or no carbon fuels, it is assumed that a mandatory limit on the EEDI for new ships would be required. Calculations made within this Study suggest that limits to the EEDI can be phased in gradually to drive the technological development necessary to achieve the overall emission reductions considered attainable by 2050.

1.22 Introduction of an EEDI limit somewhat above the current fleet average appears appropriate for 2015. By 2020, an EEDI limit below the current fleet average is suggested for most ship categories. Thereafter the EEDI limit will need to be reduced gradually to 2050 with the indices for the different ship categories tending to converge at around 50% of the current fleet average value.

1.23 For operational measures, the SEEMP and the EEOI agreed at MEPC 59 are likely to play a role in driving uptake of operational efficiency measures. Even as a voluntary measure initially, by providing advice and recommendations on energy efficiency measures, it is expected that these tools will facilitate enhanced uptake of operational energy efficiency measures in the world fleet and contribute towards realising the 850 million tonnes CO_2 reduction attributable to implementation of operational measures identified as 'Attainable' under the A1B scenario in 2050.

1.24 Despite the significant energy-efficiency potential for operational and technical measures, especially under a mandatory application regime, an overall reduction in total CO_2 emissions for shipping from the current (2007) level appears feasible only in the most optimistic of the scenarios investigated. In all others, the projected growth in world trade is likely to outweigh the emission reduction potential associated with currently known operational and technical measures.

CONTENTS

2 INTRODUCTION

2.1 This study was commissioned by the International Maritime Organization (IMO) to analyse the reduction potential from the package of energy efficiency measures finalised at MEPC 59 in July 2009 and also to estimate the projected reduction in CO_2 emissions from international shipping by the years 2020 and 2050 resulting from the agreed measures.

2.2 The study was undertaken by Lloyd's Register in partnership with DNV and builds on the Second IMO GHG study 2009 [1]. Gillian Reynolds (co-ordinator), Zabi Bazari, Tore Longva and Eirik Nyhus were the main contributors to the report; however they received considerable assistance from colleagues within their organisations.

2.3 For consistency, base data from the Second IMO GHG study 2009 was used where possible, supplemented by data, modelling capability and professional expertise pre-existing within Lloyd's Register and DNV. To contain the study to a manageable number of possible options, various assumptions needed to be made. These assumptions were agreed at a workshop attended by Lloyd's Register, DNV and representatives of the IMO Secretariat on 8 September 2009.

Emissions from shipping

2.4 Carbon dioxide is the most significant greenhouse gas (GHG) emitted by ships, both in terms of quantity and overall global warming potential. Other sources of GHG emissions are not included in this study.

2.5 Shipping is estimated to have emitted 1015 million tonnes of CO_2 in 2007, corresponding to 3.3% of the global emissions. Of this, international shipping is estimated to have emitted 870 million tonnes, or about 2.7% of the global total in 2007 [1].

2.6 Shipping has been shown to be, in general, an energy-efficient mode of transport compared to other transport modes. Nevertheless, there are significant opportunities for increasing energy efficiency and reducing CO_2 emissions and shipping is expected to be able to significantly reduce emissions on a tonne–mile basis. Reducing absolute emissions will be more challenging.

MEPC 59 energy efficiency measures

2.7 Non-mandatory instruments addressing technical and operational measures to increase energy efficiency and reduce GHG emissions from international shipping were finalised at MEPC 59. These were:

- Interim Guidelines on the method of calculation and (separately) the voluntary verification of the Energy Efficiency Design Index for new ships (circulated as MEPC.1/Circ.681 and MEPC.1/Circ.682 on 17 August 2009) [2,3];

- Guidance for the development of a ship energy efficiency management plan (SEEMP) (circulated as MEPC.1/Circ.683 on 17 August 2009) [4]; and

- Guidelines for voluntary use of the Energy Efficiency Operational Indicator (EEOI) (circulated as MEPC.1/Circ.684 on 17 August 2009) [5].

2.8 Of these measures, it was considered that the Energy Efficiency Design Index for new ships and the Ship Energy Efficiency Management Plan for ships in service would have the greatest potential impact on future ship energy efficiency and CO_2 emissions. The study thus focussed on the potential impact of these two measures.

3 MEASURES TO REDUCE CO_2 EMISSIONS

3.1 At present, there is no viable large scale alternative to carbon based fuels which could eliminate CO_2 emissions. Electrification, a possible long term option for land based transport, is not viable for shipping in service at sea. Thus the principal ways of reducing CO_2 emissions towards 2050 are considered to be a mix of operational measures, technology developments and use of alternative lower carbon content fuels.

Operational measures

3.2 The potential savings from operational measures are significant and go beyond energy management and speed reductions. New modes of co-operation between cargo owners, charterers and ship owners, as well as port-related issues also contribute. In addition, better fleet planning, large-scale improvements of vessel utilisation, and minimising non-productive ballast voyages are possible through further consolidations in the industry both on the liner and charter side. Climate change will in itself provide opportunities for new and shortened transportation routes, notably opening up the Northern Sea Route for part of the year from around 2030. Expansion of canals such as the Panama Canal, due to be completed by 2015, will enable more energy-efficient design and shorten transportation routes.

3.3 Operational means to reduce the fuel consumption and CO_2 emissions can be considered in three categories:

- *Enhanced technical management*: Measures include enhanced weather routeing; optimized trim and ballasting; hull and propeller cleaning; better main and auxiliary engine maintenance and tuning; ;enhanced voyage and performance measurement and reporting; efficient operation of larger electrical consumers; and efficient deployment of new technology. Implementation of many of these measures requires execution of programmes of change management and training;

- *Enhanced logistics and fleet planning*: Measures include combining cargoes to achieve a higher utilisation rate' use of combination carriers' optimisation of logistic chains – enhanced routeing' fewer/shorter ballast legs; larger cargo batches; adjustments for optimised arrival times and slower steaming – and changed contract formats between charterer and ship owner; and

- *Port related*: Currently, the largest restrictions are related to limitations on ship draft, length and beam, congestion and other limitations on quick port turn-around. Implementation requires infrastructure development. Measures can include, typically: larger port capacity; fewer restrictions on ship draft, beam or length; 24/7 port operation; quicker loading and discharging; flexible design of cargo handling equipment; and more efficient port clearance and slot time allocation.

Alternative fuels

3.4 Within the foreseeable future, existing propulsion systems are likely to continue to dominate with carbon-based fuels being the only realistic large volume fuel for shipping over the next 20 years and, probably, even longer.

3.5 Natural gas will initially become an alternative to conventional residual or diesel oil fuels in some regions and, later, more widely when liquefied natural gas (LNG) or compressed natural gas (CNG) distribution infrastructures become available. With currently available propulsion machinery, natural gas emits around 20% less CO_2 emissions than residual or diesel oil fuels. The use of fuel cells running on natural gas is expected first for auxiliary engines and, later, in the small ship category. Feasibility studies for fuel cells powered by natural gas report no emissions of NO_x, SO_2 or particulate matter (PM) and a significant reduction in CO_2 emissions compared to diesel engines burning a similar fuel.

3.6 The agreement at MEPC 58 to reduce maximum allowable fuel sulphur content is likely to result in reduced use of residual fuels beyond 2020 (or 2025 dependent upon the outcome of the fuel availability review), although the continued use of HFO in combination with scrubber technology has not been ruled out. A switch to marine diesel, gas oil or natural gas will allow more optimal combustion thus leading to higher efficiency and reduced PM. Low sulphur fuels will also allow waste heat recovery plants to operate with lower exhaust temperatures, thereby generating more energy for auxiliary systems.

3.7 Sustainable biofuel, hydrogen and carbon capture and storage are currently the only known fuels or technologies that could support a dramatically lower carbon future. Although technically feasible as a fuel for ships, it is unlikely that enough sustainable biofuel will become available to shipping in the next 20 years to significantly change the global CO_2 emissions of the world fleet. It is also considered unlikely that hydrogen and carbon capture and storage will have a significant impact on shipping in the next two decades. In the period from 2030 to 2050, these options could emerge as viable solutions. Alternatively, radically new fuels and/or technologies which are not currently being considered may mature to play an important role.

Technology developments

3.8 Technologies which are available to significantly improve energy efficiency in the short- medium- and long-term (where indicated) include:

- Hulls with less resistance and improved steering configurations;
- Advanced underwater hull coating systems, including air lubrication systems;
- More hydro-dynamically-efficient aft-ship, propeller and rudder arrangements;
- Reduced air drag through improved aerodynamic efficiency of hull and superstructure;
- Lower energy consumption in main and auxiliary engines;
- Waste heat recovery and ship's thermal energy integration;
- Miscellaneous technologies to reduce minor energy consumers including deck paint, pipe insulation, lighting and air conditioning;
- Zero or minimum ballast configurations;
- Improved autopilots (IBS/INS);

- Marine fuel cells (longer term);
- Use of wind power and solar panels, as supplement to auxiliary engines; and
- Use of light construction materials (longer term).

3.9 Wind and solar energy will not power ships alone, but may contribute alongside engines in the future. Various sail arrangements have been tested on merchant vessels over the years. Testing of kites and Flettner rotors is also on-going and their usage may increase as they may also be suitable for retrofitting. Nuclear propulsion requires a special infrastructure and emergency response capabilities and it is not considered that it will play a significant role in merchant ships, although some uptake of this technology is projected.

Applicability

3.10 The applicability of emissions reduction measures to new or existing vessels are considered to be as follows:

- Technological measures - mainly applicable to new builds. For simplicity, it was generally assumed that there would be no uptake of technical measures on ships less than 400 GT, offshore, fishing and service vessels (of all sizes) to which the EEDI would not apply;

- Operational measures - mainly applicable to existing vessels including new ships in their operational phase. This category includes technologies suitable for retrofit; and

- Alternative fuels - applicable both to new builds and existing vessels. However, uptake of most alternative fuels is not considered a retrofit option as it may involve significant changes to an existing vessel. In this study, it is assumed that uptake of alternative fuels by the existing fleet will be minimal.

4 METHODOLOGY

Overall approach

4.1 In order to analyse the emission reduction potential of the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) and to estimate the potential for reduction in CO_2 emissions from international shipping by the years 2020 and 2050, the approach described in the following paragraphs was adopted.

4.2 The potential of operational and technical measures and alternative fuels to contribute to CO_2 emission reduction over the years to 2050 was assessed using a combination of existing data and professional knowledge and expertise. In order to realise this energy-efficiency and CO_2 emission reduction potential, it was considered that the EEDI together with a mandatory performance threshold could be an appropriate tool to drive uptake of new technologies and use of alternative fuels.

4.3 The required EEDI limit to drive more energy efficient ship design and realise the CO_2 emission reduction potential associated with technical innovation and use of lower/no carbon fuels was therefore estimated. Effective implementation of the Ship Energy Efficiency Management Plan was assumed to drive the CO_2 emission reduction associated with operational measures.

Scenarios for future emission projections

4.4 Scenario planning is commonly used to evaluate an uncertain future. In this Study, scenarios were used to provide possible fleet and emission growth projections to 2050 upon which different projections for the impact of technical, operational and alternative fuel measures in increasing energy efficiency and reducing CO_2 emissions from ships could be overlaid.

4.5 The scenarios used were based on the assumptions relating to global development in the IPCC Special Report on Emissions Scenarios [6] and correspond to the A1B and B1 scenarios examined in the Second IMO GHG Study 2009.

4.6 These scenarios both assume a more globalized world with similar populations. A1B assumes rapid and successful economic development, economic and cultural convergence globally, pursuit of personal wealth and use of a balanced mix of energy sources. In contrast B1 emphasises a high level of environmental and social consciousness, a change toward a service and information economy, reduction in material intensity and the introduction of clean and resource efficient technology.
These scenarios were selected as it was considered that they resulted in a range of shipping growth due to increased world trade without representing extreme scenarios.

Forecast of CO_2 emission reduction potential to 2050

4.7 The potential of operational and technical measures and alternative fuels to contribute to CO_2 emission reduction over the years to 2050 was assessed using a combination of published data [1,7-9] and professional knowledge and expertise.

4.8 The overall forecast of adoption of measures by the industry was categorised as:

- **Low uptake** – representing the minimum uptake of measures consistent with absence of regulatory or market based drivers;

- **Attainable –** considered attainable based on effective use of technological and operational measures with moderate support from market-based drivers in the form of higher fuel or carbon prices to encourage uptake of technologies and energy management techniques and practices; and

- **Optimistic** – Very high fuel prices or substantial regulatory or market based drivers will be required to encourage commercial development and uptake of more costly alternative fuels or energy systems. Under this scenario, the world fleet is likely to look different and be operated differently to the current fleet. Reduction potentials included in this category generally corresponded to the upper value of emission reduction potentials included in the Second IMO GHG Study 2009 [1].

4.9 Summary results showing the fuel consumption reduction potentials and the assumed future average carbon content of fuel used for the emissions projections are included in Appendix I.

Modelling

4.10 A simulation model, designed specifically to account for the uptake of emission reduction technologies and measures and the implementation of regulations to control emissions, has been used to predict likely CO_2 emission levels to 2050. This model has been applied in several previous studies [9-11].

4.11 The model uses installed power to reflect the size and transport capacity of the fleet, assuming that, if no reduction measures are applied, the same amount of energy per tonne-mile and emission per energy produced will apply as determined in the base year (2007). The future fleet emissions are constructed using fleet growth rates and scrapping rates to find an annual installed power of the fleet, and then applying, activity level; specific emission levels and emission reduction factors to produce the modelled emissions for a given year.

4.12 The model uses emission reduction scenarios, describing the effects of technical and operational measures to be implemented in the fleet, as well as scenarios for growth and scrapping. The model keeps track of the year of build for all ships, and scraps the oldest and least energy-efficient ships first. By including the scrapping rate, the renewal rate of the fleet is taken into account. A high scrapping rate will ensure a faster uptake of new technologies. For simplicity, a scrapping rate for all ships of 2% from 2007-2025 and 3% from 2025-2050 is used.

Fleet development

4.13 The study uses the same segmentation used in the Second IMO GHG Study 2009 dividing the fleet into three broad categories covering all ships above 100 GT:

- Coastal shipping – Ships used in regional (short sea) shipping; mainly small ships <15000 dwt and RoPax vessels;
- Ocean-going shipping – larger ships suitable for intercontinental trade, primarily tankers and bulk carriers (but also including gas and car carriers); and
- Container ships (all sizes). Although small container feeder vessels could be considered to be short-sea vessels, the demand for container feeders is linked with the demand for global container transport in general. Thus, all pure containerships were placed in this single category.

4.14 The baselines and annual growth rates utilised are based on those in the Second IMO GHG study 2009; scrapping rates are equivalent to those given in MEPC 58/INF.14 (see Table 1). The same scrapping rates are used for both growth scenarios.

	Baseline (2007)		Annual growth rate (%) 2007-2050 [1]		Annual scrapping rate (%) [9]	
	CO_2 emissions (MT) [1]	**Transport efficiency (g/tonne-mile) [1]**	**A1B**	**B1**	**2007-2025**	**2025-2050**
Ocean-going shipping	422	13 (tankers) 10 (bulk carriers)	2.1	1.4	2.0	3.0
Container	219	29	5.2	4.3	2.0	3.0
Coastal shipping	374*	38	2.1	1.4	2.0	3.0
Total	**1015**	**-**	**3.3**	**2.5**	**-**	**-**

*** includes 163 MT from ships (small vessels (100-400 gt), offshore, fishing, service vessels) to which the EEDI will not apply [12]**

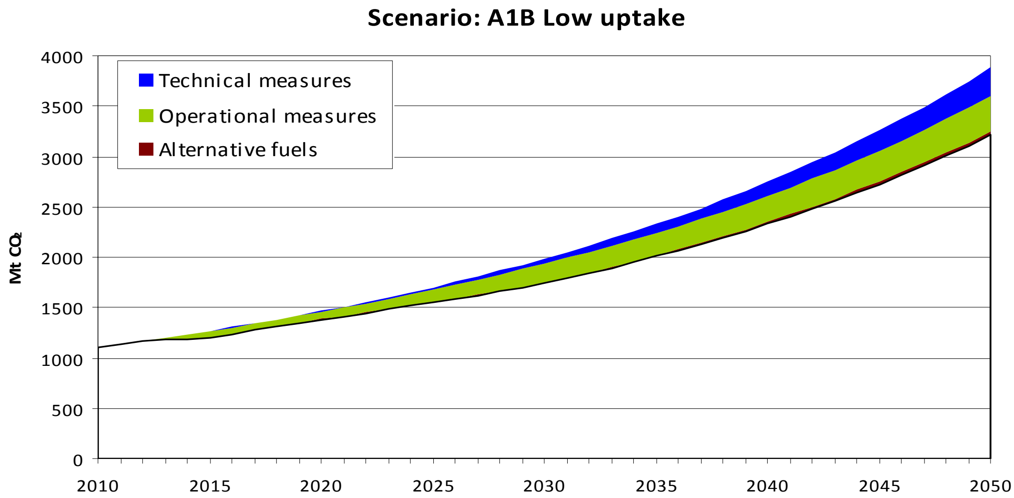
Table 1: Baseline and fleet development assumptions

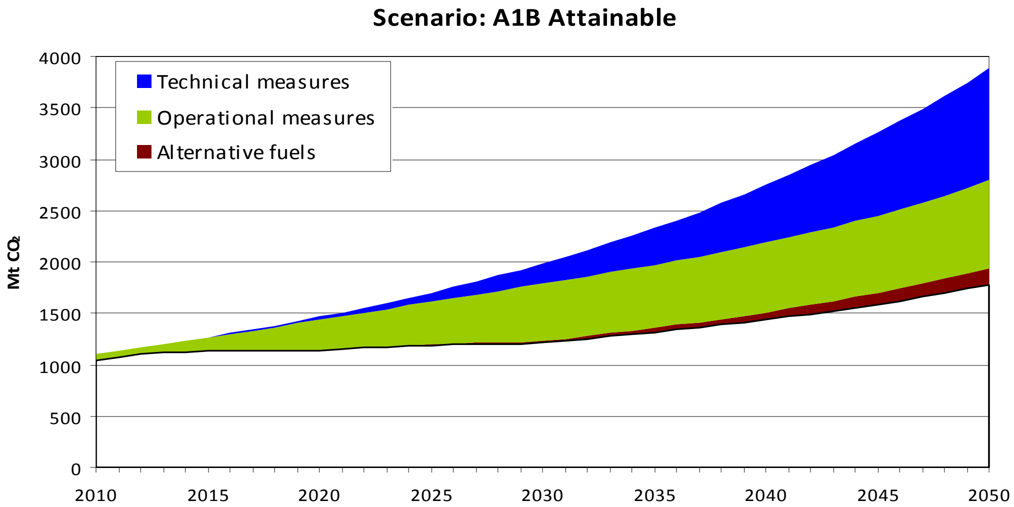
5 RESULTS

Emission projections to 2050

5.1 Results are presented throughout for two future scenarios for future global development taken from the IPCC Special Report on Emissions Scenarios [6], scenario A1B and scenario B1.

5.2 Figures 1 and 2 demonstrate the reduction potential of technological and operational measures and alternative fuels for the range of uptake forecasts examined. The underside of the lower curve on each figure represents the forecast overall annual CO_2 emission figure for shipping for the year shown on the horizontal axis. Thus for scenario A1B, the ‘low uptake’ of measures scenario indicates a total CO_2 emission of around 3,211 MT for 2050, whereas the ‘attainable’ scenario indicates emissions are reduced to around 1,782 MT and the ‘optimistic’ that emissions are reduced to around 1,137 MT. Corresponding values for the different forecasts for uptake of technological and operational measures in a B1 global development scenario indicates total CO_2 emissions in 2050 of around 2,338 MT for the ‘low uptake’ of measures scenario; reduction of CO_2 emissions to around 1,303 MT in the ‘attainable’ scenario and to around 835 MT in the ‘optimistic’ scenario in 2050.





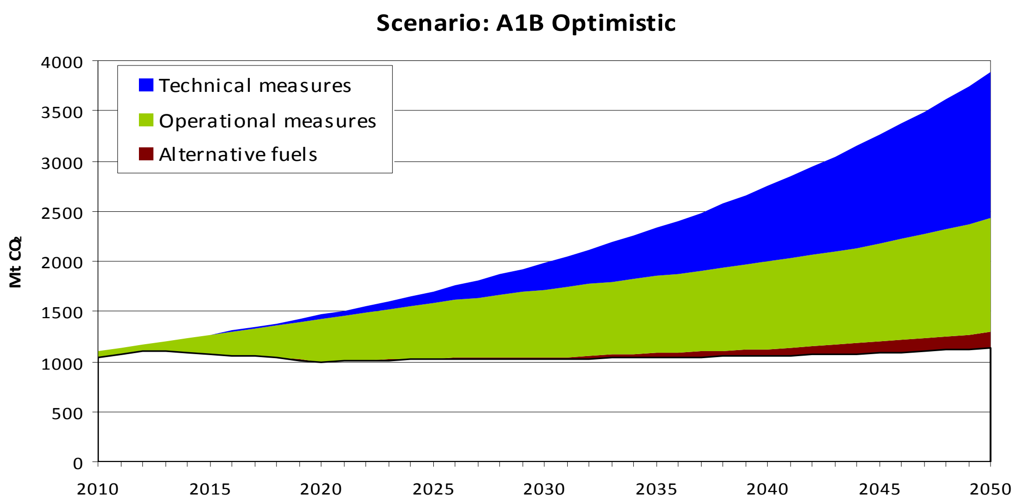


Figure 1 Reduction potential of technological and operational measures and alternative fuels for a range of uptake forecasts for scenario A1B

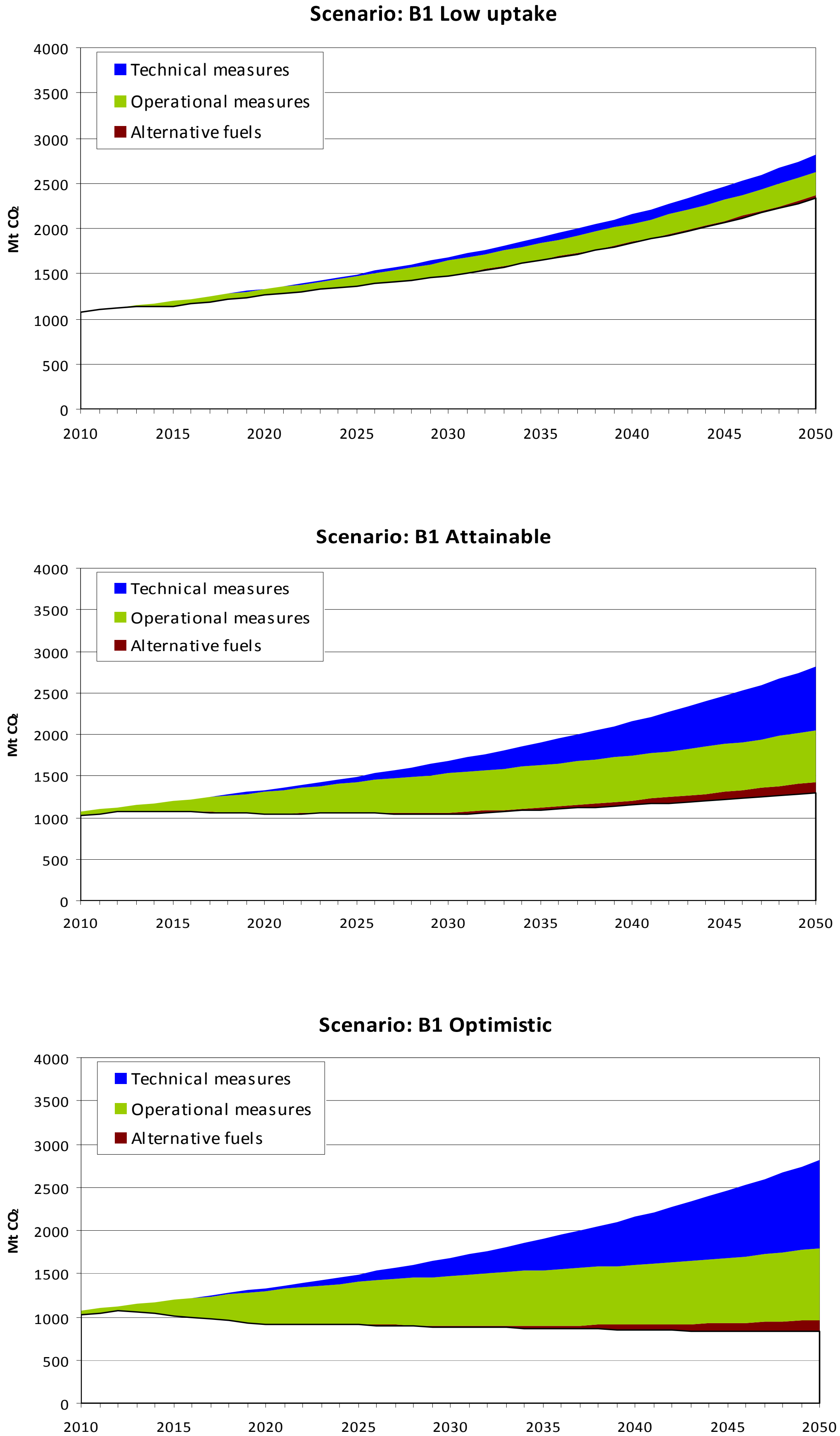


Figure 2 Reduction potential of technological and operational measures and alternative fuels for a range of uptake forecasts for scenario B1

Emission reduction by measure

5.3 Figure 3 shows the effect of technological and operational measures and use of alternative fuels in 2020 and 2050 for the different growth and technology uptake scenarios. The resultant reduced emission levels are signified by the lower light blue columns.

5.4 Operational measures, particularly speed reduction, can be seen to have an effect almost immediately. Technological measures take far longer to show a significant impact, primarily because these measures have only been considered as applicable to new build ships. The contribution of existing alternative fuels to CO_2 reduction in the years to 2050 appears low.

5.5 An overall reduction in CO_2 emissions from the 2007 level appears only in the B1/ optimistic scenario.

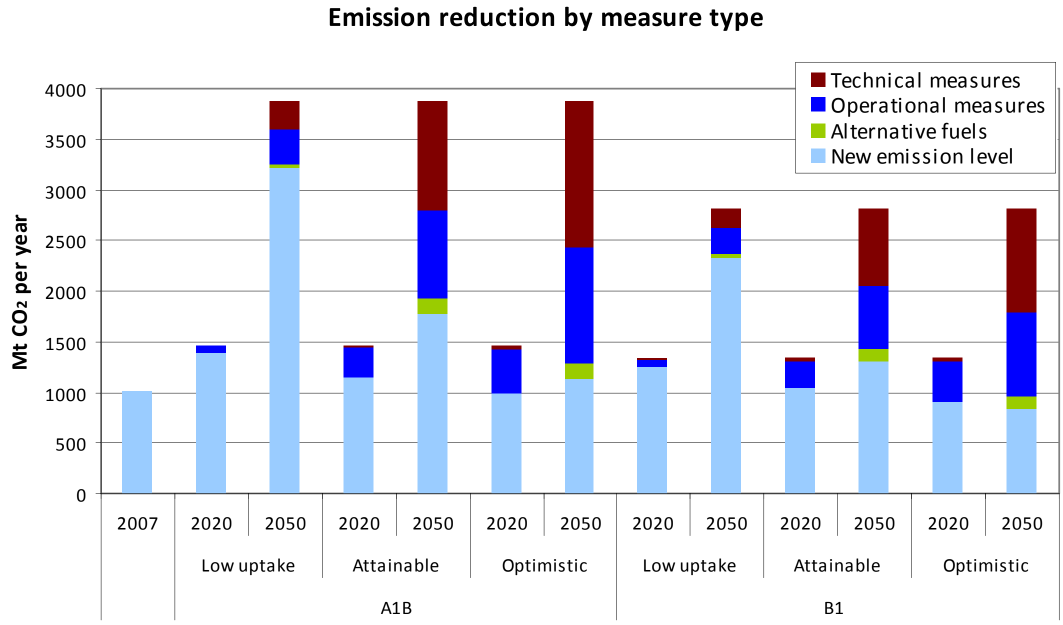


Figure 3 Emission reduction per measure type in 2020 and 2050 for the different scenarios

Emission reduction by ship category

5.6 Emission reductions for the different ship categories are shown in Figure 4. The most striking observation is the predicted growth in emissions from container ships between 2020 and 2050. The coastal and ocean going ship categories are predicted to emit similar levels of emissions to one another in 2020 and 2050. These emissions will constitute a generally decreasing proportion of the total emissions, consistent with the increased proportion attributable to container ships.

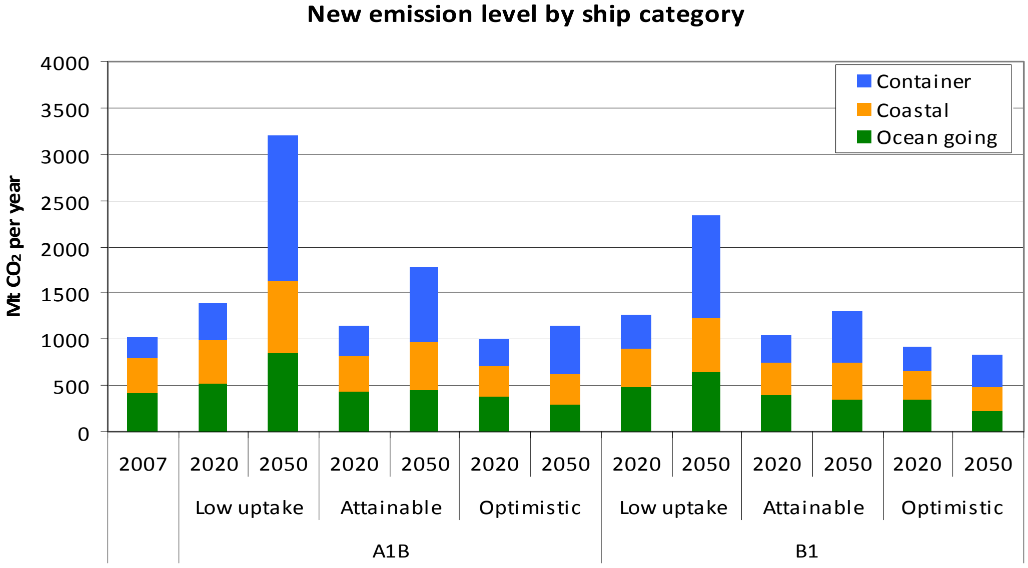


Figure 4: Emission level by ship category in 2020 and 2050 for the different scenarios

Transport efficiency

5.7 Transport efficiency (Table 2, Figure 5 with further information in Appendix III) was calculated using the 2007 levels given in the Second IMO GHG Study 2009 and the emission reduction due to each technology scenario as estimated within this study. The ocean-going segment is split into tankers and bulk carriers. There is no difference between the A1B and B1 scenarios as fleet size is not directly relevant to transport efficiency.

Table 2 Transport efficiency in g CO_2/tonne-mile associated with the different energy efficiency measures' uptake scenarios

		Low uptake		Attainable		Optimistic	
	2007	2020	2050	2020	2050	2020	2050
Coastal	38.0	36.0	33.0	30.2	23.2	26.3	15.5
Container	29.0	27.3	23.7	21.9	12.1	19.4	7.7
Bulk (ocean-going)	10.0	9.4	8.3	7.9	4.4	6.8	2.8
Tanker (ocean-going)	13.0	12.3	10.7	10.2	5.7	8.8	3.6

5.8 Improved efficiency is apparent for all scenarios in 2020 with respect to 2007 with further efficiencies to 2050. Tanker and bulk carriers are consistently more efficient than container ships due to average operational speed and ship size. Smaller coastal vessels tend to be least efficient due to their size and relative engine power (economy of scale).

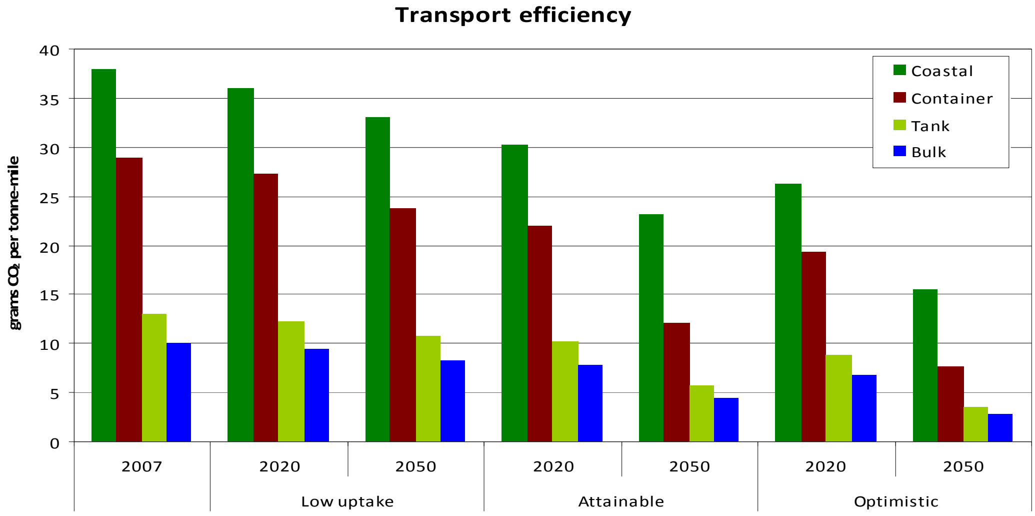


Figure 5 Transport efficiency in 2020 and 2050 for the different ship categories

6 THE IMPACT OF IMO ENERGY EFFICIENCY MEASURES

The role of the SEEMP and EEOI in driving operational improvements

6.1 Management plans are well established tools within the Marine industry for providing a non-prescriptive approach to managing operational issues. The Ship Energy Efficiency Management Plan (SEEMP), for which guidelines for development have recently been agreed by the IMO, follows established management system approaches including the International Safety Management (ISM) Code and the International Ship and Port Facility Security (ISPS) Code.

6.2 The energy efficiency and emission reduction potential associated with operational measures are demonstrated in Figures 1-3. Significant potential is apparent, which can be realised more rapidly than for technological measures. As enhanced efficiency translates directly into reduced fuel use, the uptake of efficiency-enhancing measures can generally be expected to be cost effective to implement [1].

6.3 Increased fuel price in future years as competition for finite hydrocarbon fuel resources intensifies, will drive the uptake of energy efficiency measures. However, additional drivers are likely to be required to stimulate uptake of the range of possible measures to counterbalance an increase in emissions linked to the predicted growth in world trade. These could include environmental regulations, market-based instruments and other measures.

6.4 Amongst these drivers, the SEEMP, is likely to play its part in driving uptake of operational efficiency measures. Even as a voluntary measure initially, by providing advice and recommendations on energy efficiency measures, it is expected that this tool will facilitate enhanced uptake of operational energy efficiency measures in the world fleet.

6.5 The Energy Efficiency Operational Indicator (EEOI), for which guidelines for voluntary use (MEPC.1/Circ.684) were agreed by IMO in July 2009, provides a measurement tool to allow continuous assessment of the overall vessel transportation efficiency. It can thus provide a quantitative yardstick for the impact on efficiency of the SEEMP and other measures. It is also considered likely that an increasing number of charterers will start to look towards EEOI performance when placing their contracts.

6.6 Uptake of the full range of efficiency enhancing measures, however, cannot be achieved without close cooperation throughout the supply chain and with ports. A broad regulatory regime encompassing, for example, port development, logistic chains and charter party agreements, is likely to be required to realise the full potential of the operational efficiency measures.

The role of the EEDI in driving technological development

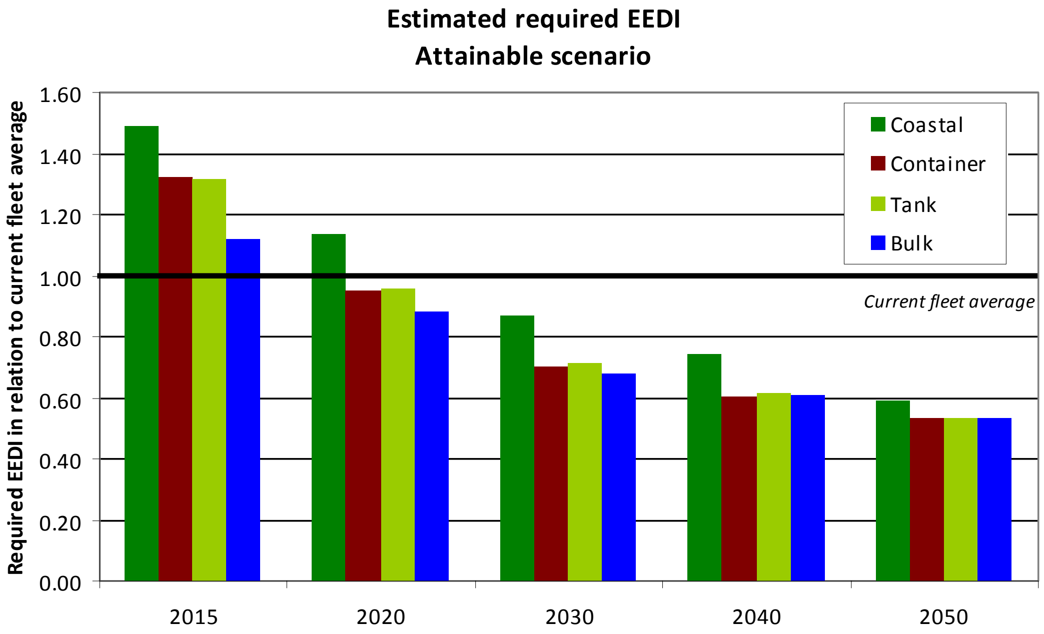
6.7 Significant potential for technological measures to enhance energy efficiency and reduce CO_2 emissions is also apparent (Figures 1-3). However, it is assumed that a mandatory limit on the EEDI for new ships would be required to drive energy-efficient design and technology uptakes and realise the full CO_2 emission reduction potential associated with technical innovation and the use of lower or no carbon fuels.

6.8 A methodology has been developed to determine the EEDI level required for each category of ship in this study in order to achieve a certain emission reduction. This study assumes that the impact of an EEDI limit will depend on the level of spread (expressed by the standard deviation) of EEDI values for the current fleet around the current fleet average or 'baseline'. Different ships types have different variance: Bulk carriers generally are fairly uniform vessels and the standard deviation of the individual ships compared to the regression line is low. For tankers, container ships and, in particular, coastal vessels, the spread is more significant.

6.9 On the basis of the emission projections generated in this study (Figures 1 and 2), the required EEDI to realise the calculated CO_2 emission reduction potentials were estimated. A detailed description of the methodology and mapping between ship categories and EEDI ship types used are found in Appendix IV.

6.10 The results are shown in Figure 6 for both the 'attainable' and 'optimistic' scenarios. The values are relative to the current fleet average value. A value above 1 indicates an EEDI value above the current fleet average value while a value below 1 indicates an index level below the current fleet average. Results are not provided for 'low uptake' on the basis that an EEDI would not be required to drive a low uptake of CO_2 emission reduction measures.

6.11 The results for both the technology uptake scenarios presented suggest introduction of a moderate EEDI limit in 2015 with that for bulk carriers, tankers and container ships being closer to the current fleet average EEDI than for coastal vessels. This is due to the fact that for vessel segments with low variation around the baseline an EEDI limit close to the baseline will have less effect as fewer vessels will be affected. A less stringent EEDI level will be sufficient for ship segments with high variance (scatter) as removing the ship designs with the highest EEDI levels will have a large impact on the emission levels. After 2015, the EEDI will need to increase gradually to 2050 with the indices for the different ship categories tending to converge around 40-60% lower than the current fleet average values by 2050.



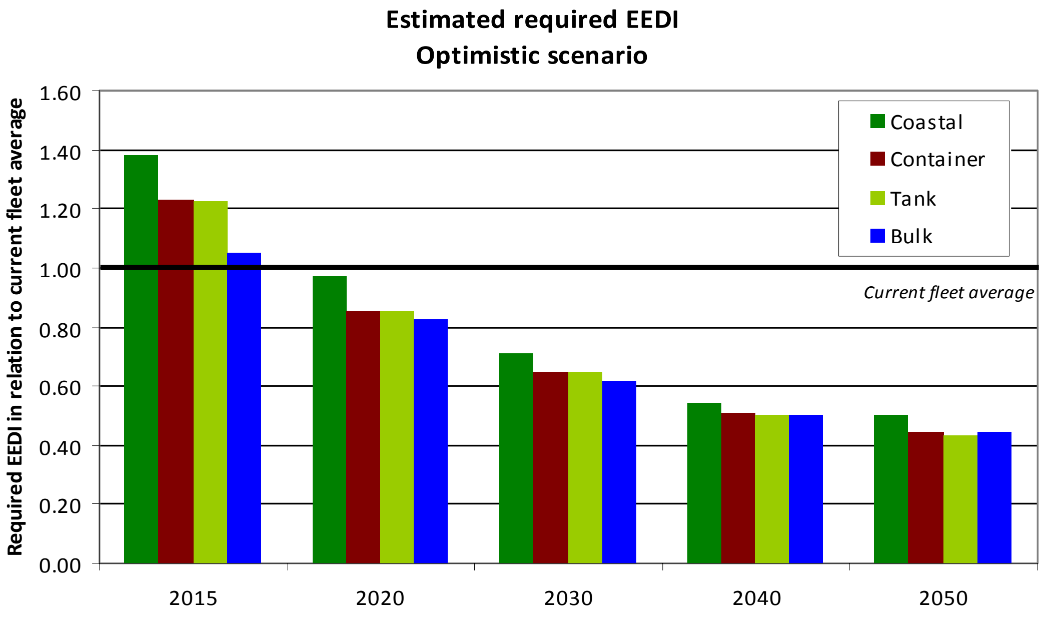


Figure 6 Required EEDI to realise CO_2 emission reduction potential of technological developments and use of alternative fuels

The calculated required percentage reductions in EEDI values are relative to the current fleet average for the various ship categories. Required EEDI limits would thus be in the form illustrated below (Figure 7).

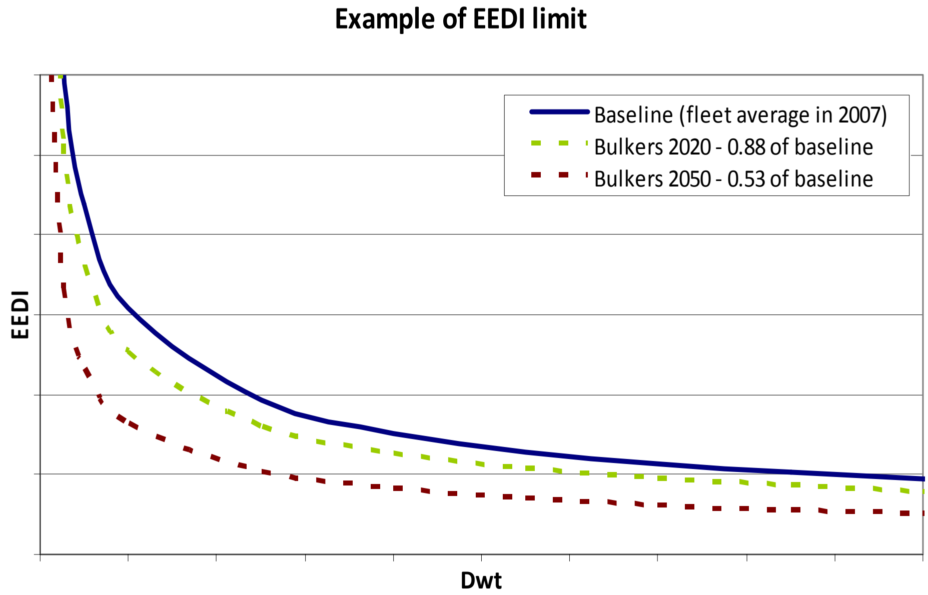


Figure 7 Example of limits for bulk carriers in relation to the current fleet average (or 'baseline') using the optimistic uptake scenario

7 CONCLUDING REMARKS

7.1 Significant potential for reduction of CO_2 emissions from ships due to operational and technical measures is apparent to 2050 with emission reduction due to operational measures likely to be realised more rapidly than that for technical measures. Alternative fuels appear unlikely to deliver a significant reduction unless a low or no carbon fuel suitable for widespread use by ships emerges during the period to 2050.

7.2 Implementation of energy efficiency measures can be cost effective; however, it is likely that adoption of these measures will need to be stimulated. For operational measures, the voluntary SEEMP and EEOI developed at MEPC 59 are likely to play a role in driving uptake of operational efficiency measures. Although not anticipated to be mandatory in the foreseeable future, by providing advice and recommendations on energy efficiency measures, it is expected that these tools will facilitate enhanced uptake of the energy efficiency measures in the world fleet.

7.3 To drive more energy-efficient ship design and realise the CO_2 emission reduction potential associated with technical innovation and the use of lower or no carbon fuels, it is assumed that a mandatory limit on the EEDI for new ships would be required. Calculations made within this study suggest that limits to the EEDI can be phased in gradually to drive the technological development necessary to achieve the overall emission reductions considered attainable by 2050.

7.4 Introduction of an EEDI limit close to the current fleet average appears appropriate for ocean-going tankers and bulk carriers in 2015; whilst a more relaxed EEDI for container ships and coastal vessels appears appropriate initially. By 2020, an EEDI below the current fleet average is suggested for most ship categories and global development scenarios. Thereafter, the EEDI will need to increase gradually to 2050 with the indices for the different ship categories tending to converge at around 50% of the current fleet average value. This figure is consistent with the maximum emission reduction achievable with known existing or developing technologies. However, future breakthroughs in propulsion technologies and/or fuels may enable further reductions.

7.5 Despite the significant CO_2 emission reduction potential for operational and technical measures, an overall reduction in total CO_2 emissions for shipping from the current level appears only in the most optimistic of scenarios investigated. In all others, the projected growth in world trade outweighs the emission reduction potential.

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Appendix I

Estimated fuel consumption reduction potentials and assumed future average marine fuel carbon content used to generate future emission projections

Ship segment	Year																	
	2010			2015			2020			2030			2040			2050		
	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic
Coastal ships	0	1	1	2	5	7	4	13	20	6	24	35	8	30	45	10	35	50
Container ships	0	1	1	2	5	7	4	14	20	6	25	35	8	32	45	10	37	50
Tankers and bulk carriers	0	1	1	2	5	7	4	15	20	6	30	35	8	37	45	10	43	50

Table A1 – Fuel consumption reduction potentials (%) relative to 2007 due to technological measures

Ship segment	Year																	
	2010			2015			2020			2030			2040			2050		
	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic
Coastal ships	0	5	5	5	10	15	5	20	30	10	30	40	10	30	45	10	30	50
Container ships	0	5	5	5	10	15	5	22	30	10	35	40	10	35	45	10	35	50
Tankers and bulk carriers	0	5	5	5	10	15	5	20	30	10	30	40	10	30	45	10	30	50

Table A2 – Fuel consumption reduction potentials (%) relative to 2007 due to operational measures

	Year																		
	2007	2010			2015			2020			2030			2040			2050		
	Base	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic	Low Uptake	Attain-able	Optim-istic
		Coastal Ships																	
Percentage of average fuel carbon content relative to 2007 fuel carbon content	100	100	100	100	100	99	99	100	99	99	99	96	96	99	92	92	98	85	84
		Ocean going ships (inc. container ships)																	
Percentage of average fuel carbon content relative to 2007 fuel carbon content	100	100	100	100	100	100	100	100	99	99	99	96	96	99	95	95	99	95	95

Table A3 – Assumed average level (%) of marine fuel carbon content relative to 2007 carbon content

Appendix II

Projected emission reductions attributable to technical and operational measures and use of alternative fuels

CO_2 emission reduction per measure in tonnes x 10^6 (MT) relative to 2007 levels

	A1B						B1					
	Low uptake		Attainable		Optimistic		Low uptake		Attainable		Optimistic	
	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050
Operational measures	73	357	295	854	427	1137	66	260	269	621	390	835
Alternative fuels	0	38	32	157	2	157	0	27	1	128	1	128
Technical measures	9	276	30	1090	42	1452	7	195	24	768	33	1023

CO_2 emission reduction per measure as a percentage relative to 2007 levels

	A1B						B1					
	Low uptake		Attainable		Optimistic		Low uptake		Attainable		Optimistic	
	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050
Ocean-going	5	9	20	22	29	29	5	9	20	22	29	30
Coastal	0	1	0	4	0	4	0	1	0	5	0	5
Container	1	7	2	28	3	37	1	7	2	27	2	3
Total	**6**	**17**	**22**	**54**	**32**	**71**	**6**	**17**	**22**	**54**	**32**	**70**

CO_2 emission level per ship category in tonnes x 10^6 (MT)

		A1B						B1					
		Low uptake		Attainable		Optimistic		Low uptake		Attainable		Optimistic	
	2007	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050
Ocean-going	422	522	849	433	447	376	286	478	644	398	345	346	222
Coastal	374	464	781	387	517	337	338	425	593	355	394	310	258
Container	219	398	1581	319	818	283	513	357	1101	287	564	254	355
Total	**1015**	**1384**	**3211**	**1139**	**1782**	**996**	**1137**	**1260**	**2338**	**1040**	**1303**	**910**	**835**

CO_2 emission share per ship category as a percentage

		A1B						B1					
		Low uptake		Attainable		Optimistic		Low uptake		Attainable		Optimistic	
	2007	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050	2020	2050
Ocean-going	42	38	26	38	25	38	25	38	28	38	26	38	27
Coastal	37	34	24	34	29	34	30	34	25	34	30	34	31
Container	22	29	49	28	46	28	45	28	47	28	43	28	42

Appendix III

Projected change in transport efficiencies (in gCO_2/tonne-nautical mile) for the different ship categories over time

Transport efficiency (g CO_2/t-nmile)

'Low uptake'	**2007**	**2015**	**2020**	**2030**	**2040**	**2050**
Coastal	38.0	36.1	36.0	33.9	33.5	33.0
Container	29.0	27.5	27.3	25.2	24.3	23.7
Bulk (ocean-going)	10.0	9.5	9.4	8.8	8.5	8.3
Tanker (ocean-going)	13.0	12.3	12.3	11.4	11.1	10.7

'Attainable'	**2007**	**2015**	**2020**	**2030**	**2040**	**2050**
Coastal	38.0	34.2	30.2	25.7	24.4	23.2
Container	29.0	26.0	21.9	16.3	13.8	12.1
Bulk (ocean-going)	10.0	9.0	7.9	6.3	5.3	4.4
Tanker (ocean-going)	13.0	11.7	10.2	8.1	6.9	5.7

'Optimistic'	**2007**	**2015**	**2020**	**2030**	**2040**	**2050**
Coastal	38.0	32.2	26.3	21.5	18.3	15.5
Container	29.0	24.5	19.4	13.9	10.0	7.7
Bulk (ocean-going)	10.0	8.5	6.8	5.1	3.8	2.8
Tanker (ocean-going)	13.0	11.0	8.8	6.7	4.9	3.6

Appendix IV

Method of calculation of EEDI control limits

Method of calculation of EEDI required to drive technological innovation

1 The reduction potential of the technologies described in this study is the relative reduction of the average EEDI of future new builds compared to the average EEDI of the present fleet. The objective is to identify the EEDI limit required to achieve these reduction percentages.

2 The relationship is dependent on the spread of the samples around the baseline expressed by a standard deviation. Baselines for different ship types were presented in MEPC 58/4/8. The standard deviations presented in Table A3.2 for the different ship types were not presented in MEPC 58/4/8 [A1], but were retrieved from the background data.

3 As the ocean-going and coastal ship categories used in this study are split on size, a weighted average of the technology uptake has been used to find the average emission reduction percentage for bulk carriers and tankers. The split between small (coastal) and large (ocean-going) ship categories, measured in CO_2 emissions, are shown in Table A3.2. While the standard deviation from the fleet average (or 'baseline') value may differ for different sizes of ship (i.e. small vessels might have larger standard deviation), and this would have an impact on the effect of an EEDI limit, it was beyond the scope of this study to assess this.

Ship type	Split between ocean-going and coastal category	Standard deviation in baselines	Standard deviation used in this study
Bulk carrier	98%/2%	0.13	0.15
Tanker (incl. gas)	84%/16%	0.23 (0.19 for gas)	0.20
Container ship	-	0.18	0.20
Coastal ships	0%/100%	0.28 – 0.38	0.30

Table A3.2 Standard deviation for the baselines

4 In this study three standard deviations, 0.15, 0.20 and 0.30, have been assessed, covering the relevant range for all ship types. Ocean-going ships are assumed to have a standard deviation of 0.15; container ships 0.20 and coastal ships 0.30. A flat percentage for all ship sizes is assumed within all segments. By using the total percentage reduction of technical measures and alternative fuels for each period the required EEDI can be read from Figure A2. Figure A1 shows the results expressed in terms of the required EEDI in relation to the current fleet average or 'baseline'. A negative value indicates a required EEDI above the current fleet average value.

5 Setting a mandatory limit on the EEDI for future ships will lower the average EEDI for all new builds. However, the new average will not be equal to the set EEDI limit. This appendix explains the relationship between the set EEDI limit and the average EEDI.

6 The estimated EEDI values are calculated for every ship in the fleet, and plotted against the capacity in order to create a baseline. These baselines are based on previously presented regression analyses [A1, A2, A3]. The EEDI values can be shown to be normally distributed around the regression line [A4]. The regression line represents the average EEDI value for a segment, with 50% of the vessels having EEDI values above the average (poor performers) and 50% having lower EEDI values (good performers).

7 By imposing a limit to how much the EEDI can deviate from the baseline (denoted as X in reference A2) the new builds will have a different distribution. It can be assumed that this will not be a normal distribution: most new builds will tend to lie close to the limit, complying with the requirement, but not necessarily more. However, depending on the stringency of the limit, some new builds are likely to perform well beyond compliance while in more stringent scenarios most ships will only just comply.

8 A gamma distribution has two parameters (θ and k), describing the shape of the curve. By changing these two parameters the new assumed distribution can be tailored to account for the form of the original (normal) distribution and the stringency of the EEDI limit. When the new distribution has been found, the new mean can be calculated.

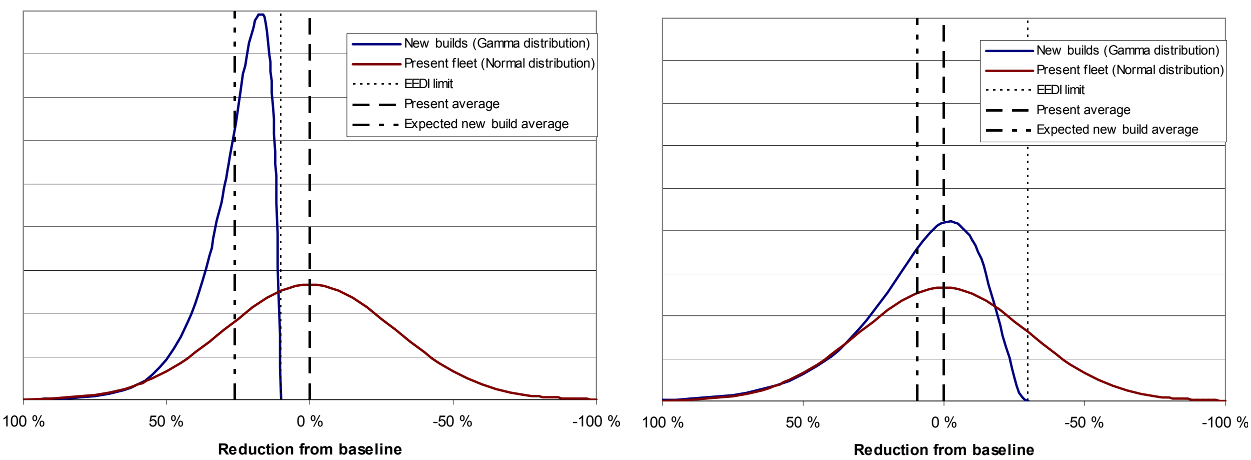

Figure A1: Setting the limit below (left) and above (right) the baseline

9 The following principles are used when determining the parameters in the new distributions:

- The lower tail (to the left in the two charts in Figure A1) should be similar to the original distribution. This tail represents the best performers, and it is assumed that these ship designs will not be changed significantly or the number increased by a mandatory EEDI limit;

- In a case where the limit is below the current average, the distribution will be heavily skewed with a peak very close to the limit. It is assumed that with a strict limit ships will lie close to the maximum allowed EEDI, and that most designs will have a small margin to ensure compliance; and

- Where a mandatory limit is above the current average (right chart in Figure A1) the peak of the distribution is assumed to lie further from the limit – indicating that the most common ship design (in relation to the EEDI) will not become worse as a result of a mandatory EEDI limit.

10 The results from estimating the new build distribution and the effect on the EEDI average are shown in Figure A2. Each point is estimated manually based on the principles described above. The resulting curves show distinctive trends even if the individual points contain some error due to the manual estimation.

11 The different ships types have different variance. Bulk carriers generally are very uniform vessels and the standard deviation of the individual ships compared to the regression line is low, except for very small ships. For tankers, container, ro-ro cargo and, especially, general cargo vessels and passenger vessels, the spread is more significant.

12 The effect of an EEDI limit varies according to the standard deviation. Setting the limit very high relative to the average of a ship type with low variance (i.e. bulk carriers) will have little or no effect as all existing designs already comply. Generally, the effect of a mandatory EEDI limit is greater for ship types with high variance. The uncertainty of the estimation increases when the limit is set below even the best performing ships, but, as the requirement becomes stricter, fewer ships will do more than just comply and the average will be closer to the limit.

13 For example, in the case of container ships which have a standard deviation of 0.18 (Table A3.2), the 0.20 line (blue) in Figure A.2 can be used. If a 20% reduction (y-axis) of the average EEDI for container new builds is required, the EEDI should be about 17-18% (x-axis) higher than the current fleet average or ‘baseline’.

Appendix IV References

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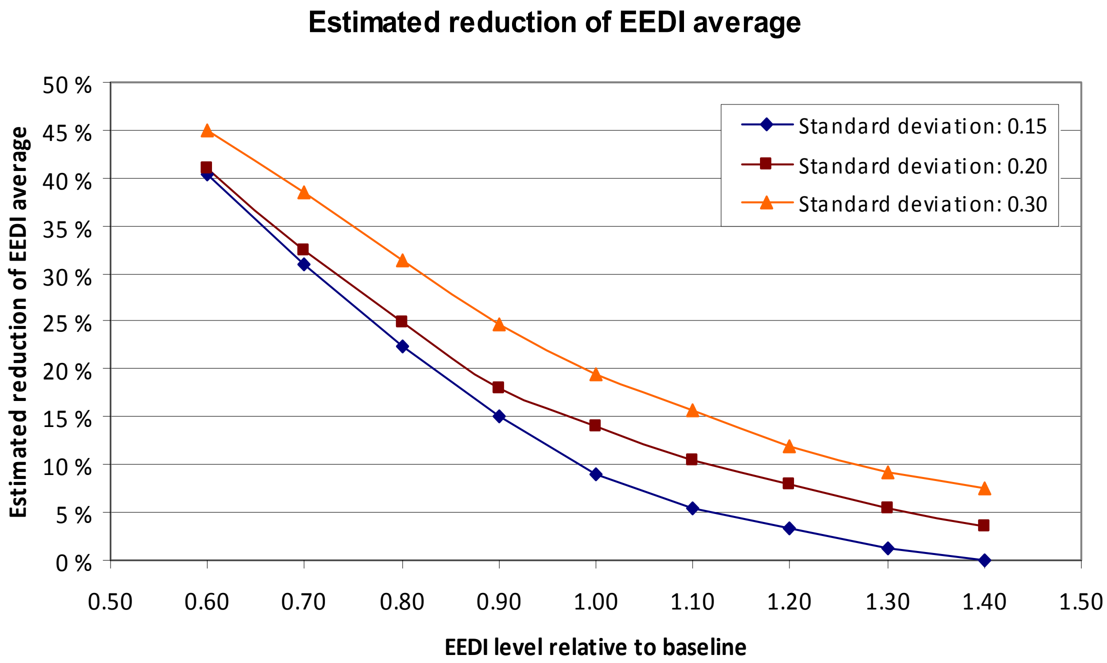

Figure A2: Estimated average reduction as a function the limit relative to baseline for three different standard deviations.

Appendix V

Summary of EEDI required to drive technological innovation

Estimated required EEDI relative to current fleet average* (or 'baseline')

'Attainable'	Bulk carrier	1.12	0.88	0.68	0.61	0.53
	Tanker (incl. gas)	1.32	0.96	0.71	0.61	0.53
	Coastal ship	1.49	1.14	0.87	0.74	0.59
	Container ship	1.32	0.95	0.70	0.60	0.53

'Optimistic'	Bulk carrier	1.05	0.83	0.62	0.51	0.44
	Tanker (incl. gas)	1.22	0.85	0.64	0.50	0.43
	Coastal ship	1.38	0.97	0.71	0.54	0.50
	Container ship	1.23	0.85	0.65	0.51	0.44

* assigned a value of 1

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