PROJECT FINAL REPORT

ASSESSMENT OF IMO MANDATED ENERGY EFFICIENCY MEASURES FOR INTERNATIONAL SHIPPING

ESTIMATED CO_2 EMISSIONS REDUCTION FROM INTRODUCTION OF MANDATORY TECHNICAL AND OPERATIONAL ENERGY EFFICIENCY MEASURES FOR SHIPS

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Date of report:

31 October 2011

EXECUTIVE SUMMARY

1 This study was commissioned by the International Maritime Organization (IMO) to analyse the potential reduction resulting from the mandated energy efficiency regulations on EEDI and SEEMP as finalised at MEPC 62 in July 2011 and also to estimate the projected reduction in CO_2 emissions from international shipping for every year up to year 2050 resulting from these agreed measures, using a number of scenarios.

2 This Study was undertaken by Lloyd's Register (LR) in partnership with Det Norske Veritas (DNV). Dr. Zabi Bazari (LR) and Mr. Tore Longva (DNV) were the main contributors to the report. They additionally received assistance from colleagues within their organizations.

3 Mandatory measures to reduce greenhouse gas (GHG) emissions from international shipping were adopted by Parties to MARPOL Annex VI represented in the Marine Environment Protection Committee (MEPC) of IMO, when it met for its 62nd session from 11 to 15 July 2011 in London, representing the first ever mandatory global GHG reduction regime for an international industry sector.

4 The amendments to MARPOL Annex VI - *Regulations for the prevention of air pollution from ships,* add a new chapter 4 to Annex VI *on Regulations on energy efficiency for ships* to make mandatory the Energy Efficiency Design Index (EEDI) for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. Other amendments to Annex VI add new definitions and the requirements for survey and certification, including the format for the International Energy Efficiency Certificate. The regulations apply to all ships of 400 gross tonnage and above, and are expected to enter into force internationally through the tacit acceptance procedure on 1 January 2013.

Reduction factors (in percentage) for the EEDI relative to the reference line for each ship type.

	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 onwards
Bulk Carriers	>20,000 Dwt	0%	10%	20%	30%
	10-20,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
Gas tankers	>10,000 Dwt	0%	10%	20%	30%
	2-10,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
Tanker and combination carriers	>20,000 Dwt	0%	10%	20%	30%
	4-20,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
Container ships	>15,000 Dwt	0%	10%	20%	30%
	10-15,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
General Cargo ships	>15,000 Dwt	0%	10%	15%	30%
	3-15,000 Dwt	n/a	0-10%*	0-15%*	0-30%*
Refrigerated cargo carriers	>5,000 Dwt	0%	10%	15%	30%
	3-5,000 Dwt	n/a	0-10%*	0-15%*	0-30%*

* The reduction factor is to be linearly interpolated between the two values depending on the vessel size. The lower value of the reduction factor is to be applied to the smaller ship size.

Table i – EEDI reduction factors, cut off limits and implementation phases

5 The EEDI requires a minimum energy efficiency level (CO_2 emissions) per capacity mile (e.g. tonne mile) for different ship type and size segments (Table i). With the level being tightened over time, the EEDI will stimulate continued technical development of all the components influencing the energy efficiency of a ship. Reduction factors are set until 2025 when a 30% reduction is mandated over the average efficiency for ships built between 1999 and 2009. The EEDI has been developed for the largest and most energy intensive

segments of the world merchant fleet and will embrace about 70% of emissions from new oil and gas tankers, bulk carriers, general cargo, refrigerated cargo and container ships as well as combination carriers (wet/dry bulk). For ship types not covered by the current EEDI formula, suitable formulas will be developed in the future according to a work plan agreed at MEPC 62.

6 The SEEMP establishes a mechanism for a shipping company and/or a ship to improve the energy efficiency of ship operations. The SEEMP provides an approach for monitoring ship and fleet efficiency performance over time using, for example, the Energy Efficiency Operational Indicator (EEOI) as a monitoring and/or benchmark tool. The SEEMP urges the ship owner and operator at each stage of the operation of the ship to review and consider operational practices and technology upgrades to optimize the energy efficiency performance of a ship.

7 In this study, scenario modelling was used to forecast possible world's fleet CO_2 emission growth trajectories to 2050. The scenarios included options for fleet growth, EEDI and SEEMP uptake, fuel price and EEDI waiver. Table ii shows the combined scenarios modelled in this Study.

8 A 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 CO_2 emission levels to 2050. 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.

Scenario	IPCC growth scenario	EEDI Uptake scenario	SEEMP uptake	Fuel price scenarios	Waiver scenario
A1B-1	A1B	Regulation	Low*	Reference	5%
A1B-2	A1B	Regulation	Low	High	5%
A1B-3	A1B	Regulation	High**	Reference	5%
A1B-4	A1B	Regulation	High	High	5%
B2-1	B2	Regulation	Low	Reference	5%
B2-2	B2	Regulation	Low	High	5%
B2-3	B2	Regulation	High	Reference	5%
B2-4	B2	Regulation	High	High	5%
A1B-3W	A1B	Regulation	High	Reference	30%

* 30% ** 60%

Table ii – Combined scenarios

9 Based on scenarios modelled in this Study, results shows that the adoption by IMO of mandatory reduction measures from 2013 and onwards will lead to significant emission reductions by the shipping industry (see Figure i).

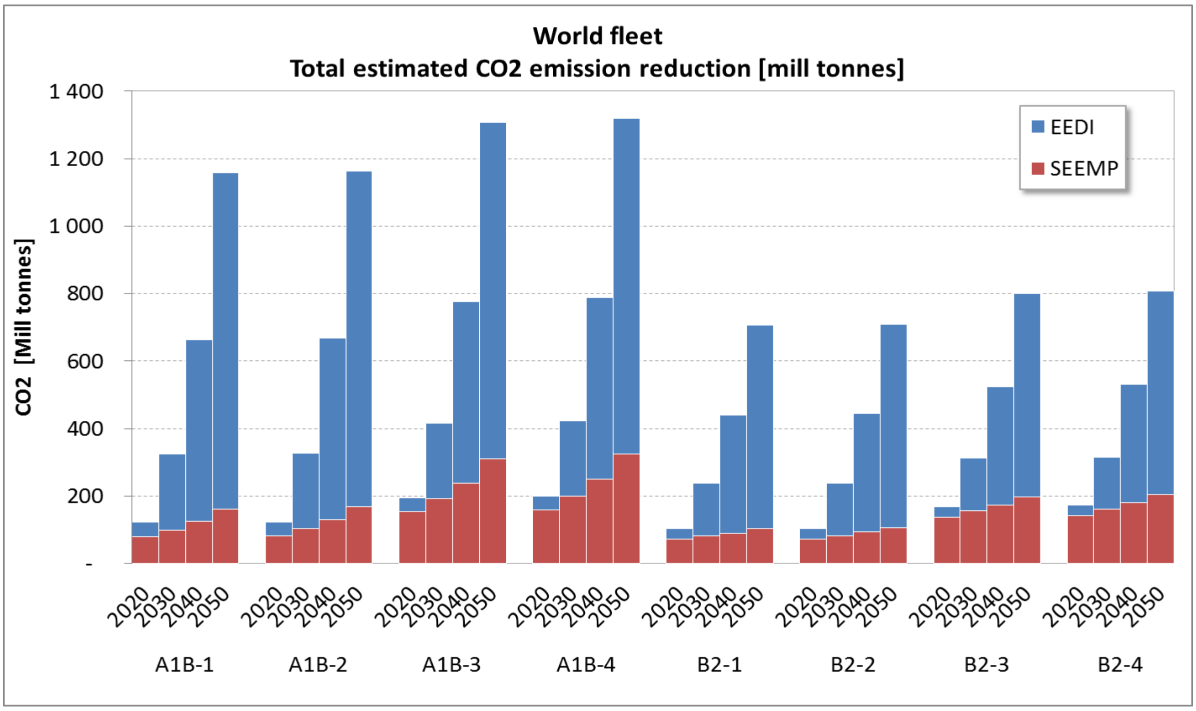

Figure i – Overall annual CO_2 reduction potential for SEEMP and EEDI (waiver 5%)

Findings

10 According to Figure i:

.1 By 2020, an average of 151.5 million tonnes of annual CO_2 reductions are estimated from the introduction of the EEDI for new ships and the SEEMP for all ships in operation, a figure that by 2030, will increase to an average of 330 million tonnes annually (Table iii, showing the average for scenarios A1B-4 and B-2);

Year	BAU Mill tonnes	Reduction Mill tonnes	New level Mill tonnes
2020	1103	152	951
2030	1435	330	1105
2040	1913	615	1299
2050	2615	1013	1602

Table iii - Estimated average CO_2 emission reductions (million tonnes) for world fleet compared with estimated BAU CO_2 emissions (million tonnes)

.2 Compared with Business as Usual (BAU), the average annual reductions in CO_2 emissions and fuel consumed are estimated between 13% and 23% by 2020 and 2030 respectively (Tables iii);

.3 CO_2 reduction measures will result in a significant reduction in fuel consumption (Table iv) leading to a significant saving in fuel costs to the shipping industry, although these savings require deeper investments in more efficient ships and more sophisticated technologies, as well as new practices, than the BAU scenario.

Year	2020		2030	
Scenarios	Low (B2-1) Mill tonnes	High (A1B-4) Mill tonnes	Low (B2-1) Mill tonnes	High (A1B-4) Mill tonnes
BAU fuel consumption	340	390	420	530
Reduction in fuel consumption	30	70	80	140
New fuel consumption level	310	320	340	390

Table iv - Annual fuel consumption reduction (in million metric tonnes) for world fleet

.4 The average annual fuel cost saving is estimated between US$20 and US$80 billion (average US$50 billion) by 2020, and between US$90 and US$310 billion (average US$200 billion) by 2030 (Table v).

	High (A1B-4)		Low (B2-1)	
Year	2020 $billion	2030 $billion	2020 $billion	2030 $billion
BAU fuel cost	490	1170	240	510
Reduction in fuel cost	80	310	20	90
New fuel cost level	410	860	220	420

Table v - Annual fuel cost reduction (in billion US$) for world fleet

11 The results of the study indicate that SEEMP measures (mainly operational) have an effect mostly in the medium term (e.g. 2020) whilst EEDI measures (technical) should have significant impact on the long term (e.g., 2030-2050) as fleet renewal takes place and new technologies are adopted; however, none of the scenarios modelled will achieve an absolute reduction in total CO_2 level relative to year 2010 (Figure ii).

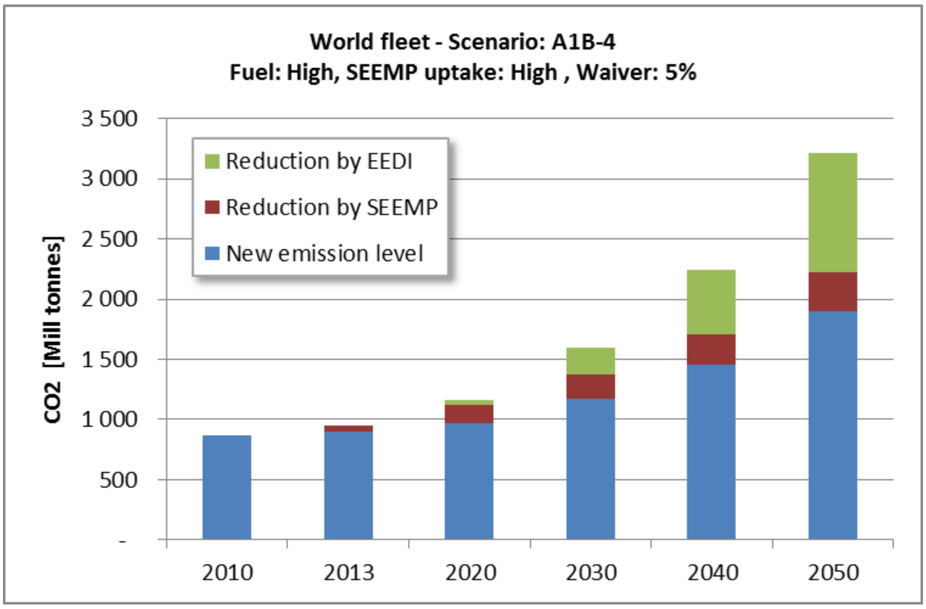

Figure ii - Annual emission reduction by 2050 and new emissions levels (scenario A1B-4)

Concluding remarks

12 Based on the results of this Study, the following conclusions may be made:

.1 Significant reduction of CO_2 emissions from ships due to EEDI and SEEMP regulations is foreseen to 2050 with emission reduction due to SEEMP (primarily operational measures) likely to be realised more rapidly than that for EEDI (primarily technical measures), as the effect of EEDI will occur only as and when older, less efficient, tonnage is replaced by new, more efficient tonnage.

.2 Mandatory application of EEDI will 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. Calculations made within this Study suggest that the agreed EEDI limits can be achieved via technological developments and some design speed reduction as highlighted in this report.

.3 Forecasts with different scenarios indicate total annual CO_2 emissions in 2050 of 3215 million tonnes for BAU and new emissions level of 1895 million tonnes (1320 million tonnes reduced) for scenario A1B-4 (high growth combined with high SEEMP uptake and high fuel price) and a total annual CO_2 emissions in 2050 of around 2014 million tonnes for BAU and new emissions level of 1344 million tonnes (706 million tonnes reduced) for scenario B2-1 (low growth combined with low SEEMP uptake and reference fuel price).

.4 For EEDI, an annual reduction of about 1000 million tonnes of CO_2 for scenario A1B and 600 million tonnes of CO_2 for scenario B2 is foreseen in 2050. For SEEMP, an annual reduction of about 325 million tonnes of CO_2 for scenario A1B-4 and 103 million tonnes of CO_2 for scenario B2-1 is foreseen by 2050.

.5 Transport efficiency will improve with the same rate as the emission reduction taking into account the growth rate of the fleet. In addition to Figures 6a and 6b, Table vi provides the numeric transport efficiency development for different ship types. As indicated, various vessels' transport energy efficiency nearly doubles and the emissions per cargo unit nearly halves from 2005 to 2050.

Year	Bulk carrier	Gas tanker	Tanker	Container ship	General cargo ship	Refrigerated cargo carrier
2005	9	13	13	30	40	40
2010	9	12	12	28	37	37
2020	8	10	10	23	30	30
2030	7	9	9	20	27	27
2050	5	7	7	16	21	20

Table vi - Transport efficiency (g CO_2/tonne mile) improvement associated with the different ship types using scenario B2-4/A1B-4

.6 The impact of the waiver clause in Regulation 19.5 is estimated to be low on total emission reductions due to EEDI. A change of waiver level from 5% to 30% will result in a decrease in CO_2 reduction levels by 7 million tonnes per year in 2030 (overall reduction is 416 million tonnes for this scenario).

.7 Based on the analysis provided in this Study, it is concluded that the likelihood of Flag States or shipowners to opt for an EEDI waiver is low due to low compliance costs and commercial disadvantage of non-compliance. Accordingly, the uptake level taken in this Study as 5% (low) and 30% (high) is regarded as reasonable. It is most likely that waiver uptake will be at the level of 5% as current indications imply.

	EEDI reduction measure	**SEEMP Related measure**
1	Optimised hull dimensions and form	Engine tuning and monitoring
2	Lightweight construction	Hull condition
3	Hull coating	Propeller condition
4	Hull air lubrication system	Reduced auxiliary power
5	Optimisation of propeller-hull interface and flow devices	Speed reduction (operation)
6	Contra-rotating propeller	Trim/draft
7	Engine efficiency improvement	Voyage execution
8	Waste heat recovery	Weather routing
9	Gas fuelled (LNG)	Advanced hull coating
10	Hybrid electric power and propulsion concepts	Propeller upgrade and aft body flow devices
11	Reducing on-board power demand (auxiliary system and hotel loads).	
12	Variable speed drive for pumps, fans, etc.	
13	Wind power (sail, wind engine, etc.)	
14	Solar power	
15	Design speed reduction (new builds)	

Table vii-Technologies for EEDI reductions and SEEMP related measures

.8 Implementation of SEEMP-related energy efficiency measures are generally cost effective; however, it is likely that adoption of these measures will need to be stimulated. Follow-on monitoring and audits, and high carbon and fuel prices are expected to play a role in driving uptake of SEEMP efficiency measures. Although it is not anticipated to have a target-based regulatory framework for SEEMP in the foreseeable future; putting in place an effective audit/monitoring system, building awareness and resolving split incentive issues for operational energy efficiency measures will facilitate enhanced uptake of SEEMP measures in the world fleet.

.9 The mandatory use of SEEMP based on current IMO regulations will provide a procedural framework for shipping companies to recognise the importance of the operational energy saving activities. It will significantly boost the level of awareness and, if implemented properly, will lead to a positive cultural change. However, and in view of lack of regulatory requirements for target setting and monitoring, SEEMP's effectiveness will need to be stimulated / incentivised via other initiatives.

.10 To make the application of SEEMP more effective and to prepare the shipping industry for likely future carbon pricing via MBMs, it seems that use of the EEOI (Energy Efficiency Operational Indicator) or a similar performance indicator should be encouraged or mandated. This will involve more accurate and verifiable measurement of fuel consumption that could pave the way for CO_2 foot printing and data verification in the future.

.11 The estimated reductions in CO_2 emissions, for combined EEDI and SEEMP, from the world fleet translate into a significant annual fuel cost saving of about US$50 billion in 2020 and about US$200 billion by 2030; using fuel price increase scenarios that take into account the switch to low sulphur fuel in 2020.

.12 Investigations show that ship hydrodynamic and main engine optimisation will bring about energy saving opportunities of up to around 10% with no significant additional cost of shipbuilding. In addition, main and auxiliary engines are already available with reduced specific fuel consumption of about 10% below the values used in the reference line calculations. The above two combined effects is indicative that cost of compliance, for an "average ship", to phases 0 and 1 will not be significant.

.13 As a consequence of current developments in ship design and new technologies coming onto market, the cost of EEDI compliance in phase 1 seems to be marginal as the 10% reduction requirement may be achieved by low-cost hull form design and main engine optimisations. Cost of compliance for phase 2 and phase 3 may be higher and will involve some design-speed reduction for an average ship. However, the overall life-cycle fuel economy of the new ships will be positive as indicated by the high savings in fuel costs.

.14 Despite the significant CO_2 emission reduction potential resulting from EEDI and SEEMP regulations, an absolute reduction in total CO_2 emissions for shipping from the 2010 level appears not to be feasible using these two measures alone. For all scenarios, the projected growth in world trade outweighs the achieved emission reduction using EEDI and SEEMP, giving an upward trend, albeit at a very much reduced rate compared to BAU.

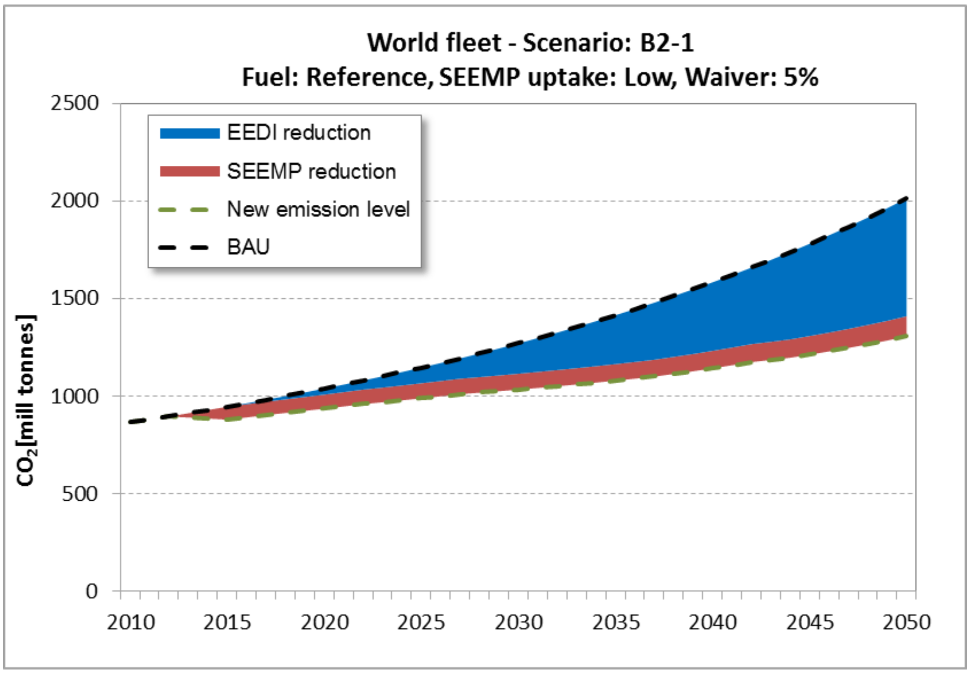

Figure 4a – World fleet CO_2 level projections (B2-1 scenario)

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1 INTRODUCTION

1.1 This study was commissioned by the International Maritime Organization (IMO) to analyse the potential reduction resulting from the mandated energy efficiency regulations on EEDI and SEEMP as finalised at MEPC 62 in July 2011 and also to estimate the projected reduction in CO_2 emissions from international shipping for every year up to year 2050 resulting from these agreed measures, using a number of scenarios.

1.2 This Study was undertaken by Lloyd's Register (LR) in partnership with Det Norske Veritas (DNV). Dr. Zabi Bazari (LR) and Mr. Tore Longva (DNV) were the main contributors to the report. They additionally received assistance from colleagues within their organizations.

1.4 As part of this study, the impact of the EEDI waiver clause (Regulation 19.5) as well as the potential technologies that can be used to achieve the future Required EEDI levels is studied. Also, energy efficiency measures that could be the subject of SEEMP implementation are studied and their likely level of uptake is investigated in order to quantify the effectiveness of SEEMP.

1.5 For consistency with previous IMO studies, base data from the Second IMO GHG study 2009 [1] was used where possible, supplemented by data, modelling capability and professional expertise pre-existing within LR and DNV. The same growth scenarios A1B and B2, as per the previous studies, were used in conjunction with updated baseline data for 2010. The simulated cut-off ship capacities and EEDI reduction factors were those recorded in the newly adapted Chapter 4 of MARPOL Annex VI "Regulation on Energy Efficiency for Ships" [2].

MEPC 62 energy efficiency regulations

1.6 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]. Despite being an energy-efficient mode of transport compared with other transport modes, there are opportunities for increasing energy efficiency and reducing CO_2 emissions from shipping.

1.7 To realise the above potentials, mandatory energy efficiency instruments for international shipping were developed and agreed formally at MEPC 62. These are "Regulations on Energy Efficiency for Ships", included as Chapter 4 of MARPOL Annex VI [2]. Accordingly, having a SEEMP for all existing ships over 400 GT, an Attained EEDI and a Required EEDI for a number of ship types is mandated from 1st January 2013[1].

1.8 The Regulations on Energy Efficiency for Ships in Chapter 4 of MARPOL Annex VI make reference to IMO guidelines developed by the Organization. Several draft sets of Guidelines have been developed and are due to be considered further, with a view to be considered for adoption at MEPC 63. The draft guidelines are:

- Guidelines on the method of calculation of the Energy Efficiency Design Index (EEDI) for new ships [3].
- Guidelines on Survey and Certification of the EEDI [4].
- Guidelines for calculation of reference lines for use with the Energy Efficiency Design Index [13].

1 Regulation 19 of MARPOL Annex VI allows for Flag State to waiver the EEDI related regulations for up to a maximum of 4 years.

- Guidelines for the development of a Ship Energy Efficiency Management Plan (SEEMP) [5].

- Guidelines for determining minimum propulsion power and speed to enable safe manoeuvring in adverse weather conditions (under development).

1.9 Additionally, IMO has developed Guidelines for voluntary use of the Energy Efficiency Operational Indicator (EEOI) [6].

1.10 In this Study, the scope of application of the Required EEDI and SEEMP has been fully taken into account in order to quantify their impact on future level of CO_2 from shipping.

CO_2 reduction measures

1.11 At present, the principal ways of reducing CO_2 emissions towards 2050 are considered to be a mix of operational measures, technological developments and use of alternative fuels with lower carbon content. In this Study, it is assumed that:

- Uptake of new technologies and low carbon fuels will be mainly driven by the EEDI regulations.

- Uptake of operational measures and cost effective technology upgrades will be encouraged by the SEEMP combined with increasing fuel and carbon prices.

2 EEDI APPLICATION ASPECTS

Ship types

2.1 EEDI will only be applicable to new ships of more than 400 GT. Currently, the EEDI does not apply to vessels such as offshore, fishing and service vessels (of all sizes), turbine ships and diesel electric ships. Additionally, currently ro-ro ships and passenger ships are excluded from the Required EEDI regulation. Although these ships may be included in the regulation in future years, the impact of future application of EEDI regulations for these ships on overall CO_2 reductions are not assessed in this Study.

2.2 The ships included in this study are those named under Regulation 21 (on Required EEDI) and are as follows:

1. Bulk carriers
2. Gas carriers
3. Tankers
4. Container ships
5. General cargo ships
6. Refrigerated cargo ships
7. Combination carriers

2.3 From the above list, the combination carriers have been amalgamated with the tankers as a single group, in accordance with Regulation 21.4.

EEDI reduction factor, cut off levels and implementation phases

2.4 Regulation 21 stipulates that the Attained EEDI should be less than or equal to the Required EEDI. The Required EEDI itself has to be below the Reference EEDI[2] by a

[2] Reference EEDI refers to EEDI as calculated from Reference Line (Regulation 21.3).

percentage denoted as "X" that is referred to as the "reduction factor". The reduction factors used in this study are those due to regulation 21 as shown in Table 1.

2.5 Based on Regulation 21, ship sizes below certain capacities (see Table 1) are excluded from having a Required EEDI during the first phases of implementation. All the ships below the cut off limit have been excluded from the EEDI calculation in this Study, assuming no emission reduction.

2.6 Regulation 21 provides the EEDI implementation phases as shown in Table 1. In this Study, it is assumed that Phase 3 ends in 2040 and that a new Phase 4 will be introduced in 2040 with an EEDI reduction factor of 40%, applicable from 2040 and onwards.

Reduction factors (in percentage) for the EEDI relative to the reference line for each ship type.

	Size	Phase 0 1 Jan 2013 – 31 Dec 2014	Phase 1 1 Jan 2015 – 31 Dec 2019	Phase 2 1 Jan 2020 – 31 Dec 2024	Phase 3 1 Jan 2025 onwards
Bulk Carriers	>20,000 Dwt	0%	10%	20%	30%
	10-20,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
Gas tankers	>10,000 Dwt	0%	10%	20%	30%
	2-10,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
Tanker and combination carriers	>20,000 Dwt	0%	10%	20%	30%
	4-20,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
Container ships	>15,000 Dwt	0%	10%	20%	30%
	10-15,000 Dwt	n/a	0-10%*	0-20%*	0-30%*
General Cargo ships	>15,000 Dwt	0%	10%	15%	30%
	3-15,000 Dwt	n/a	0-10%*	0-15%*	0-30%*
Refrigerated cargo carriers	>5,000 Dwt	0%	10%	15%	30%
	3-5,000 Dwt	n/a	0-10%*	0-15%*	0-30%*

* The reduction factor is to be linearly interpolated between the two values depending on the vessel size. The lower value of the reduction factor is to be applied to the smaller ship size.

Table 1 – EEDI reduction factors, cut off limits and implementation phases [2]

2.7 In this Study, it is assumed that no change to Table 1 of Regulation 21 (above) will be introduced as a result of the reviews described in regulation 21.6[3].

EEDI waiver

2.8 Regulation 19.5 (on Application) stipulates a waiver clause by which Flag States have the option to defer the implementation of EEDI regulations for 4 years. Regulation 19.5.3 provides an additional two and a half years if date of delivery of the ship is used for regulatory compliance.

2.9 The impact of waiver clause and the likelihood of high and low uptake of waiver by flag States were studied. The results are documented in Appendix 1; showing that as it stands now, most of Flag States may not use the waiver option, and if they do it would likely be on a ship-by-ship basis, and therefore the waiver option uptake will be low. This view is based on consideration of declared positions at date of Study by Flag States and shipping industry representative bodies, and consideration of both cost of compliance and cost of non-compliance.

EEDI and ship technologies

2.10 Technologies which are available to significantly improve energy efficiency in the short, medium and long-term include (see also Table 2):

[3] According to Regulation 21.6, IMO is committed to review the EEDI-related regulations at the beginning of Phase 1 and midpoint of Phase 2 in order to decide if there is a need for changes to any aspect of EEDI Regulations.

- Ship capacity enhancement
    - Larger ships
    - Purposely designed ships for specific routes/cargo mixers
    - Multi-purpose ships (combination carriers) to avoid ballast (empty) legs
    - Use of light weight construction materials;
    - Zero or minimum ballast configurations;

- Hull and propeller
    - Hull optimisation for less resistance and improved sea margins.
    - Advanced underwater hull coatings and monitoring.
    - More hydro-dynamically efficient aft-ship, propeller and rudder arrangements.
    - Reduced air drag through improved aerodynamics of hull and superstructure.
    - Hull air lubrication systems.

- Engines, waste heat recovery and propulsion system
    - More efficient main and auxiliary engines (de-rating, electronic control, long-stroke, variable geometry turbocharger, etc.);
    - Waste heat recovery and ship's thermal energy integration;
    - Fuel cell and hybrid electric technologies

- Alternative fuels
    - LNG
    - Nuclear

- Alternative sources of energy
    - Solar panels
    - Wind power such as kites, sails and flettner rotors

2.11 Table 2 shows the list of technologies that is expected to be used for reducing future ship's EEDI.

No.	EEDI reduction measure	Remark
1	Optimised hull dimensions and form	Ship design for efficiency via choice of main dimensions (port and canal restrictions) and hull forms.
2	Lightweight construction	New lightweight ship construction material.
3	Hull coating	Use of advanced hull coatings/paints.
4	Hull air lubrication system	Air cavity via injection of air under/around the hull to reduce wet surface and thereby ship resistance.
5	Optimisation of propeller-hull interface and flow devices	Propeller-hull-rudder design optimisation plus relevant changes to ship's aft body.
6	Contra-rotating propeller	Two propellers in series; rotating at different direction.
7	Engine efficiency improvement	De-rating, long-stroke, electronic injection, variable geometry turbocharging, etc.
8	Waste heat recovery	Main and auxiliary engines' exhaust gas waste heat recovery and conversion to electric power.
9	Gas fuelled (LNG)	Natural gas fuel and dual fuel engines.
10	Hybrid electric power and propulsion concepts	For some ships, the use of electric or hybrid would be more efficient.
11	Reducing on-board power demand (auxiliary system and hotel loads).	Maximum heat recovery and minimising required electrical loads flexible power solutions and power management.
12	Variable speed drive for pumps, fans, etc.	Use of variable speed electric motors for control of rotating flow machinery leads to significant reduction in their energy use.
13	Wind power (sail, wind engine, etc.)	Sails, fletnner rotor, kites, etc. These are considered as emerging technologies.
14	Solar power	Solar photovoltaic cells.

15	Design speed reduction (new builds)	Reducing design speed via choice of lower power or de-rated engines.

Table 2 – Technologies for EEDI reduction

2.12 The above technologies are further classified into groups and their likely application to various ship types and ship sizes are investigated. Appendix 2 shows the results of this investigation for some ship types and sizes ("average ship" in each class size). Accordingly, it is anticipated that for phases 0 and 1 (by 2020), and for an "average ship" in the class, EEDI compliance will be achieved mainly via hull, propeller and main engine optimisation (paint, hull form, propeller and aft body design improvements, engine optimisation and de-rating, etc.). Beyond 2020 (phases 2 and 3), the uptake of new technologies and some design speed reduction are foreseen for compliance with EEDI.

3 SEEMP APPLICATION ASPECTS

3.1 For SEEMP, it is assumed that all existing and new ships above 400 GT will have a SEEMP on board from the first renewal/intermediate survey of the IAPP certificate after 1st January 2013. In this Study, all these ships are included in the SEEMP calculation.

SEEMP and operational measures

3.2 The potential savings from operational measures are significant and go beyond ship-board energy management and speed reductions. New modes of co-operation between cargo owners, charterers and shipowners, 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. As such, operational measures to reduce the fuel consumption and CO_2 emissions can be considered in three categories:

- *Enhanced technical and operational management*: Measures include enhanced weather routing; optimized trim and ballasting; hull and propeller cleaning; better main and auxiliary engine maintenance and tuning; enhanced voyage execution and performance measurement, monitoring and reporting; efficient operation of larger electrical consumers; and deployment of cost effective propulsion, engines and auxiliary technology upgrades;

- *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 shipowner; and

- *Port related*: Removing restrictions on ship size (e.g. ship draft, length and beam, congestion), and limitations on quick port turn-around. Implementation requires infrastructure development and virtual arrival support. 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.

3.3 A SEEMP is expected to lead to primarily enhanced technical and operational management (first bullet above). Logistics and port-related energy efficiency measures are also influenced by a SEEMP but to a second degree as these measures involve many stakeholders and are more complicated to implement.

No.	Energy Efficiency Measure	Remark
1	Engine tuning and monitoring	Engine operational performance and condition optimisation.
2	Hull condition	Hull operational fouling and damage avoidance.
3	Propeller condition	Propeller operational fouling and damage avoidance.
4	Reduced auxiliary power	Reducing the electrical load via machinery operation and power management.
5	Speed reduction (operation)	Operational slow steaming.
6	Trim/draft	Trim and draft monitoring and optimisation.
7	Voyage execution	Reducing port times, waiting times, etc. and increasing the passage time, just in time arrival.
8	Weather routing	Use of weather routing services to avoid rough seas and head currents, to optimize voyage efficiency.
9	Advanced hull coating	Re-paint using advanced paints.
10	Propeller upgrade and aft body flow devices	Propeller and after-body retrofit for optimisation. Also, addition of flow improving devices (e.g. duct and fins).

Table 3 – SEEMP related measures

3.4 There are a large number of operational measures that could be included in a SEEMP. Previous studies on Marginal Abatement Cost (MAC) have lead to a number of MAC Curves (MACC) [7 and 8] for various ship types showing the cost and reduction effect of a range of measures which are used in this Study as listed in Table 3.

3.5 The above measures were further analysed to identify their energy saving potentials. The results are documented in Appendix 3. Accordingly and in general, SEEMP measures have a potential of up to about 30% reduction in an individual ship's fuel use on a tonne/mile basis if fully implemented compared to current practice. However, this level is unlikely to be achieved as discussed below.

SEEMP uptake level

3.6 The identified cost-effective reduction potentials due to SEEMP (Appendix 3, Table 3.1) are the upper limit estimates assuming that SEEMP will be 100% effective (i.e. all measures will be completely implemented). In practice, the uptake level will always be less than 100%. To choose a reasonable uptake level for SEEMP scenario modelling, a study was performed taking into account the following:

- Effectiveness of similar IMO mandated management plans (e.g. VOC and BWMS).
- Best practice energy efficiency management by shipping industry.
- Experience on the use of environmental management systems.
- Impact of fuel price

3.7 Appendix 4 presents the results of this analysis. Based on this, the level of uptake in the form of SEEMP effectiveness was chosen as 30% and 60% representing low and high uptake respectively.

4 METHODOLOGY

Overall approach

4.1 In order to analyse the CO_2 emission reduction potential of various EEDI and SEEMP scenarios, the approach described in the following paragraphs was adopted.

4.2 Scenario planning is commonly used to evaluate an uncertain future. In this study, scenarios were used to provide possible fleet and emission growth trajectories to 2050 upon which different projections for the impact of the EEDI on new ships and impact of SEEMP on all ships could be overlaid.

Fleet growth scenarios

4.3 The fleet growth scenarios used were based on the assumptions relating to global development in the IPCC Special Report on Emissions Scenarios and correspond to the A1B and B2 scenarios examined in the Second IMO GHG Study 2009 [1] and by the IMO Expert Group that examined Market Based Measures (MEPC 61/INF.2). The scrapping rate is assumed to be 3% per year. The growth and scrapping rates are given in Table 4.

	Growth rate		Scrapping rate
	A1B	B2	
Bulk carrier	2.1 %	1.4 %	3.0 %
Gas carrier	2.1 %	1.4 %	3.0 %
Tanker / Combination carrier	2.1 %	1.4 %	3.0 %
Container ship	5.2 %	4.3 %	3.0 %
General cargo ship	2.1 %	1.4 %	3.0 %
Refrigerated cargo carrier	2.1 %	1.4 %	3.0 %

Table 4 – Fleet development based on growth and scraping rates

4.4 Scenario 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 scenario B2 describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continuously increasing population and intermediate economic development.

EEDI and SEEMP scenarios

4.5 The values for EEDI reduction factors, cut-off levels and implementation phases are considered as agreed by MEPC 62 within the new chapter 4 Regulation on Energy Efficiency for Ships [2], as presented in Table 1.

4.6 Two waiver scenarios were selected based on analysis performed and presented in Appendix 1 (see also Section 2):

- Low waiver uptake at 5%
- High waiver uptake at 30%

4.7 Two SEEMP uptake scenarios were selected based on analysis performed and presented in Appendix 4 (see also Section 3):

- SEEMP low uptake at 30% (i.e. 30% of total SEEMP potential can be realised).
- SEEMP high uptake at 60%.

Fuel price scenarios

4.8 Two fuel price scenarios included as “reference” and “high”, which was taken from Appendix 2 in the report from the Expert Group for Market-based Measures [9], and extrapolated to provide prices to 2050 (see Figure 1):

- Reference fuel: 371/594 $/tonne for residual/distillate fuel in 2009 rising to 1008/1935 $/tonne in 2050.

- High: 371/594 $/tonne for residual/distillate fuel in 2009 rising to 1416/2719 $/tonne in 2050.

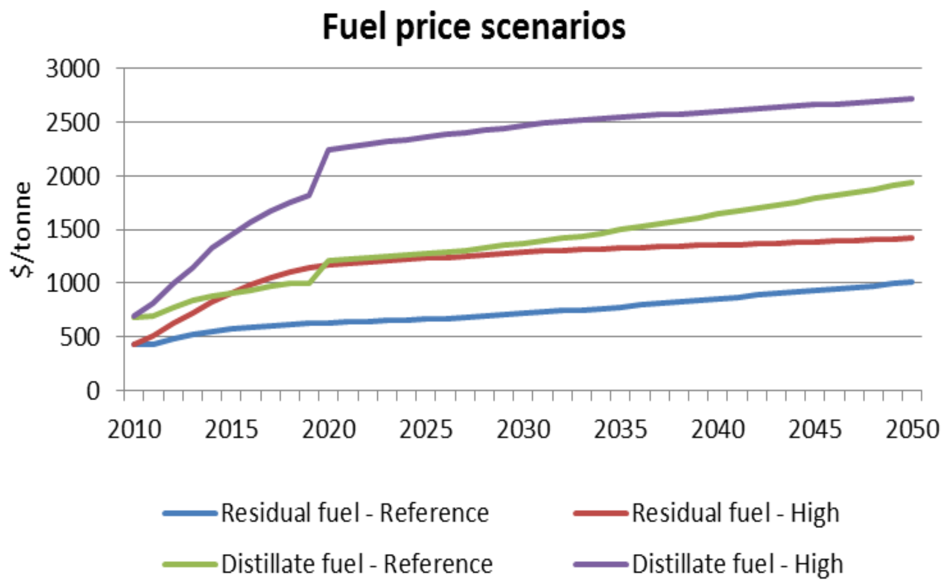

Figure 1 – Fuel price scenarios. The sharp increase in distillate fuel in 2020 is due to the 0.5% global sulphur requirement

4.9 The split between heavy fuel oil (HFO) and marine distillate (MGO) are taken as follows:

- 80% HFO and 20% MGO from 2013 to 2019, and
- 20% HFO and 80% MGO from 2020 and onwards.

Overview of scenarios modelled

4.10 Table 5 shows the combined scenarios modelled in this Study.

Scenario	IPCC growth scenario	EEDI Uptake scenario	SEEMP uptake	Fuel price scenarios	Waiver scenario
A1B-1	A1B	Regulation	Low*	Reference	5%
A1B-2	A1B	Regulation	Low	High	5%
A1B-3	A1B	Regulation	High**	Reference	5%
A1B-4	A1B	Regulation	High	High	5%
B2-1	B2	Regulation	Low	Reference	5%
B2-2	B2	Regulation	Low	High	5%
B2-3	B2	Regulation	High	Reference	5%
B2-4	B2	Regulation	High	High	5%
A1B-3W	A1B	Regulation	High	Reference	30%

* 30% ** 60%

Table 5 – Combined scenarios

Simulation model

4.11 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 [10-12].

4.12 The model calculates emissions as a function of 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 (start of 2010). 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.

4.13 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.

Fleet baseline and development

4.14 The Study uses 6 ship types for which the EEDI is mandatory, listed in paragraph 2.2 of this report. The emission estimates in the Second IMO GHG 2009 study [1] is used as baseline. The IMO GHG study estimates the emission in 2007 and in this study it is assumed that the same level is emitted in 2010 to account for economic downturn experienced since 2008, an approach that was also chosen by the MBM-EG. The same study also gives the transport efficiency in emission per transport work. The emissions per ship type are estimated based on the relative emissions calculated in MEPC 60/WP.5.

4.15 The baseline CO_2 emissions and ship CO_2 efficiency levels are given in Tables 6 and 7 respectively.

Ship type	**CO_2 emission 2010**
Bulk carrier	169.3
Gas tanker	40.8
Tanker	181.3
Container ship	231.6
General cargo ship	91.1
Refrigerated cargo carrier	18.6
Other	132.9
Total	**865.6**

Table 6 – Baseline data for international shipping (numbers in million tonnes CO_2 in 2010)

Ship type	**2005**	**2010**
Bulk carrier	9	9
Gas tanker	13	12
Tanker	13	12
Container ship	30	28
General cargo ship	40	37
Refrigerated cargo carrier	40	37

Table 7 – Baseline data (numbers in grams CO_2 per tonne-nm; MEPC 59/INF.10 Figure 7.3)

Method of inclusion of EEDI reduction factor

4.16 A methodology has been developed to determine the impact of future EEDI regulatory limits on the global fleet of merchant ships. This Study assumes that the impact of a given EEDI limit will depend on the level of spread (expressed by the standard deviation) of EEDI values for the current fleet reference line. Different ship types have different spread: Bulk carriers generally are fairly uniform vessels and the standard deviation of individual ships compared with the regression line is low. For Tankers, Container ships and, in particular, General Cargo ships, the spread is more significant. A detailed description of the methodology is given in Appendix 5.

4.17 The estimated average emission reduction for new ships resulting from the EEDI reduction factor requirements (Table 8), is calculated based on Figure A2 in Appendix 5 and is shown in Table 9.

	Reduction factor (from Table 1)							
	2013	2015	2017	2020	2025	2030	2040	2050
Bulk carrier	0 %	10 %	10 %	20 %	30 %	30 %	40 %	40 %
Gas tanker	0 %	10 %	10 %	20 %	30 %	30 %	40 %	40 %
Tanker	0 %	10 %	10 %	20 %	30 %	30 %	40 %	40 %
Container ship	0 %	10 %	10 %	20 %	30 %	30 %	40 %	40 %
General cargo ship	0 %	10 %	10 %	15 %	30 %	30 %	40 %	40 %
Refrigerated cargo carrier	0 %	10 %	10 %	15 %	30 %	30 %	40 %	40 %

Table 8 – EEDI reduction factors

	Average EEDI reduction rate							
	2013	2015	2017	2020	2025	2030	2040	2050
Bulk carrier	9 %	15 %	15 %	22 %	31 %	31 %	40 %	40 %
Gas tanker	14 %	18 %	18 %	25 %	33 %	33 %	41 %	41 %
Tanker	14 %	18 %	18 %	25 %	33 %	33 %	41 %	41 %
Container ship	14 %	18 %	18 %	25 %	33 %	33 %	41 %	41 %
General cargo ship	20 %	25 %	25 %	25 %	39 %	39 %	45 %	45 %
Refrigerated cargo carrier	14 %	18 %	18 %	18 %	33 %	33 %	41 %	41 %
Other	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %

Table 9 - Average emission reduction of new builds

4.18 For EEDI, it is assumed that there will be a 2-year period between contract date and delivery date. This has been included in the model so that the effect of the EEDI requirements in the different phases is delayed by 2 years compared to the figures in Table 9.

4.19 The effect of waiver of the EEDI is included in the model by reducing the emission reduction from EEDI by 5% (low uptake) and 30% (high uptake) from 2015 to 2019 (this includes the 2 year delay described above).

4.20 The reduction factor is linearly interpolated between the lower cut off limit and a higher limit where the full reduction factor is applied (see footnote of Table 1). Because of the lack of precise data on number and emission levels of ships falling in between these limits, this Study uses the full reduction factor on all ships above the lower cut-off limit as an approximation. This slightly overestimates the emission reduction from these ships, but the overall impact is small and negligible.

Method of inclusion of SEEMP reduction potentials

4.21 The potential of operational and technology upgrade measures to contribute to CO_2 emission reduction over the years to 2050 was assessed using the procedure as explained in Section 3.

4.22 The Study uses the assumption that only cost-effective measures will be implemented as a consequence of a mandatory SEEMP. The SEEMP only works as a catalyst and increases the awareness in the industry of potential measures. The methodology used to calculate cost-effectiveness is given in [12]. Two scenarios on fuel prices give a range of cost-effective measures.

4.23 Uptake of operational measures (change in operational procedures) are impacted by a range of factors including_non-financial barriers for implementation such as split incentives and delivery capacity. However, there is a correlation between high uptake and high fuel prices, as the financial gain will help to overcome the barriers. Thus, the high fuel price/high uptake and reference fuel price/low uptake are the two most likely scenarios.

4.24 A number of individual operational and retrofit measures were included in the model with cost and reduction potential (Appendix 3). In addition, a generic EEDI reduction measure was added to represent the general increase in energy efficiency by reduced EEDI on new builds. This approach ensures that the effect of combining measures is taken into account. The design improvements implemented to lower the EEDI to the required level will make the absolute reduction from an operational measure lower compared to a previous design – even if the relative reduction is the same. For a detailed description of the methodology see [7] and [12].

4.25 Table 3.1 in Appendix 3 shows the potential emission reduction relative to the baseline (i.e. without taking into account any reduction by the EEDI). These numbers are used in the model and Table 3.2 in Appendix 3 shows the results, with SEEMP emission reduction per ship type and scenario relative to the emission level after deducting the emission reduction caused by the EEDI, and taking into account the uptake of SEEMP.

Method of calculation of fuel cost

4.26 The model projects the annual fuel consumption and CO_2 emissions of the world fleet as described above. The fuel price scenarios contain the cost of fuel per year from 2010 to 2050 (see Figure 1). The annual fuel cost and savings are calculated by multiplying the fuel price with the annual fuel consumption and estimated savings.

5 RESULTS

Emission reduction to 2050

5.1 Results are presented throughout for two future IPCC growth scenario A1B and scenario B2. The results on EEDI relate to EEDI reference lines, reduction factors and cut off levels from IMO Regulations on Energy Efficiency of Ships [2]. All the reported results herein relates to a waiver uptake of 5%, unless otherwise stated. Additionally, scenarios for fuel prices, SEEMP uptake and waiver uptake have been included as shown in Table 5.

5.2 Figures 2a and 2b show the CO_2 reduction potential relative to Business As Usual (BAU) for various scenarios. Combination A1B-4 provides the highest annual reduction potential (1,320 million tonnes CO_2 in 2050) while combination B2-1 provides the lowest reduction potential (706 million tonnes CO_2 in 2050).

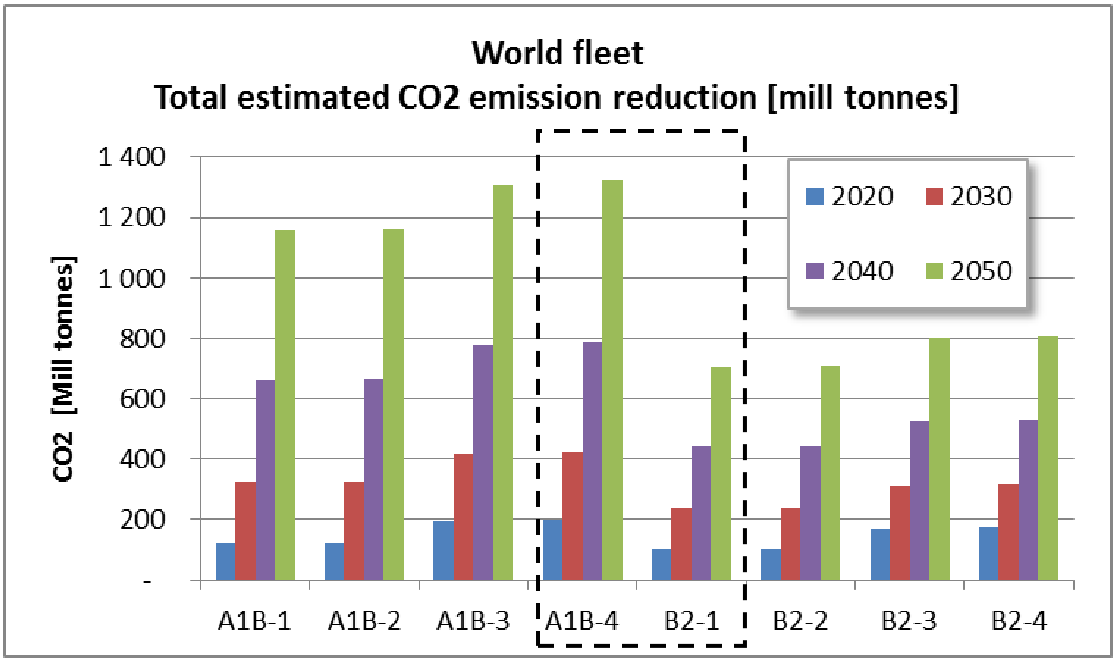

Figure 2a – Overall annual CO_2 reduction with alternative scenarios (waiver 5%)

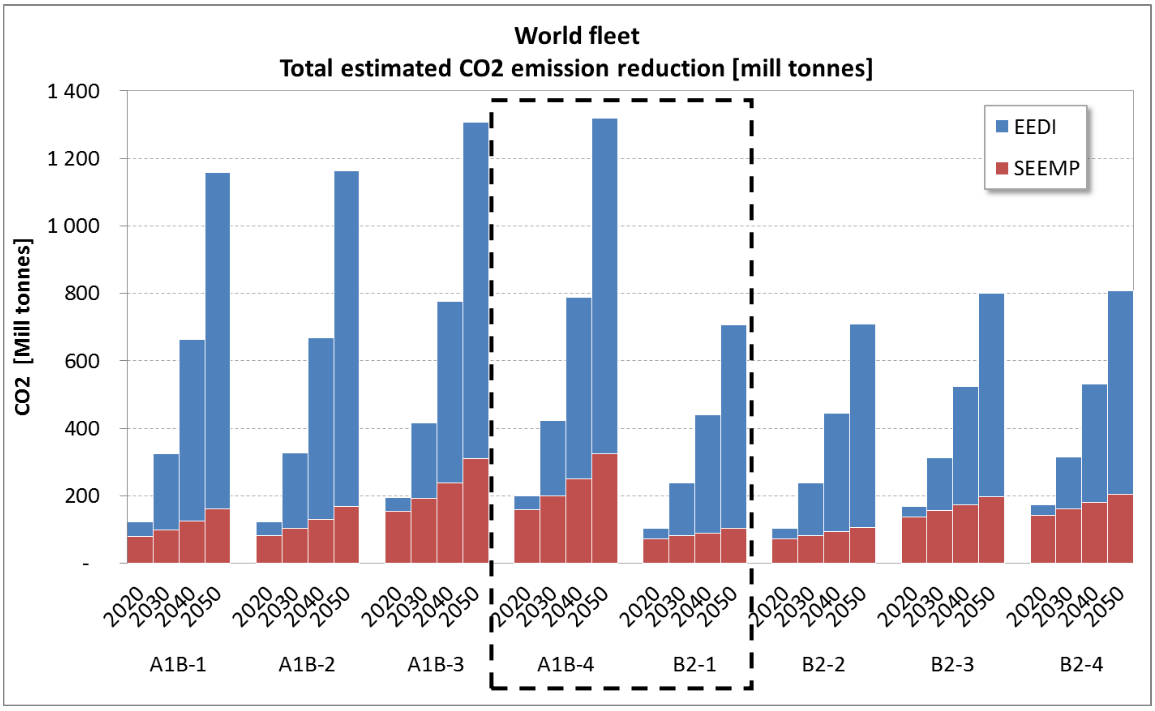

Figure 2b – Overall annual CO_2 reduction for SEEMP and EEDI (waiver 5%)

5.3 In terms of CO_2 emissions reduction rates, scenario A1B-4 shows the fastest reduction with time (from 22 million tonnes per year in 2013 to 1320 million tonne per year in 2050) while scenario B2-1 shows slowest reduction with time (from 21 million tonnes per year in 2013 to 706 million tonne per year in 2050). It should be noted that the above numbers are the CO_2 reduction estimates and not the absolute level of CO_2 emissions produced.

5.4 For EEDI, an annual reduction of about 1000 million tonnes of CO_2 for A1B scenario and 600 million tonnes of CO_2 for B2 scenario is foreseen in 2050. For SEEMP, an annual reduction of about 325 million tonnes of CO_2 for A1B-4 scenario and 103 million tonnes of CO_2 for B2-1 scenario is foreseen in 2050.

5.5 Appendix 6 shows the corresponding numerical data in tabulated format; a summary of which is shown in Table 10, providing overall (combined EEDI and SEEMP) annual CO_2 emission reductions for the world fleet for all the scenarios modelled.

World fleet Total estimated CO2 emission reduction [million tonnes/year]									
Year	**A1B-1**	**A1B-2**	**A1B-3**	**A1B-4**	**B2-1**	**B2-2**	**B2-3**	**B2-4**	**A1B-3W**
2010	-	-	-	-	-	-	-	-	-
2013	22	22	42	43	21	22	41	42	42
2020	122	123	196	200	103	104	169	173	189
2030	324	327	416	423	237	238	312	316	409
2040	662	667	776	788	441	444	523	531	-
2050	1 158	1 164	1 306	1 320	706	709	800	808	1 306

Table 10 - Estimated CO_2 emission reductions for world fleet

5.6 Figures 3a and 3b show the effect of EEDI and SEEMP measures for scenarios A1B-4 and B2-1 respectively. Results indicate that SEEMP measures (mainly operational) produce the most significant effect in the short to medium term while EEDI measures (new ships) produce more impact on the long term (e.g. 2030) as fleet renewal takes place and new technologies are adopted.

5.7 As indicated in Figures 3a and 3b (and also Figures 4a and 4b), none of the scenarios will achieve a reduction in absolute total CO_2 level from shipping relative to year 2010 (compare values for “new emissions level”).

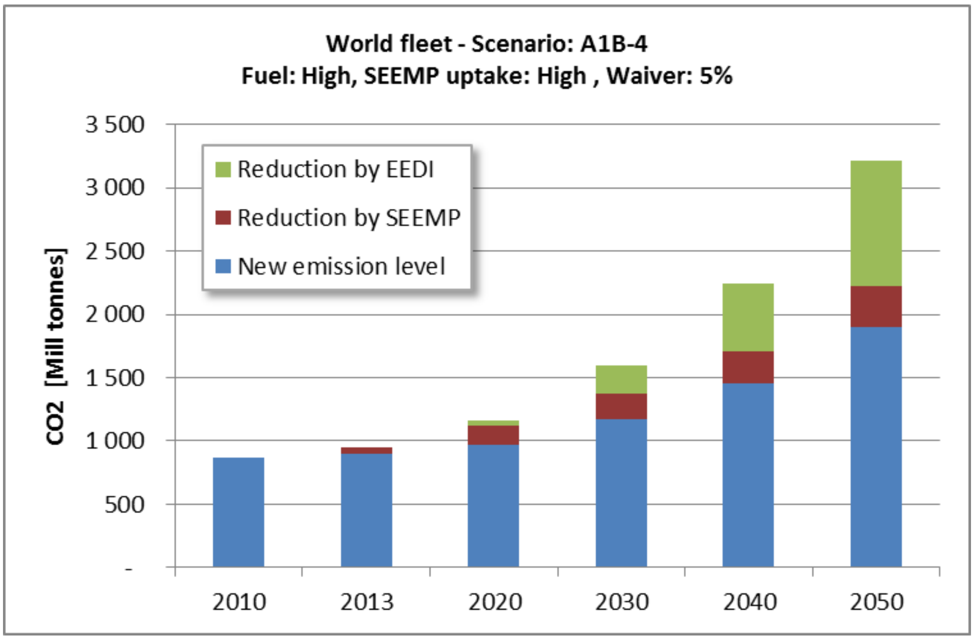

Figure 3a – Annual emission reduction by 2050 and new emissions levels (scenario A1B-4)

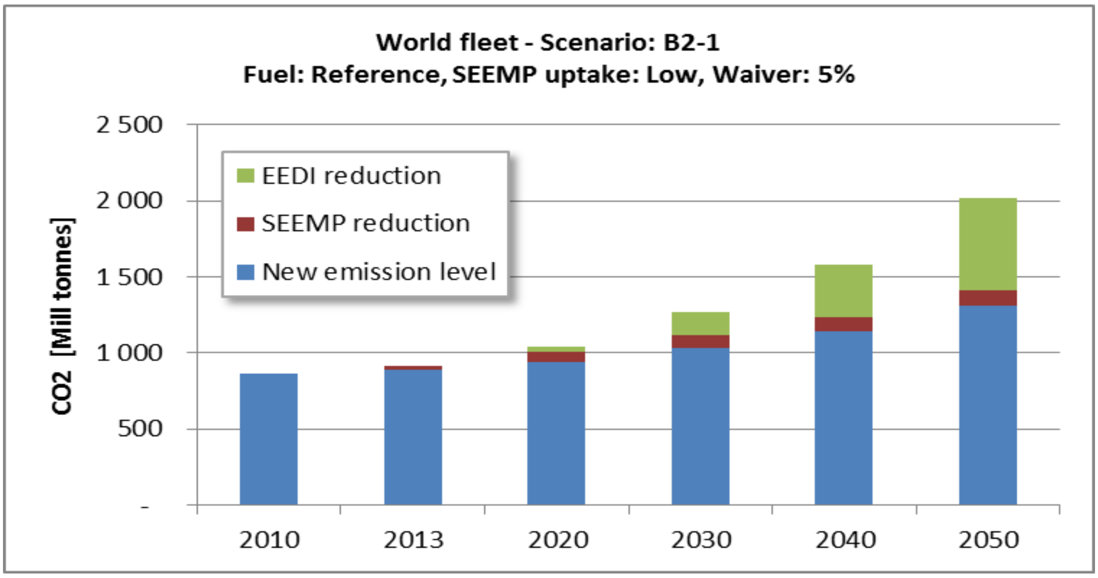

Figure 3b – Annual emission reduction by 2050 and new emissions levels (scenario B2-1)

Emission projections to 2050

5.8 Figures 4a and 4b demonstrate the reduction potential of EEDI and SEEMP for scenarios A1B-4 and B2-1 respectively. The upper side of the upper curve shows the BAU (Business as Usual). The underside of the lower curve on each figure represents the forecast overall annual CO_2 emission figures (new emission level). The difference between the two curves shows the overall reduction due to the combined EEDI and SEEMP.

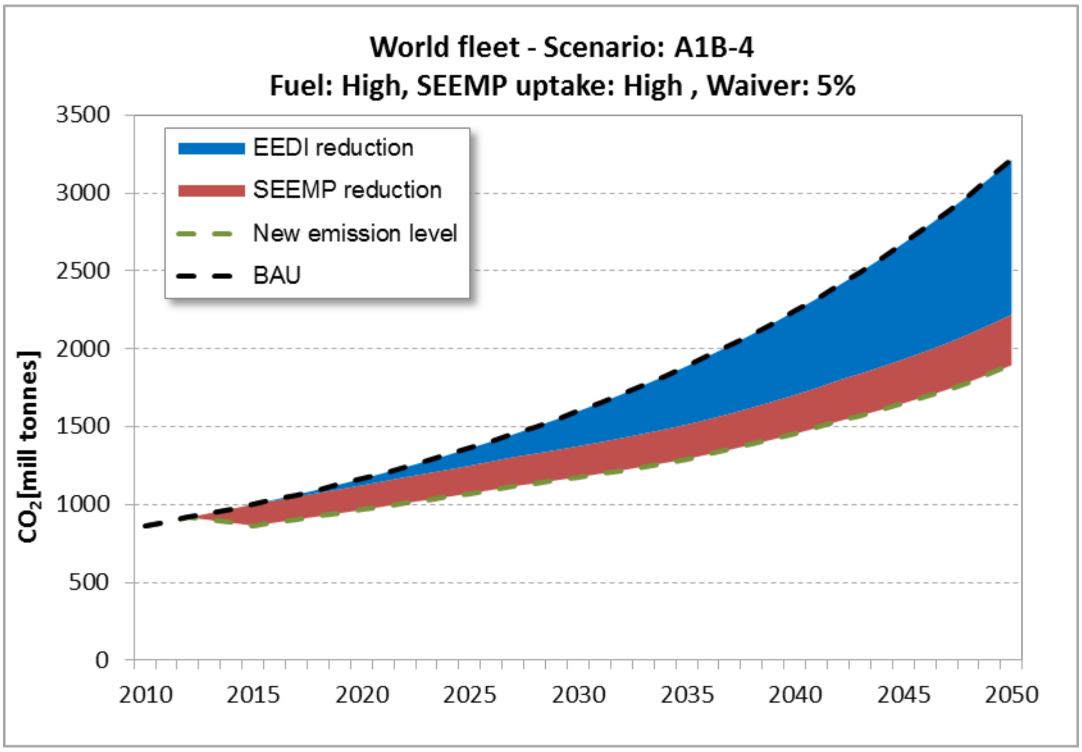

Figure 4a – World fleet CO_2 level projections (A1B-4 scenario)

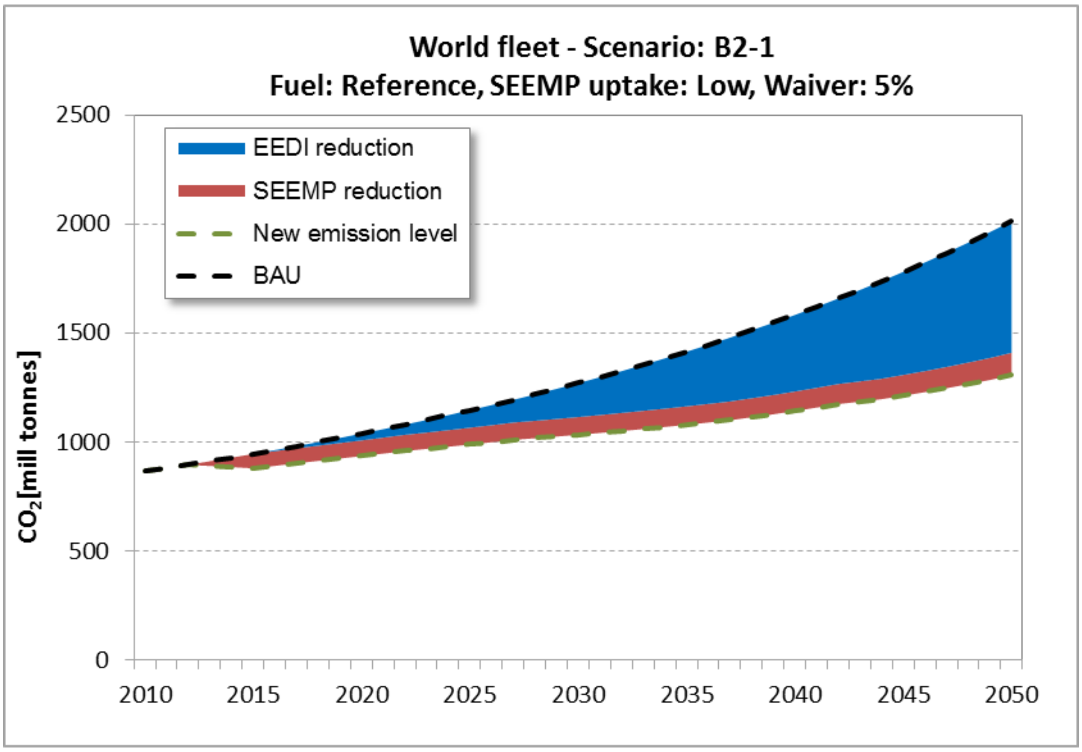

Figure 4b – World fleet CO_2 level projections (B2-1 scenario)

5.9 As indicated in Figures 4a and 4b, the world marine CO_2 will still show an increasing trend towards 2050; but the growth level will be significantly curtailed by uptake of EEDI and SEEMP.

5.10 Corresponding values for the different scenarios indicates the international shipping's total annual CO_2 emissions in 2050 of around 3200 million tonnes for BAU and new emissions level of 1900 million tonnes (1300 million tonne reduced) for the scenario A1B-4 (high growth combined with high SEEMP uptake and high fuel price) and a total annual CO_2 emissions in 2050 of around 2000 million tonnes for BAU and new emissions level of 1300 million tonnes (700 million tonne reduced) for the scenario B2-1 (low growth combined with lowest SEEMP uptake and reference fuel price).

5.11 While Figures 4a and 4b represent results for two extreme scenarios of A1B-4 and B2-1, Appendix 7 provides the projections for other scenarios modelled.

Emission reduction by ship category

5.12 Figures 5a and 5b shows the CO_2 emissions reduction estimates for scenario A1B-4 for various ship types. The most striking observation is the predicted growth in CO_2 emissions reduction potential for Container ships. This is primarily due to the assumed high growth rate for this segment. Next to Container ships are emissions reduction potentials for Bulk Carriers and Tankers.

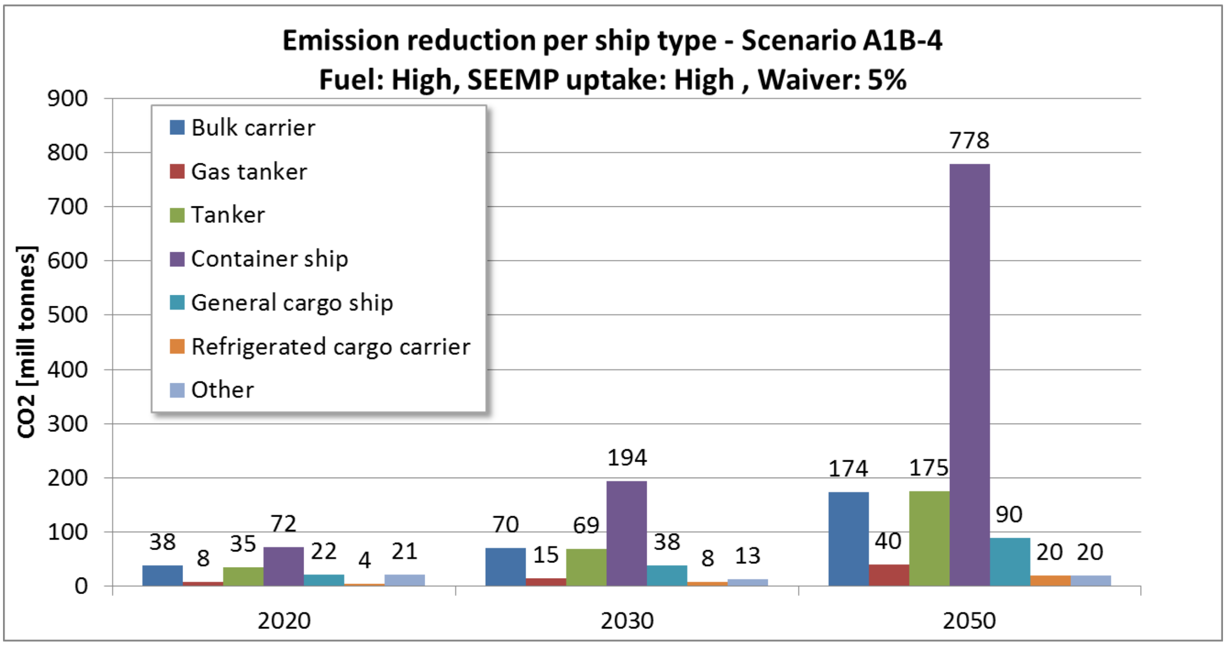

Figure 5a – Estimated CO_2 emission reduction by ship category for scenario A1B-4

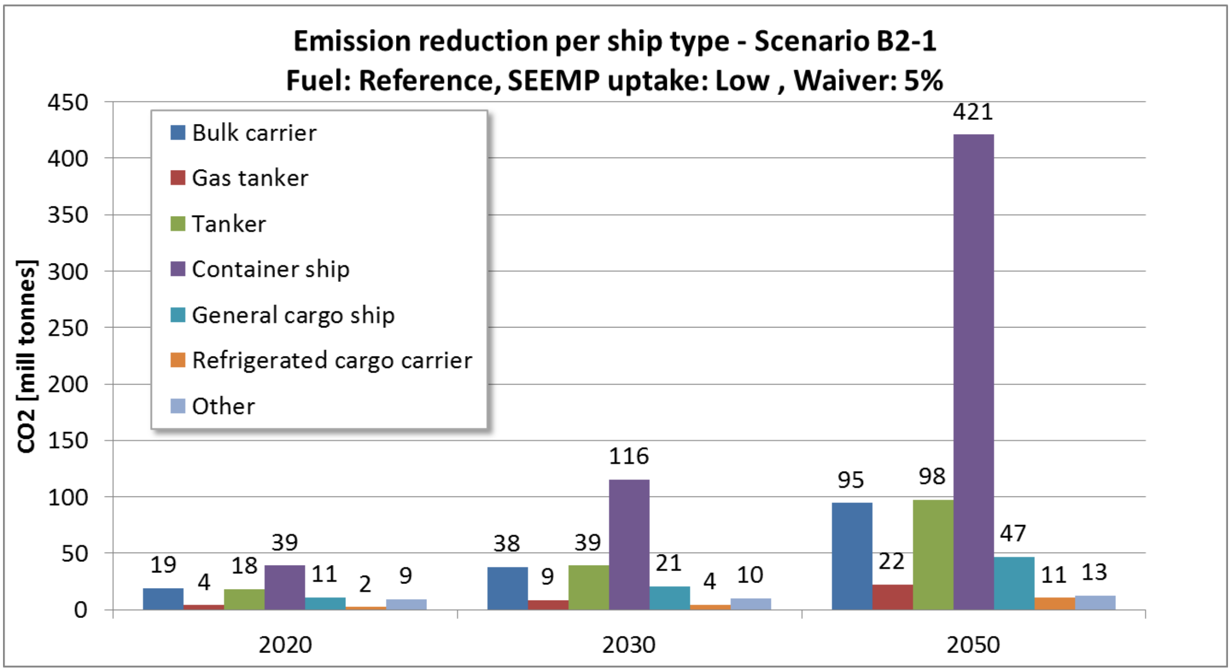

Figure 5b – Estimated CO_2 emission reduction by ship category for scenario B2-1

Transport efficiency

5.13 Transport efficiency (CO_2 emission per transport work) was calculated using the baseline levels predicted for 2005 in the Second IMO GHG Study 2009 (Figure 7.3 [1]) and the emission reduction due to the required EEDI and SEEMP uptake as estimated within this Study. The Second IMO Study 2009 [1] did not use the same ship types as in the EEDI guidelines and transport efficiency was not given specifically for Refrigerated cargo carriers and Gas tankers. These ship types were in this Study given the same efficiency as General cargo ships and Tankers, respectively.

5.14 Figures 6a and 6b show the transport efficiency for world fleet for scenario A1B-4 and B2-1 respectively (Appendix 8 present transport efficiency for all the scenarios modelled). When calculating efficiency improvement the fleet growth is not relevant and the same efficiency improvement would be achieved i.e. in both A1B-1 and B2-1.

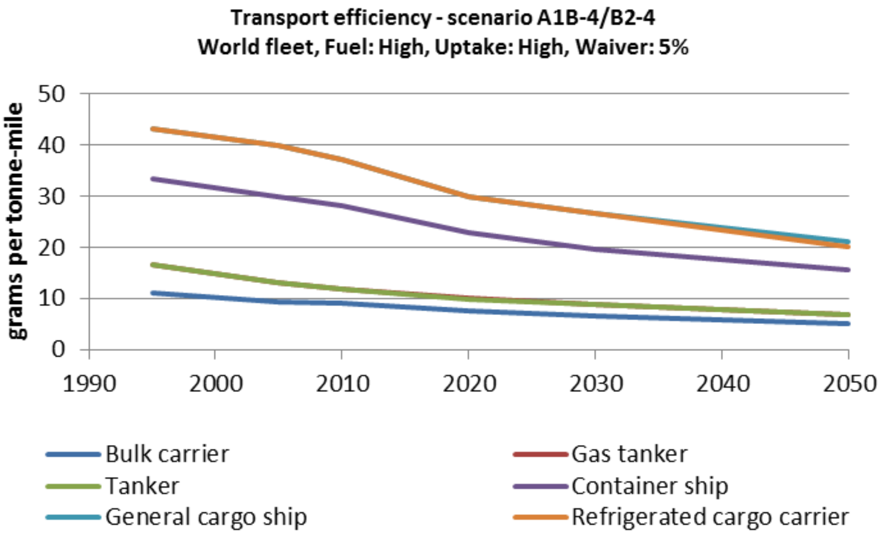

Figure 6a – World fleet CO_2 transport efficiency trends (scenario A1B-4/B2-4)

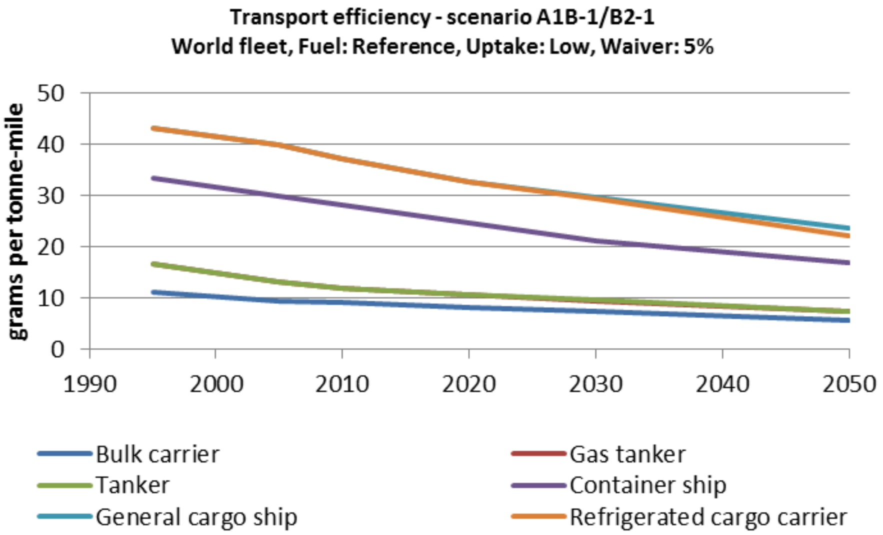

Figure 6b – World fleet CO_2 transport efficiency trends (scenario A1B-1/B2-1)

5.15 The transport efficiency will improve with the same rate as the emission reduction. In addition to Figures 6a and 6b, Table 11 provides the numeric transport efficiency development for the different ship types under scenario B2-4 / A1B-4. As indicated, various vessels' transport energy efficiency nearly doubles and the emissions per cargo unit nearly halves from 2005 to 2050.

Year	Bulk carrier	Gas tanker	Tanker	Container ship	General cargo ship	Refrigerated cargo carrier
2005	9	13	13	30	40	40
2010	9	12	12	28	37	37
2020	8	10	10	23	30	30
2030	7	9	9	20	27	27
2050	5	7	7	16	21	20

Table 11 - Transport efficiency (g CO_2/tonne mile) improvement associated with the different ship types using scenario B2-4/A1B-4

Impact of waiver

5.16 As indicated in Table 5, two waiver scenarios were modelled. Figure 7 shows the impact of waiver on CO_2 reductions due to EEDI. As Figure 7 shows, the impact of waiver is estimated to be low on total CO_2 emissions reduction potential due to EEDI. A change of waiver level from 5% to 30% will result in a decrease in CO_2 reduction levels by 7 million tonnes of CO_2 per year in 2030 (overall reduction due to EEDI is 224 million tonnes for this scenario in 2030). In 2050 the fleet renewal will have removed all ships affected by the waiver and the same reduction level will have been achieved.

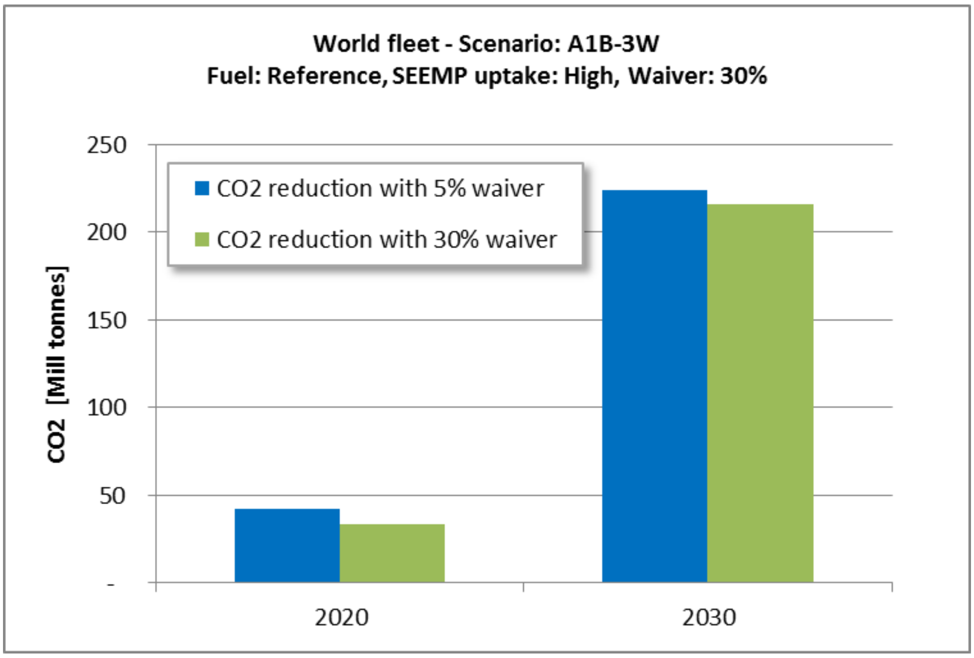

Figure 7 – The impact of waiver on EEDI-related CO_2 reduction under scenario A1B-3.

5.17 Analyses show that the cost of compliance to phases 0 and 1 will be marginal and Flag States and shipowners will have no financial justification for opting for waivers. An EEDI non-compliant ship may be regarded by charterers as in-efficient and thereby suffer in commercial terms and is also likely to have lower second hand value, and may loose on future EEDI-based incentives and where EEDI is used for chartering, port discounts, flag registration discounts, etc. This makes the waiver option unattractive for the majority of ships and shipowners. Based on the above analysis, issuing of EEDI waivers may not only bring no tangible capital cost benefits to owners but it may incur significant commercial risk.

5.18 Based on the analysis provided in this Appendix, it is concluded that the likelihood of Flag States or ship owners to opt for EEDI waiver is low. Accordingly, the level of waiver taken in this study as 5% (low) and 30% (high) is regarded as reasonable. It is most likely that waiver will be at the level of 5% as current indications imply.

Impact of fuel price

5.19 The impact of fuel prices on CO_2 reduction takes place via higher uptake of SEEMP measures. As demonstrated in Figure 8 the differences between the fuel price scenarios are negligible if SEEMP uptake is assumed constant (not changing with fuel price). Most operational measures are relatively cheap and even in the reference fuel price scenario, most measures are cost effective. Therefore in the high fuel price scenarios very few additional measures will be implemented. However, in the long run we may expect new solutions, technologies and measures to be developed as a consequence of higher fuel prices, and thus increase the level of reduction even further. This effect has not been taken into account in this study.

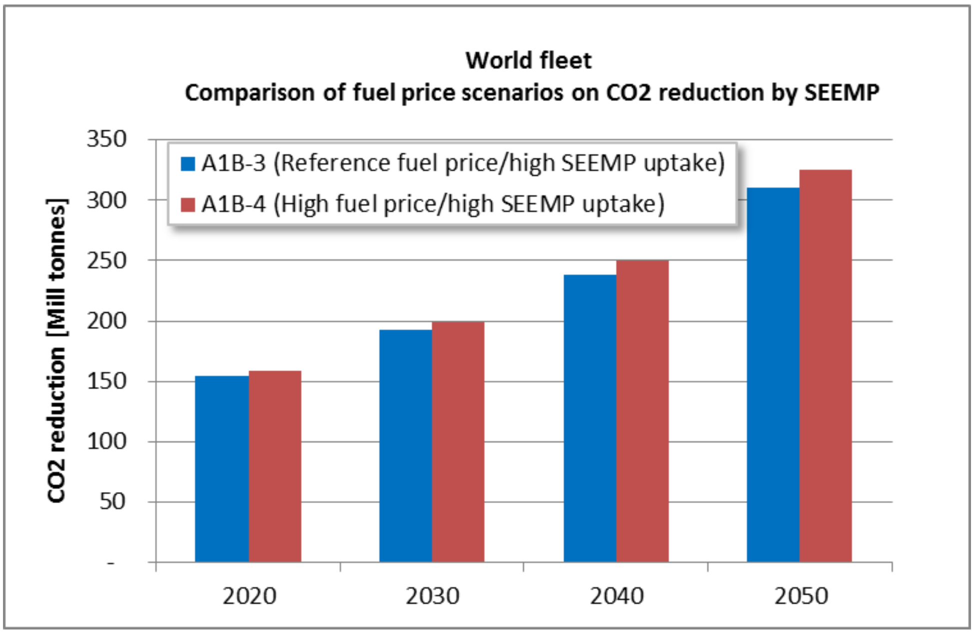

Figure 8 – The impact of fuel price (fixed SEEMP uptake) on CO_2 reduction

5.20 Indications are that in the absence of any regulatory pressure, the uptake of SEEMP will be mainly driven by fuel and carbon prices. Therefore, it is reasonable to assume that a low fuel price will correlate with a low SEEMP uptake (30% in this Study) and a high fuel price will correlate with a high SEEMP uptake (60% in this study). For such a case, the actual impact of fuel price is likely to be as shown in Figure 9.

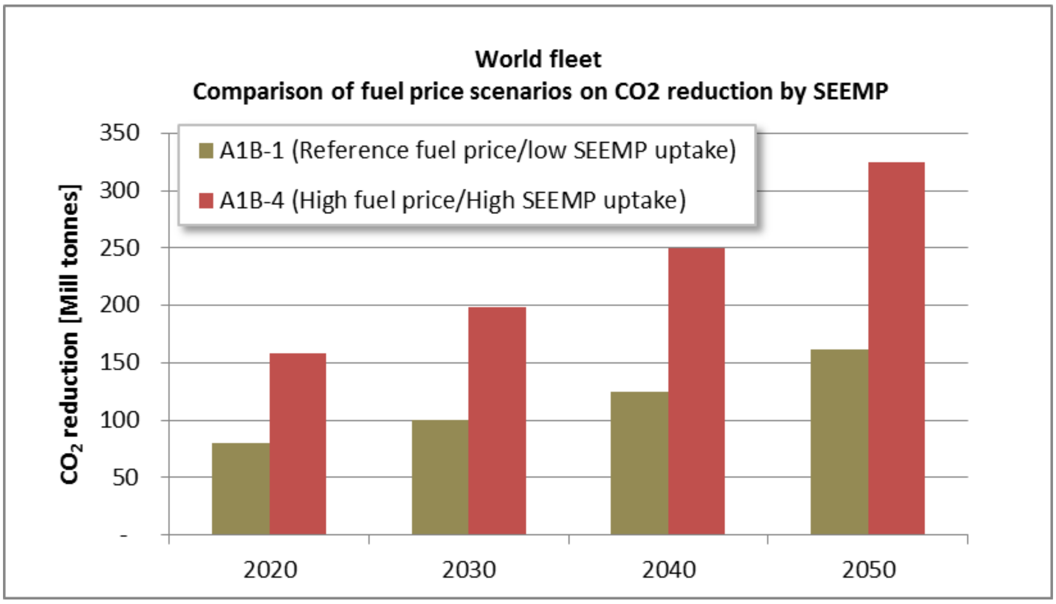

Figure 9 – The impact of fuel price on CO_2 reduction using two SEEMP uptake ratios

Fuel consumption and fuel cost projections to 2050

5.21 Using the figures for fuel consumption and CO_2 emissions plus fuel price scenarios, it is possible to calculate the saving in fuel used and associated costs for various scenarios. This has been carried out in this Study to demonstrate the financial benefits of the IMO mandated Energy Efficiency Regulations.

5.22 The world fleet fuel consumption is directly linked to the CO_2 emissions which is shown in Figures 4a and 4b; therefore similar trends apply to fuel consumption projections.

5.23 Figures 10a and 10b show the world fleet fuel cost for scenarios A1B-4 and B2-1 respectively. The fuel cost is estimated using fuel consumption and fuel price scenarios. The jump in fuel cost in 2020 is due to the chosen fuel price scenario resulting from change in tighter sulphur regulations under MARPOL Annex VI regulation 14.

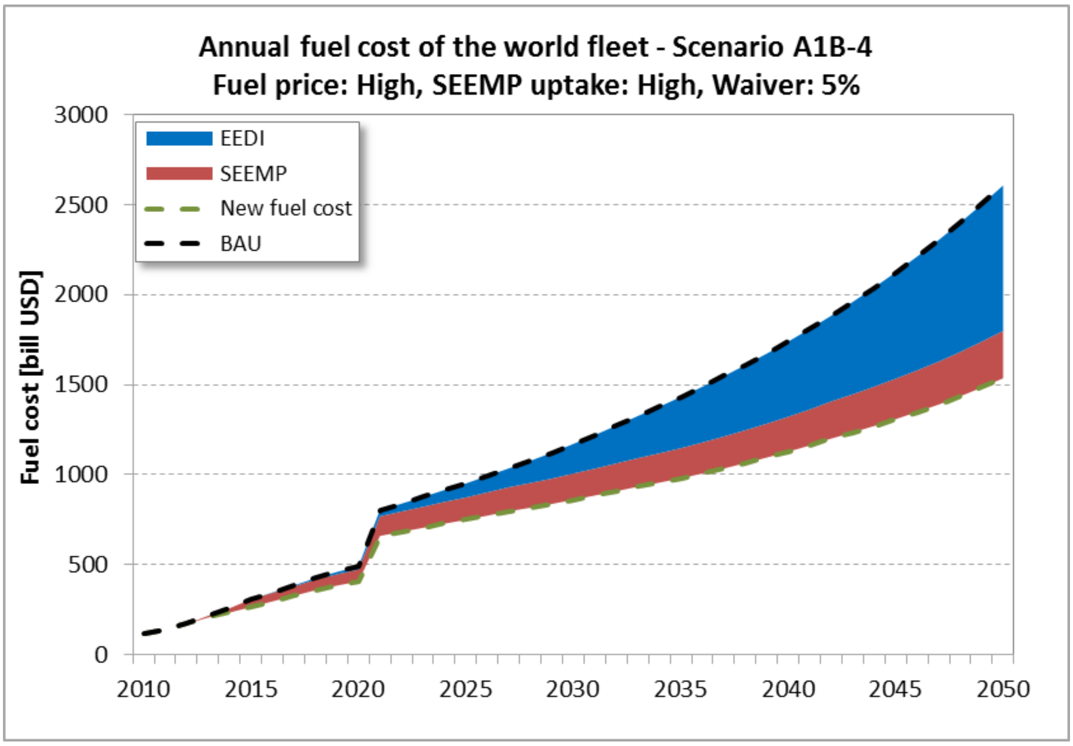

Figure 10a – World fleet fuel cost projections (A1B-4 scenario)

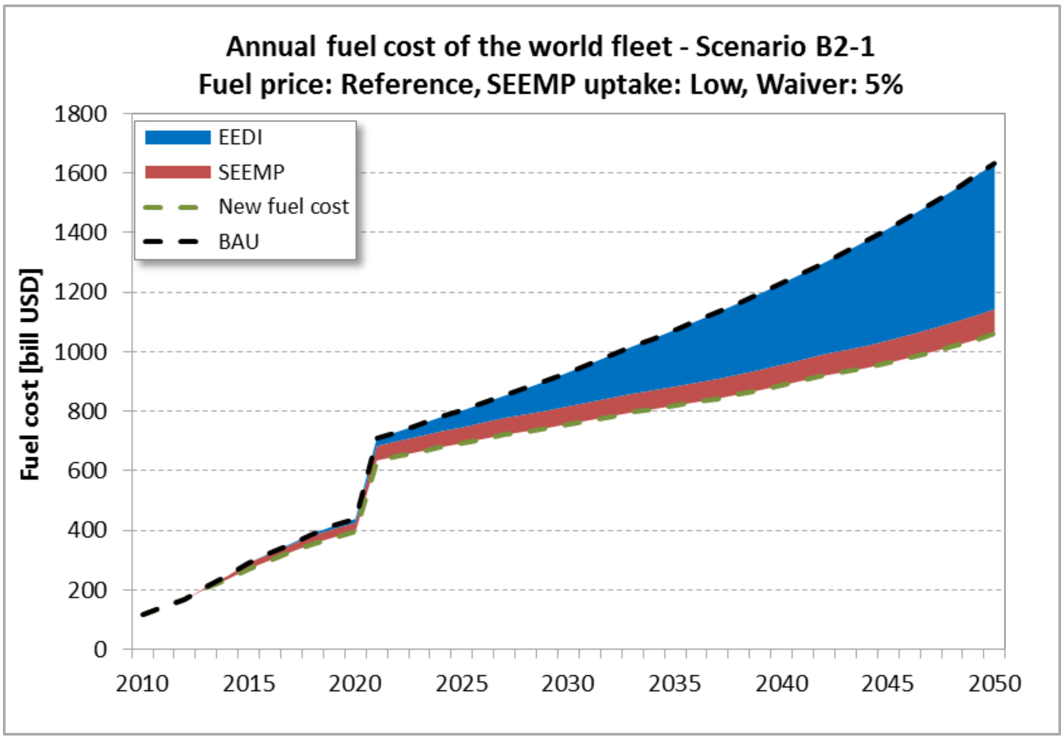

Figure 10b – World fleet fuel cost projections (B2-1 scenario)

5.24 As indicated in Figures 10a and 10b, the world shipping fuel cost will be impacted significantly by EEDI and SEEMP. Corresponding numeric values of total annual fuel consumption and cost of the world's fleet in 2050 for alternative scenarios are given in Tables 12a and 12b.

	A1B-4			B2-1		
Year	2020	2030	2050	2020	2030	2050

BAU consumption level	390	530	1060	340	420	670
Reduction level	70	140	430	30	80	230
New consumption level	320	390	630	310	340	440

Table 12a – Annual fuel consumption (in million tonnes) for world fleet

	A1B-4			B2-1		
Year	2020	2030	2050	2020	2030	2050
BAU cost level	490	1170	2600	240	510	1150
Reduction level	80	310	1070	20	90	400
New fuel cost level	410	860	1530	220	420	750

Table 12b – Annual fuel cost for world fleet in billion USD

5.25 As indicated in Table 12b, a forecast fuel cost reduction of 80, 310 and 1070 billion USD/year for scenario A1B-4 are estimated for years 2020, 2030 and 2050 respectively. Corresponding fuel cost reduction of world's fleet for scenario B2-1 are 20, 90 and 400 billion USD/year for 2020, 2030 and 2050 respectively

Fuel consumption and fuel cost projections to 2050 for typical ship types

5.26 Figures 11a and 11b shows the fuel consumption projection for a VLCC and a typical Panamax container ship respectively. The numbers corresponds to the fuel consumption of a newly built vessel for each current year. The baseline fuel consumption per year is assumed to be 23,000 tonnes for the VLCC and 27,000 tonnes for the container vessel in 2010.

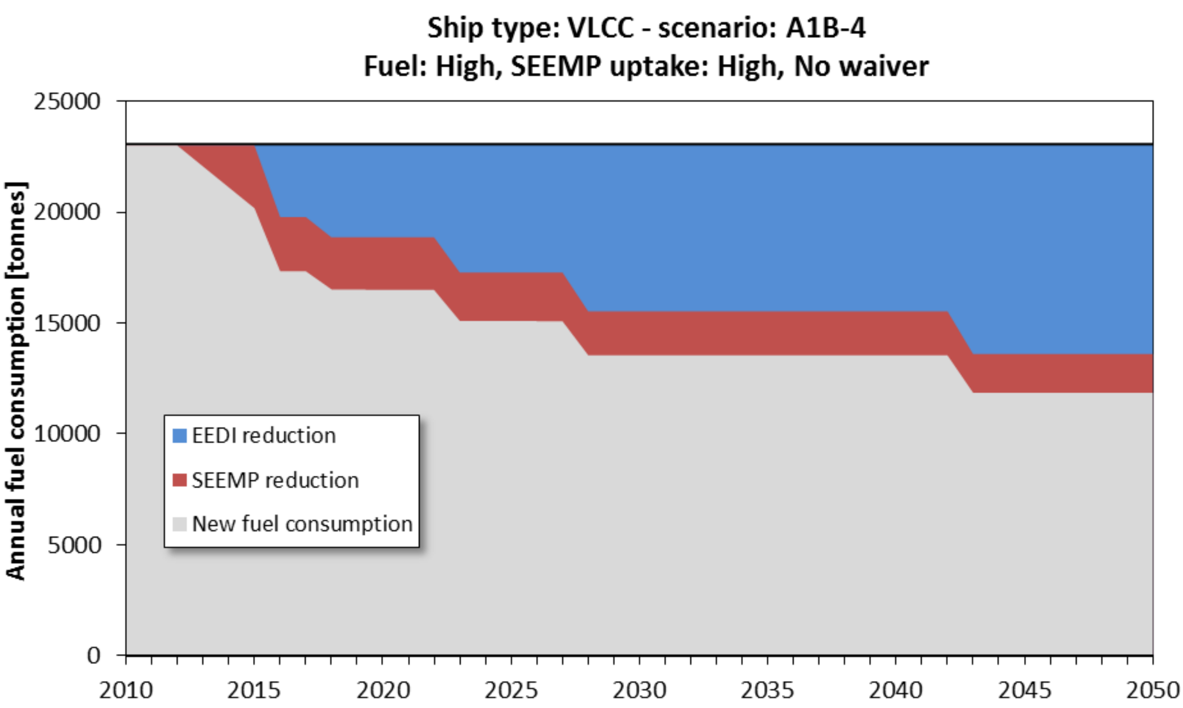

Figure 11a – Annual fuel consumption for a new built VLCC

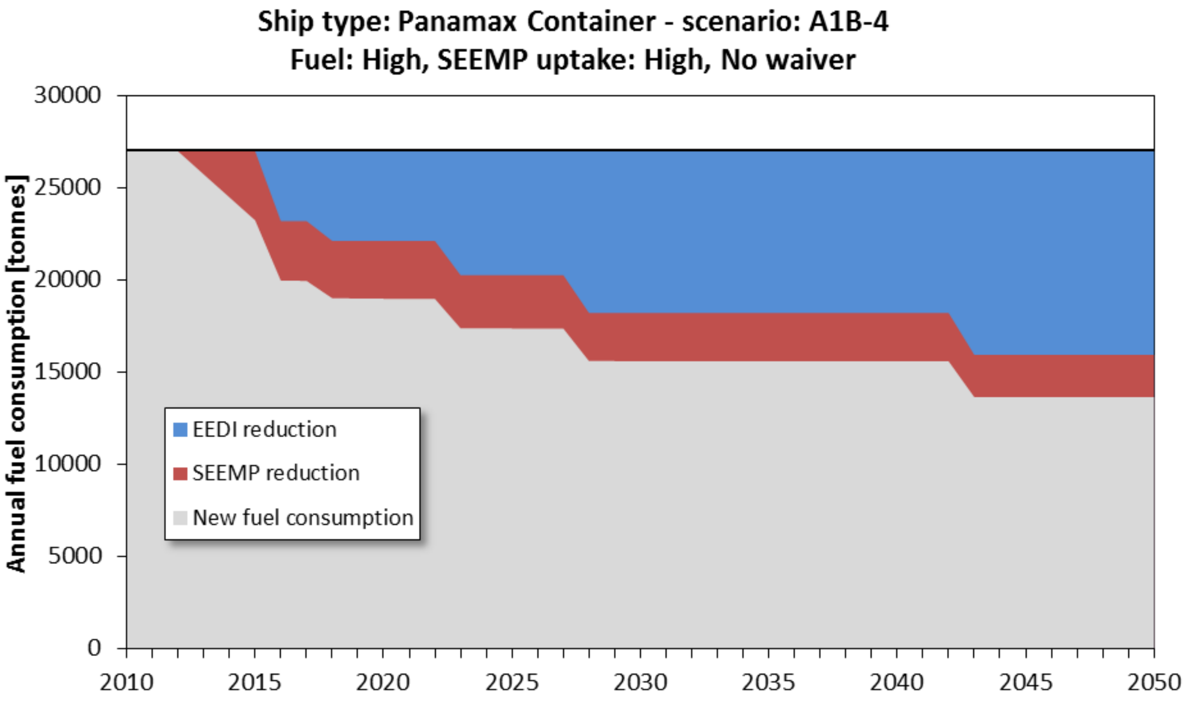

Figure 11b – Annual fuel consumption for a new built Panamax Container vessel

5.27 Figures 11a and 11b shows that the annual fuel consumption for each generation of newly build vessel will decrease as a result of EEDI and SEEMP. The sharp decline in fuel consumption seen at a number of years is due to the EEDI impact and the reduction in the Required EEDI of the vessel.

5.28 Figures 12a and 12b shows the annual fuel cost projection for the same VLCC and container ship respectively. The increasing fuel costs which would reach US$56 million/year for the VLCC and US$66 million/year for the container vessel in 2050 are estimated to decrease via EEDI and SEEMP by US$27 million and US$33 million respectively.

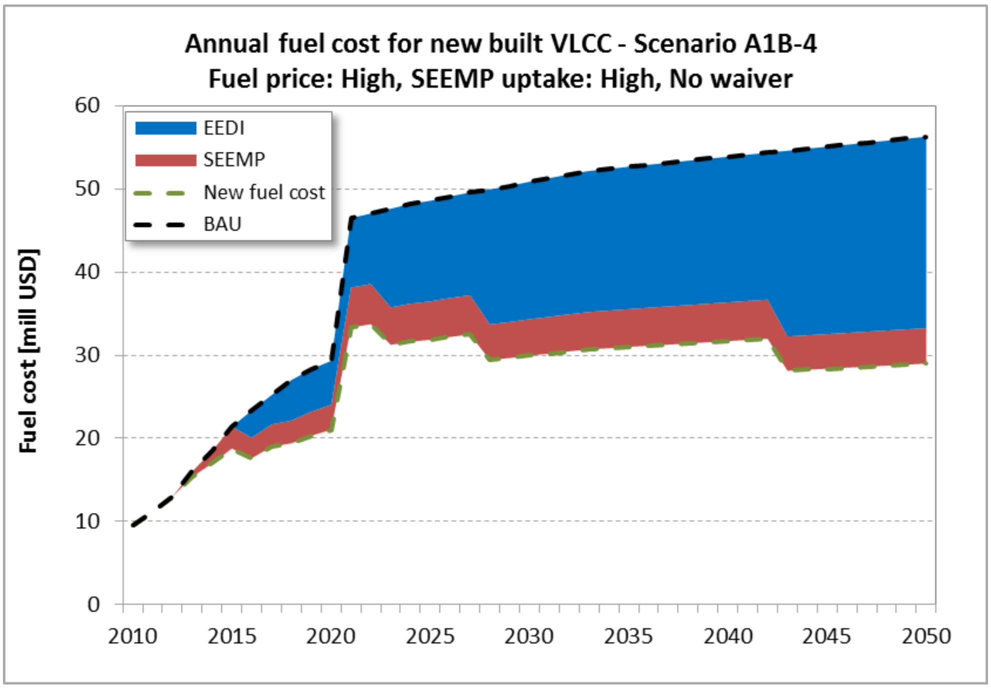

Figure 12a – Annual fuel cost for a new built VLCC

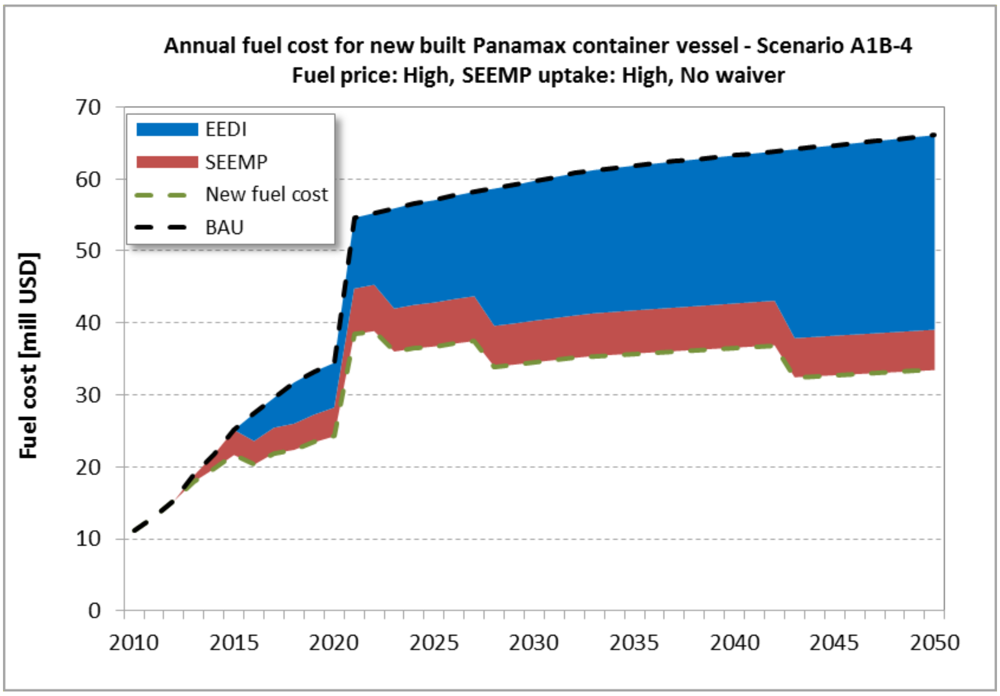

Figure 12b – Annual fuel consumption for a new built Panamax Container vessel

Cost of compliance to EEDI

5.29 For an average ship (e.g. an average VLCC with an average speed and average EEDI as analysed in Appendix 2), the cost of complying to the EEDI requirements in phase 0 and phase 1 is expected to be low and is more than compensated by the reduced fuel consumption. Existing investigations show that ship hydrodynamic and main engine optimisation will bring about energy saving opportunities of up to about 10% with no significant additional cost of shipbuilding. In addition, main and auxiliary engines are already available with reduced specific fuel consumption of about 10% below the values used in the reference line calculations.

5.30 The above two combined effects is indicative that cost of compliance, for an “average ship”, to phases 0 and 1 will not be significant. However, ships that for some commercial reasons, that may have design speeds well over the average design speed, may need to face either higher technology cost or lower design speed. On the other hand, there are ships already below the current reference lines, for which compliance may extend to phase 2 al low-cost through normal hull and design optimisations.

6 CONCLUDING REMARKS

6.1 Significant reduction of CO_2 emissions from ships due to EEDI and SEEMP regulations is foreseen to 2050 with emission reduction due to SEEMP (primarily operational measures) likely to be realised more rapidly in the short to medium term than that for EEDI (primarily technical measures), as the effect of EEDI will occur as and when older and less efficient tonnage is replaced by new more efficient tonnage.

6.2 Mandatory application of EEDI will 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. Calculations made within this Study suggest that the existing limits to the EEDI can be realised in phases 0 and 1 primarily via technological developments and in phases 2 and 3 with some design speed reduction.

6.3 Forecasts with different scenarios indicate total annual CO_2 emissions in 2050 of 3215 million tonnes for BAU and new emissions level of 1895 million tonnes (1320 million tonnes reduced) for scenario A1B-4 (high growth combined with high SEEMP uptake and high fuel price) and a total annual CO_2 emissions in 2050 of around 2014 million tonnes for BAU and new emissions level of 1344 million tonnes (706 million tonnes reduced) for scenario B2-1 (low growth combined with low SEEMP uptake and reference fuel price).

6.4 For EEDI, an annual reduction of about 1000 million tonnes of CO_2 for scenario A1B and 600 million tonnes of CO_2 for scenario B2 is foreseen in 2050. For SEEMP, an annual reduction of 325 million tonnes of CO_2 for scenario A1B-4 and 103 million tonnes of CO_2 for scenario B2-1 is foreseen by 2050.

6.5 The impact of the waiver clause in Regulation 19.5 is estimated to be low on total emissions reduction due to EEDI. A change of waiver level from 5% to 30% will result in a decrease in CO_2 reduction levels by 7 million tonnes per year in 2030 (overall reduction is 416 million tonnes for this scenario).

6.6 Implementation of SEEMP-related energy efficiency measures is generally cost effective; however, it is likely that adoption of these measures will need to be stimulated. Follow-on monitoring and audits, and high carbon and fuel prices are expected to play a role in driving uptake of SEEMP efficiency measures. Although it is not anticipated to have a target-based regulatory framework for SEEMP in the foreseeable future; putting in place an effective audit/monitoring, building awareness and resolving split incentive issues for operational energy efficiency measures will facilitate enhanced uptake of SEEMP in the world fleet.

6.7 To make the application of SEEMP more effective and to prepare the shipping industry for likely future carbon pricing via MBMs, it seems that use of EEOI (Energy Efficiency Operational Indicator) or a similar performance indicator should be encouraged or mandated. This will involve more accurate and verifiable measurement of fuel consumption that could pave the way for CO_2 foot printing and data verification in the future.

6.8 The estimated reductions in CO_2 emissions, for combined EEDI and SEEMP, from the world fleet translate into a significant average annual fuel cost saving of about US$50 billion in 2020 and about US$200 billion by 2030; using fuel price increase scenarios that take into account the switch to low sulphur fuel in 2020.

6.9 As a consequence of current developments in ship design and new technologies coming onto market, the cost of EEDI compliance in phase 1 seems to be marginal as the 10% reduction requirement may be achieved by low-cost hull form design and main engine optimisations. Cost of compliance for phase 2 and phase 3 may be higher and will involve some design-speed reduction for an average ship. However, the overall fuel economy of the new ships will be positive as indicated by the high savings in fuel costs

6.10 Despite the significant CO_2 emission reduction potential resulting from EEDI and SEEMP regulations, an absolute reduction in total CO_2 emissions for shipping from the 2010 level appears not to be feasible using these two measures alone. For all scenarios, the projected growth in world trade outweighs the achieved emission reduction using EEDI and SEEMP, giving an upward trend, albeit at a very much reduced rate compared to BAU.

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Appendix 1

Analysis of Waiver Uptake

A1-1 Introduction

1 Within the resolution 203(62) [2], regulation 19.5 gives flag States the option to issue a waiver for the EEDI, effectively meaning that ships under the flags which choose this option will be exempt of complying with EEDI until 1st January 2017 (based on contract date) or 1st July 2019 (based on delivery date). The waiver is widely attributed to the close association between IMO GHG reduction talks and the ongoing political discussion at the UN Framework Convention on Climate Change.

2 The purpose of this analysis is to make an assessment of the impact of waiver clause on uptake of EEDI for new ships. To achieve this, the following was carried out:

- Review of positions taken by flag States on waiver.
- Review of positions taken by the shipping industry on waiver.
- Evaluation of cost of compliance to EEDI (additional capital expenditure).
- Evaluation of cost of non-compliance to EEDI (ship's second hand value, chartering impact, fuel use impact, etc.)

Based on the above, concluding remarks on the level of uptake of waiver is given.

A1-2 Flag States position

3 At the time of publication of this report, there has been no definite decision by any Flag State to opt for waiver option.

A1-3 Shipping industry position

International Chamber of Shipping (ICS)

4 The Board of Directors of the International Chamber of Shipping (ICS), whose member national ship-owners' associations represent all sectors and trades and over 80% of the world merchant fleet, in their meeting on 13 September 2011 expressed the following on EEDI waiver.

- "With respect to the adoption of the IMO Energy Efficiency Design Index (EEDI), the ICS Board considered the theoretical right of flag States to issue waivers to ship-owners taking delivery of new ships, which had been agreed by IMO for political reasons in order to allay concerns amongst developing nations. The ICS Board concluded that no responsible ship-owner would want to order a new ship (that was covered by the new IMO regulation) without an EEDI, since this would almost certainly impact on in its ability to trade".

- The Chairman of ICS mentioned that "As a signal of good faith and commitment to the uniform global implementation of the IMO agreement on CO_2, ICS strongly recommends that all ships of a type for which the index has already been agreed should be delivered by shipyards with an EEDI - regardless of any Flag State waiver that might be available for a limited time."

BIMCO

5 BIMCOs Marine Committee at its 22nd meeting in October 2011 discussed the issue of EEDI waiver and issued the following statement:

- "BIMCO has evaluated the commercial implication of new ships built after 1 January 2013 being granted waivers from the Flag State for compliance with the EEDI requirement. It is BIMCO's firm recommendation that due to the lifespan of ships and the significant uncertainties in respect of governments' environmental agendas and how these may be applied, members should abstain from building new ships without certified EEDI compliance. Such ships would be compromised in relation to their future second-hand value in the market, potentially restricted in their ability to trade worldwide and be less attractive in the charter market due to their perceived lower efficiency".

- BIMCO later on has emphasised that "their advice against waiver in no way bears a political signal. On the contrary, it is purely an acknowledgment of shipping being a global business and in line with BIMCO's objectives to promote fair business practices, free trade and open access to markets"

A1-4 Technology cost of compliance to EEDI

6 The waiver applies to the first 4 years of EEDI regulation. The evaluation of cost of compliance to EEDI regulation during these 4 years shows that this cost will be low. This is due to the following reason:

- **EEDI Reference Lines:** The construction of EEDI reference lines are based on assumption of engines BSFC (Brake Specific Fuel Consumption) of 190 and 215 g/kWh for main and auxiliary engines respectively. This gives effectively up to 10% advantage to ships for compliance.

- **Ship hydrodynamic optimisation:** Ship hydrodynamic (resistances) has a major impact on EEDI. A number of reported investigations shows that ship hydrodynamic optimisation will bring about energy saving opportunities of up to about 10% with actually no significant extra cost of shipbuilding. This on its own will be sufficient to ensure compliance to phases 0 and 1 of EEDI for the majority of ships.

- **Preparation for future more stringent phases 2 and 3:** It is believed that the future adoption of technologies for phases 2 and 3 of EEDI regulation (beyond 2020) will be based on experience gained with EEDI during phases 0 and 1. Those Flag States that opt for waiver will deprive themselves of gaining this experience and will have difficulty in adapting to EEDI regulations when the period of waiver elapses.

7 Based on the above, it is concluded that cost of compliance to phases 0 and 1 will not be significant and flag States and ship-owners will have no financial justification for opting for waiver. This makes the uptake of waiver option unattractive for the majority of ships and shipowners.

A1-5 Commercial cost of non-compliance to EEDI

8 Shipping is mainly an international industry and non-compliance to even voluntary regulations normally puts the non-compliant ship in some commercial disadvantage. An EEDI non-complaint ship is expected to suffer from the following:

- **Higher ship fuel cost:** A non-compliant EEDI ship is likely to be less efficient than the EEDI-compliant ship. This will translate to additional fuel cost of the vessel over its entire operation lifecycle.

- **Cost of re-verification:** Obtaining an EEDI verification (if desired later on) and certification during service period will incur significantly additional cost than obtaining EEDI verification during the normal ship construction and commissioning trials.

- **Second hand value:** A ship without an EEDI is likely to have lower second have value as this will imply that it is not an energy efficient ship

- **Opportunity costs:** The non-EEDI ship may loose on future EEDI-based incentives and where EEDI is used for chartering, port discounts, flag registration discounts, etc. Incentives could be driven by ports, Flag States, charterers and Port States.

- **Charter-ability:** Ships with EEDI is expected to have a better charter-ability opportunity as against those without. A ship with no EEDI may be regarded as an energy in-efficient ship.

9 Based on the above analysis, the 4-year waiver of EEDI compliance may not only bring no tangible capital cost benefits to owners but it may incur significant commercial risks for the ship and also some future opportunity costs.

A1-6 Level of waiver uptake

10 At MEPC 62, a number of countries supported the waiver clause to be included notably Brazil, China and Saudi Arabia. Assuming, that waiver will be taken up by these flag states, it is possible to estimate the level of waiver uptake. As of October 2011, the existing tonnage and number of ships for these three flags compared to the global fleet were analysed and constitute together 4.6% of the global fleet.

11 Based on the above assumption, a 5% waiver is forecast. Other scenarios can be modelled as soon as position of various flag States are known.

A1-7 Conclusions

12 Based on the analysis provided in this Appendix, it is concluded that the likelihood of flag States or shipowners to opt for an EEDI waiver is low due to lower compliance costs and commercial disadvantage of not doing so. Accordingly, the level waiver uptake level taken in this Study as 5% (low) and 30% (high) is regarded as reasonable. It is most likely that waiver will be at the level of 5% as current indications imply.

Appendix 2

Technology options for various ship types / sizes in support of EEDI compliance

1 In this Appendix, a list of technology options for various ship types and sizes is provided for EEDI compliance. These technologies are closely related to those identified in Table 2 in the body of the report.

2 Tables 2.1 to 2.6 show the results of analysis for Tankers, Container ships and Bulk carriers. Column one shows the reference values for the 2010 (current status), while other columns shows how the technologies will evolve and be adopted. At the last row of each Table, the anticipated reduction in design speed is given.

3 It should be noted that the tables are devised for an “average ship in the class”. For example, the VLCC is Table 2.1 shows the VLCC with an average tonnage (307,722 tonne DWT) and an average design speed (15.74 knots). Other VLCCs in global fleet locate at both sides of this average and could have either higher or lower EEDI.

4 In the Tables, the technologies and expected level of energy saving (and thereby reduction in EEDI) are also quoted for each year. These saving potential numbers are based on the Authors’ experience and are supported by previous studies. The technologies considered are mainly those that are proven technologies (e.g. waste heat recovery) while the more emerging technologies such as hull air lubrication, LNG, wind and solar are assumed not to be widespread by 2025. It is likely that some of the emerging technologies will appear in some niche markets. However, this analysis has taken a more conservative approach.

5 Results show that ship design (hull), propellers and main engines need to be further optimised. These, in combination, will provide compliance to EEDI regulation for average ships with minimal reduction in ship design speed for phases 0 and 1. However, for phases 2 and 3, some design speed reduction are foreseen unless either use of LNG are facilitated or emerging technologies such as hull air lubrication or wind power could be utilised.

6 It is important to note that the above analysis is for an “average ship” in the class. All ships with design speeds less than the “average ship”, are expected to have an easier route to compliance while ships with higher speeds than the “average ship”, will have the more difficult route to compliance. In fact, some faster ships in the class may well need to sacrifice some of their design speed for EEDI compliance or use lower carbon fuels for compliance.

Table 2.1 - Ship type: Tanker - Average VLCC Technology options for Required EEDI compliance

		Year			
		2010	2015	2020	2025
Fuel	**Primary/secondary fuel**	HFO	HFO/MGO	HFO/MGO	MGO/HFO
	Expected EEDI reduction (%)	0	0	0	0
Hull	**Hull /ship dimensions/paint optimisation**	Conv.	Conv/OPHULL	OPHULL	OPHULL
	Expected EEDI reduction (%)	0	2	5	7
	Hull air lubrication	NA	NA	NA	HAL
	Expected EEDI reduction (%)	0	0	0	0
Propeller	**Propeller type / size / design**	FPP (C)	FPP (C)	FPP (LDSS)	FPP (LDSS)
	Expected EEDI reduction (%)	0	0	2	2
	Propeller / rudder / aft flow optimisation	FPP (C)	FPP (OP)	FPP (OP)	FPP (OP)
	Expected EEDI reduction (%)	0	2	3	4
Propulsion system and M/E	**Propulsion system type**	Direct-drive	Direct-drive	Direct-drive	Direct-drive
	Expected EEDI reduction (%)	0	0	0	0
	Main engine type/optimisation	2-stroke diesel (C)	2-stroke diesel (OP)	2-stroke diesel (OP, DR/LS)	2-stroke diesel (OP, DR/LS)
	Expected EEDI reduction (%)	0	1	4	5
	Main engine actual SFC relative to reference value	SFC (M/E)	SFC (M/E)	SFC (M/E)	SFC (M/E)
	Expected EEDI reduction (%)	0	5	5	5
A/E and auxiliary loads	**Auxiliary engine type/optimisation**	4-stroke diesel (C)	4-stroke diesel (C)	4-stroke diesel (OP)	4-stroke diesel (OP)
	Expected EEDI reduction (%)	0	0	0	0
	Auxiliary engines actual SFC relative to reference value	SFC (A/E)	SFC (A/E)	SFC (A/E)	SFC (A/E)
	Expected EEDI reduction (%)	0	5	5	5
	Auxiliary load reduction	Conv.	Conv.	VSDRIVE	VSDRIVE
	Expected EEDI reduction (%)	0	0	0	0
Heat recovery	**Waste heat recovery**	NA	NA	NA	WHR
	Expected EEDI reduction (%)	0	0	0	5
Renewable energy	**Renewable energy for propulsion**	NA	NA	NA	WINDPOWER
	Expected EEDI reduction (%)	0	0	0	0
	Renewable energy for power generation	NA	NA	NA	SOLPOWER
	Expected EEDI reduction (%)	0	0	0	0
EEDI aspects	**EEDI (Required)**	2.560	2.304	2.048	1.792
	IMO EEDI reduction factor (%)	0	10	20	30
	EEDI reduction (Technical) (%)	0	9.8	18.44	27.08
Speed	**Design speed (average)**	15.74	15.72	15.62	15.51
	Expected EEDI reduction due to speed reduction(%)	0	0.2	1.56	2.92

Table 2.2 - Ship type: Tanker - Average Panamax   Technology options for Required EEDI compliance

		Year			
		2010	2015	2020	2025
Fuel	**Primary/secondary fuel**	HFO	HFO/MGO	HFO/MGO	MGO/HFO
	Expected EEDI reduction (%)	0	0	0	0
Hull	**Hull /ship dimensions/paint optimisation**	Conv.	Conv/OPHULL	OPHULL	OPHULL
	Expected EEDI reduction (%)	0	2	5	7
	Hull air lubrication	NA	NA	NA	HAL
	Expected EEDI reduction (%)	0	0	0	0
Propeller	**Propeller type / size / design**	FPP (C)	FPP (C)	FPP (LDSS)	FPP (LDSS)
	Expected EEDI reduction (%)	0	0	2	2
	Propeller / rudder / aft flow optimisation	FPP (C)	FPP (OP)	FPP (OP)	FPP (OP)
	Expected EEDI reduction (%)	0	2	3	4
Propulsion system and M/E	**Propulsion system type**	Direct-drive	Direct-drive	Direct-drive	Direct-drive
	Expected EEDI reduction (%)	0	0	0	0
	Main engine type/optimisation	2-stroke diesel (C)	2-stroke diesel (OP)	2-stroke diesel (OP, DR/LS)	2-stroke diesel (OP, DR/LS)
	Expected EEDI reduction (%)	0	1	4	4
	Main engine actual SFC relative to reference value	SFC (M/E)	SFC (M/E)	SFC (M/E)	SFC (M/E)
	Expected EEDI reduction (%)	0	5	5	5
A/E and auxiliary loads	**Auxiliary engine type/optimisation**	4-stroke diesel (C)	4-stroke diesel (C)	4-stroke diesel (OP)	4-stroke diesel (OP)
	Expected EEDI reduction (%)	0	0	0	0
	Auxiliary engines actual SFC relative to reference value	SFC (A/E)	SFC (A/E)	SFC (A/E)	SFC (A/E)
	Expected EEDI reduction (%)	0	5	5	5
	Auxiliary load reduction	Conv.	Conv.	VSDRIVE	VSDRIVE
	Expected EEDI reduction (%)	0	0	0	0
Heat recovery	**Waste heat recovery**	NA	NA	NA	WHR
	Expected EEDI reduction (%)	0	0	0	3
Renewable energy	**Renewable energy for propulsion**	NA	NA	NA	WINDPOWER
	Expected EEDI reduction (%)	0	0	0	0
	Renewable energy for power generation	NA	NA	NA	SOLPOWER
	Expected EEDI reduction (%)	0	0	0	0
EEDI aspects	**EEDI (Required)**	5.130	4.617	4.104	3.591
	IMO EEDI reduction factor (%)	0	10	20	30
	EEDI reduction (Technical) (%)	0	9.8	18.44	24.2
Speed	**Design speed (average)**	15.09	15.07	14.97	14.65
	Expected EEDI reduction due tpo speed reduction(%)	0	0.2	1.56	5.8

Table 2.3 - Containership - Average New Panamax: Technology options for Required EEDI compliance

		Year			
		2010	2015	2020	2025
Fuel	**Primary/secondary fuel**	HFO	HFO/MGO	HFO/MGO	MGO/HFO
	Expected EEDI reduction (%)	0	0	0	0
Hull	**Hull /ship dimensions/paint optimisation**	Conv.	Conv/OPHULL	OPHULL	OPHULL
	Expected EEDI reduction (%)	0	2	4	5
	Hull air lubrication	NA	NA	NA	HAL
	Expected EEDI reduction (%)	0	0	0	0
Propeller	**Propeller type / size / design**	FPP (C)	FPP (C)	FPP (LDSS)	FPP (LDSS)
	Expected EEDI reduction (%)	0	0	2	2
	Propeller / rudder / aft flow optimisation	FPP (C)	FPP (OP)	FPP (OP)	FPP (OP)
	Expected EEDI reduction (%)	0	2	3	4
Propulsion system and M/E	**Propulsion system type**	Direct-drive	Direct-drive	Direct-drive	Direct-drive
	Expected EEDI reduction (%)	0	0	0	0
	Main engine type/optimisation	2-stroke diesel (C)	2-stroke diesel (OP)	2-stroke diesel (OP, DR/LS)	2-stroke diesel (OP, DR/LS)
	Expected EEDI reduction (%)	0	1	4	5
	Main engine actual SFC relative to reference value	SFC (M/E)	SFC (M/E)	SFC (M/E)	SFC (M/E)
	Expected EEDI reduction (%)	0	5	5	5
A/E and auxiliary loads	**Auxiliary engine type/optimisation**	4-stroke diesel (C)	4-stroke diesel (C)	4-stroke diesel (OP)	4-stroke diesel (OP)
	Expected EEDI reduction (%)	0	0	0	0
	Auxiliary engines actual SFC relative to reference value	SFC (A/E)	SFC (A/E)	SFC (A/E)	SFC (A/E)
	Expected EEDI reduction (%)	0	5	5	5
	Auxiliary load reduction	Conv.	Conv.	VSDRIVE	VSDRIVE
	Expected EEDI reduction (%)	0	0	0	0
Heat recovery	**Waste heat recovery**	NA	NA	NA	WHR
	Expected EEDI reduction (%)	0	0	0	6
Renewable energy	**Renewable energy for propulsion**	NA	NA	NA	WINDPOWER
	Expected EEDI reduction (%)	0	0	0	0
	Renewable energy for power generation	NA	NA	NA	SOLPOWER
	Expected EEDI reduction (%)	0	0	0	0
EEDI aspects	**EEDI (Required) [g CO2/tonne.nmile]**	15.840	14.256	12.672	11.088
	IMO EEDI reduction factor (%)	0	10	20	30
	EEDI reduction (Technical) (%)	0	9.8	17.48	26.12
Speed	**Design speed (average)**	24.46	24.44	24.15	23.98
	Expected EEDI reduction due to speed reduction(%)	0	0.2	2.52	3.88

Table 2.4 - Contanership - Average Panamax: Technology options for Required EEDI compliance

		Year			
		2010	2015	2020	2025
Fuel	**Primary/secondary fuel**	HFO	HFO/MGO	HFO/MGO	MGO/HFO
	Expected EEDI reduction (%)	0	0	0	0
Hull	**Hull /ship dimensions/paint optimisation**	Conv.	Conv/OPHULL	OPHULL	OPHULL
	Expected EEDI reduction (%)	0	2	4	5
	Hull air lubrication	NA	NA	NA	HAL
	Expected EEDI reduction (%)	0	0	0	0
Propeller	**Propeller type / size / design**	FPP (C)	FPP (C)	FPP (LDSS)	FPP (LDSS)
	Expected EEDI reduction (%)	0	0	2	2
	Propeller / rudder / aft flow optimisation	FPP (C)	FPP (OP)	FPP (OP)	FPP (OP)
	Expected EEDI reduction (%)	0	2	3	4
Propulsion system and M/E	**Propulsion system type**	Direct-drive	Direct-drive	Direct-drive	Direct-drive
	Expected EEDI reduction (%)	0	0	0	0
	Main engine type/optimisation	2-stroke diesel (C)	2-stroke diesel (OP)	2-stroke diesel (OP, DR/LS)	2-stroke diesel (OP, DR/LS)
	Expected EEDI reduction (%)	0	1	4	4
	Main engine actual SFC relative to reference value	SFC (M/E)	SFC (M/E)	SFC (M/E)	SFC (M/E)
	Expected EEDI reduction (%)	0	5	5	5
A/E and auxiliary loads	**Auxiliary engine type/optimisation**	4-stroke diesel (C)	4-stroke diesel (C)	4-stroke diesel (OP)	4-stroke diesel (OP)
	Expected EEDI reduction (%)	0	0	0	0
	Auxiliary engines actual SFC relative to reference value	SFC (A/E)	SFC (A/E)	SFC (A/E)	SFC (A/E)
	Expected EEDI reduction (%)	0	5	5	5
	Auxiliary load reduction	Conv.	Conv.	VSDRIVE	VSDRIVE
	Expected EEDI reduction (%)	0	0	0	0
Heat recovery	**Waste heat recovery**	NA	NA	NA	WHR
	Expected EEDI reduction (%)	0	0	0	5
Renewable energy	**Renewable energy for propulsion**	NA	NA	NA	WINDPOWER
	Expected EEDI reduction (%)	0	0	0	0
	Renewable energy for power generation	NA	NA	NA	SOLPOWER
	Expected EEDI reduction (%)	0	0	0	0
EEDI aspects	**EEDI (Required) [g CO2/tonne.nmile]**	19.500	17.55	15.6	13.65
	IMO EEDI reduction factor (%)	0	10	20	30
	EEDI reduction (Technical) (%)	0	9.8	17.48	24.2
Speed	**Design speed (average)**	24.1	24.08	23.79	23.39
	Expected EEDI reduction due to speed reduction(%)	0	0.2	2.52	5.8

Table 2.5 - Bulk carrier - Average Capesize: Technology options for Required EEDI compliance

		Year			
		2010	2015	2020	2025
Fuel	**Primary/secondary fuel**	HFO	HFO/MGO	HFO/MGO	MGO/HFO
	Expected EEDI reduction (%)	0	0	0	0
Hull	**Hull /ship dimensions/paint optimisation**	Conv.	Conv/OPHULL	OPHULL	OPHULL
	Expected EEDI reduction (%)	0	2	5	7
	Hull air lubrication	NA	NA	NA	HAL
	Expected EEDI reduction (%)	0	0	0	0
Propeller	**Propeller type / size / design**	FPP (C)	FPP (C)	FPP (LDSS)	FPP (LDSS)
	Expected EEDI reduction (%)	0	0	2	2
	Propeller / rudder / aft flow optimisation	FPP (C)	FPP (OP)	FPP (OP)	FPP (OP)
	Expected EEDI reduction (%)	0	1	3	4
Propulsion system and M/E	**Propulsion system type**	Direct-drive	Direct-drive	Direct-drive	Direct-drive
	Expected EEDI reduction (%)	0	0	0	0
	Main engine type/optimisation	2-stroke diesel (C)	2-stroke diesel (OP)	2-stroke diesel (OP, DR/LS)	2-stroke diesel (OP, DR/LS)
	Expected EEDI reduction (%)	0	2	4	5
	Main engine actual SFC relative to reference value	SFC (M/E)	SFC (M/E)	SFC (M/E)	SFC (M/E)
	Expected EEDI reduction (%)	0	5	5	5
A/E and auxiliary loads	**Auxiliary engine type/optimisation**	4-stroke diesel (C)	4-stroke diesel (C)	4-stroke diesel (OP)	4-stroke diesel (OP)
	Expected EEDI reduction (%)	0	2	4	4
	Auxiliary engines actual SFC relative to reference value	SFC (A/E)	SFC (A/E)	SFC (A/E)	SFC (A/E)
	Expected EEDI reduction (%)	0	5	5	5
	Auxiliary load reduction	Conv.	Conv.	VSDRIVE	VSDRIVE
	Expected EEDI reduction (%)	0	0	0	0
Heat recovery	**Waste heat recovery**	NA	NA	NA	WHR
	Expected EEDI reduction (%)	0	0	0	4
Renewable energy	**Renewable energy for propulsion**	NA	NA	NA	WINDPOWER
	Expected EEDI reduction (%)	0	0	0	0
	Renewable energy for power generation	NA	NA	NA	SOLPOWER
	Expected EEDI reduction (%)	0	0	0	0
EEDI aspects	**EEDI (Required) [g CO2/tonne.nmile]**	3.010	2.709	2.408	2.107
	IMO EEDI reduction factor (%)	0	10	20	30
	EEDI reduction (Technical) (%)	0	9.88	18.6	26.28
Speed	**Design speed (average)**	14.6	14.59	14.50	14.33
	Expected EEDI reduction due to speed reduction(%)	0	0.12	1.4	3.72

Table 2.6 - Bulk carrier - Average Handy size: Technology options for Required EEDI compliance

		Year			
		2010	2015	2020	2025
Fuel	**Primary/secondary fuel**	HFO	HFO/MGO	HFO/MGO	MGO/HFO
	Expected EEDI reduction (%)	0	0	0	0
Hull	**Hull /ship dimensions/paint optimisation**	Conv.	Conv/OPHULL	OPHULL	OPHULL
	Expected EEDI reduction (%)	0	2	6	8
	Hull air lubrication	NA	NA	NA	HAL
	Expected EEDI reduction (%)	0	0	0	0
Propeller	**Propeller type / size / design**	FPP (C)	FPP (C)	FPP (LDSS)	FPP (LDSS)
	Expected EEDI reduction (%)	0	1	1	2
	Propeller / rudder / aft flow optimisation	FPP (C)	FPP (OP)	FPP (OP)	FPP (OP)
	Expected EEDI reduction (%)	0	1	2	3
Propulsion system and M/E	**Propulsion system type**	Direct-drive	Direct-drive	Direct-drive	Direct-drive
	Expected EEDI reduction (%)	0	0	0	0
	Main engine type/optimisation	2-stroke diesel (C)	2-stroke diesel (OP)	2-stroke diesel (OP, DR/LS)	2-stroke diesel (OP, DR/LS)
	Expected EEDI reduction (%)	0	1	3	4
	Main engine actual SFC relative to reference value	SFC (M/E)	SFC (M/E)	SFC (M/E)	SFC (M/E)
	Expected EEDI reduction (%)	0	5	5	5
A/E and auxiliary loads	**Auxiliary engine type/optimisation**	4-stroke diesel (C)	4-stroke diesel (C)	4-stroke diesel (OP)	4-stroke diesel (OP)
	Expected EEDI reduction (%)	0	1	3	4
	Auxiliary engines actual SFC relative to reference value	SFC (A/E)	SFC (A/E)	SFC (A/E)	SFC (A/E)
	Expected EEDI reduction (%)	0	5	5	5
	Auxiliary load reduction	Conv.	Conv.	VSDRIVE	VSDRIVE
	Expected EEDI reduction (%)	0	0	0	0
Heat recovery	**Waste heat recovery**	NA	NA	NA	WHR
	Expected EEDI reduction (%)	0	0	0	0
Renewable energy	**Renewable energy for propulsion**	NA	NA	NA	WINDPOWER
	Expected EEDI reduction (%)	0	0	0	0
	Renewable energy for power generation	NA	NA	NA	SOLPOWER
	Expected EEDI reduction (%)	0	0	0	0
EEDI aspects	**EEDI (Required) [g CO2/tonne.nmile]**	6.660	5.994	5.328	4.662
	IMO EEDI reduction factor (%)	0	10	20	30
	EEDI reduction (Technical) (%)	0	9.84	16.64	21.48
Speed	**Design speed (average)**	14.1	14.09	13.86	13.49
	Expected EEDI reduction due to speed reduction(%)	0	0.16	3.36	8.52

Appendix 3

SEEMP measures reduction potentials

Energy Efficiency Measure	Bulk carrier		Gas tanker		Tanker		Container ship		General cargo/Reefer	
	Handymax	Capesize	LNG	LNG	Panamax	VLCC	Panamax	NPX		
	30-40k DWT	>100k DWT	125-155k m3	>175k m3	60-85k DWT	>200k DWT	(4-5k TEU)	(12-14k TEU)	~3.5k DWT	~10k DWT
Engine tuning and monitoring	2.5	1.8	1.8	1.8	2.2	1.6	1.6	1.6	2.9	2.9
Hull condition	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Propeller condition	1.1	0.8	1.1	0.8	1.1	0.8	0.8	0.8	1.1	1.1
Reduced auxiliary power	0.6	0.9	0.7	1	0.6	1.7	0.8	1	2.6	1.1
Speed reduction (increased port efficiency)	15	15	12	10	13	12	10	11	21	13
Trim/draft	0.7	0.7	1	1.4	0.7	0.7	1.7	1.7	0.7	0.7
Voyage execution	2.5	3.4	2.5	3.4	2.5	3.4	1.4	1.4	2.5	2.5
Weather routing	0.1	1	0.1	1	0.2	1	1	0.8	0.1	1
Advanced hull coating	3	3	3	3	3	3	3	3	3	3
Propeller upgrade and aft body flow devices	3	3	3	3	3	3	3	3	3	3
SEEMP potential taking into acc. Overlaps	**28.7**	**29.6**	**25.9**	**26.0**	**26.8**	**27.7**	**24.3**	**25.2**	**36.0**	**28.4**

Table A3-1: CO_2 reduction potential of SEEMP related measures

	A1B				B2			
Option 1: Low uptake + Ref fuel	2015	2020	2030	2040	2013	2020	2030	2040
Bulk carrier	8 %	8 %	8 %	9 %	8 %	8 %	8 %	9 %
Gas tanker	6 %	6 %	6 %	7 %	6 %	6 %	6 %	6 %
Tanker	6 %	6 %	6 %	6 %	6 %	6 %	7 %	6 %
Container ship	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %
General cargo ship	8 %	8 %	8 %	7 %	8 %	8 %	8 %	7 %
Refridgerated cargo carrier	8 %	8 %	9 %	9 %	8 %	8 %	9 %	9 %
Other	6 %	6 %	6 %	7 %	6 %	6 %	6 %	6 %
Option 2: Low uptake + Hi fuel	2015	2020	2030	2040	2013	2020	2030	2040
Bulk carrier	8 %	8 %	9 %	9 %	8 %	8 %	8 %	9 %
Gas tanker	7 %	6 %	6 %	7 %	7 %	6 %	6 %	6 %
Tanker	6 %	6 %	7 %	7 %	6 %	6 %	7 %	7 %
Container ship	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %
General cargo ship	8 %	8 %	9 %	9 %	8 %	8 %	9 %	9 %
Refridgerated cargo carrier	8 %	8 %	9 %	9 %	8 %	8 %	9 %	9 %
Other	6 %	7 %	7 %	7 %	6 %	7 %	7 %	7 %
Option 3: Hi uptake + Ref fuel	2015	2020	2030	2040	2013	2020	2030	2040
Bulk carrier	15 %	16 %	16 %	17 %	16 %	16 %	16 %	17 %
Gas tanker	11 %	11 %	12 %	13 %	11 %	11 %	12 %	12 %
Tanker	12 %	12 %	12 %	12 %	12 %	12 %	12 %	12 %
Container ship	14 %	14 %	14 %	14 %	14 %	14 %	14 %	14 %
General cargo ship	15 %	14 %	14 %	14 %	15 %	14 %	15 %	14 %
Refridgerated cargo carrier	16 %	16 %	17 %	10 %	16 %	16 %	17 %	17 %
Other	12 %	12 %	13 %	13 %	12 %	12 %	13 %	12 %
Option 4: Hi uptake + Hi fuel	2015	2020	2030	2040	2013	2020	2030	2040
Bulk carrier	15 %	16 %	16 %	17 %	16 %	16 %	16 %	17 %
Gas tanker	11 %	12 %	12 %	13 %	11 %	12 %	12 %	12 %
Tanker	12 %	13 %	13 %	13 %	12 %	13 %	13 %	13 %
Container ship	14 %	14 %	14 %	14 %	14 %	14 %	14 %	14 %
General cargo ship	16 %	16 %	17 %	17 %	16 %	16 %	16 %	17 %
Refridgerated cargo carrier	16 %	16 %	17 %	17 %	16 %	16 %	17 %	17 %
Other	13 %	13 %	14 %	14 %	13 %	13 %	14 %	14 %

Table A3-2: SEEMP-related CO_2 reduction potentials with alternative scenarios

Appendix 4

Analysis of Likely SEEMP Uptake

Introduction

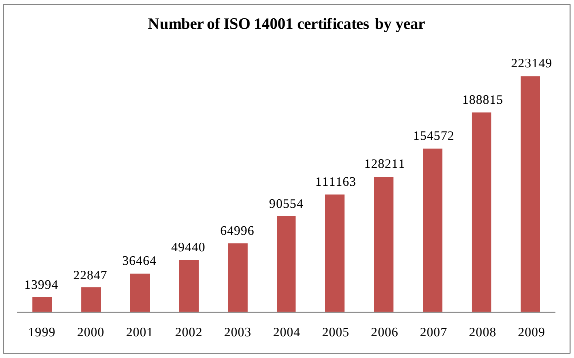
1 The SEEMP is essentially a ship-specific energy management manual/plan, which focuses on a single environmental aspect of ship operations (GHG emissions). The overall objective of the SEEMP is to minimise this impact via reduction of fuel consumption. It is assumed that the main drivers for the implementation of the SEEMP will be similar to EMS (Environmental Management System) that includes the following [NIEA, 2009]:

- Compliance with legislations.
- Environmental performance.
- Cost savings (via reduction of fuel consumption).
- Client pressure.
- Enhanced public image.

2 To analyse the likely effectiveness of SEEMP, the above drivers needs to be assessed within the context of the shipping industry. Also, review of the level of effectiveness of EMS and other management plans will provide evidence on what lies ahead with regard to SEEMP.

EMS Experiences

3 Environmental Management Systems have been around for less than 2 decades (since 1992). According to an ISO Survey, in 2009 more than 220,000 ISO 14001 certificates were issued in 159 countries/economies. The following graphs show the growth of the standard over the last decade and the top 10 countries in terms of certificates in 2009:



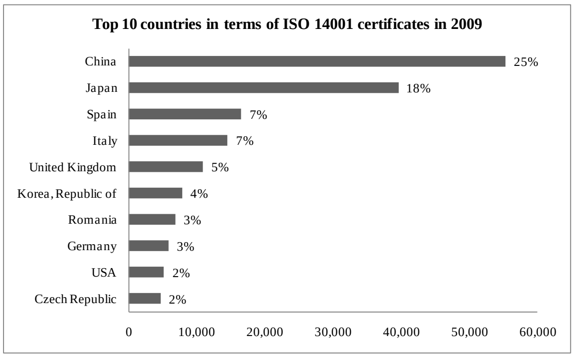


Figure A4-1: Uptake of ISO 14001 (ISO Survey, 2009)

4 A number of studies have been conducted on the subject of EMS effectiveness and the overall conclusions are that:

- The adoption of EMS has a positive outcome in the improvement of environmental performance (NIEA, 2009).
- The main benefits were observed in areas where the environmental impact is linked with cost savings, such as energy reduction (Schylander, 2004). This has a close relation to SEEMP and indicates that due to impact of SEEMP on cost, its more effective implementation is likely to be the case.
- The most important, although indirect, contribution of EMS is that it raises the awareness on environmental issues (Schylander, 2004, NIEA, 2009).

- Similar observations have been made in the shipping industry, where the introduction of EMS is associated with positive impact on environmental awareness and cultural change (Thetokas, Kaza, 2005).

5 Based on the experience from EMS, it could be argued that:

- The shipping industry is not alien to management systems and plans such as SEEMP; the ISM Code has been a mandatory instrument for more than a decade.
- Systems based on the ISO 14001 standard are used increasingly in the shipping industry.
- SEEMP is dealing with a quantitative environmental aspect with cost implications and based on EMS experience, it is expected to have a wider effectiveness.

Experience from existing IMO mandatory management plans

6 The literature on previously mandated IMO management plans such as VOC (Volatile Organic Compounds) and BWMS (Ballast Water Management Systems) were researched. Although there is widespread agreement that the industry fully comply with the relevant regulations and management plans, their use is not investigated in terms of quantifiable impact on level of VOC or transfer of alien species.

7 According to the 2nd IMO GHG study, paragraph 1.17 "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".

Experience of best-practice ship energy management

8 Ship operators have already been implementing energy efficiency operational measures suggested within the SEEMP Guidelines and set goals for reducing the energy consumption of their fleet. Performance and savings are not always monitored and reported. However, from some major operators who publish their results, it can be seen that if SEEMP is successfully promoted within the wider industry, significant reductions in CO_2 emissions can be achieved.

9 Published experiences from some major ship owning / operation companies are briefly described below:

- **Virtual arrival:** It is estimated that implementation of virtual arrival can reduce GHG emissions on the tanker and bulk carrier sectors by 5% (BP, 2010), however the concept is not yet fully evaluated in practice.
- **Slow steaming:** Maersk Line's experience from the implementation of slow steaming show that for over 1½ year since its implementation in 2009, the relative CO_2 emissions were reduced by 7% (Maersk Line, 2010). Maersk Tankers is implementing super-slow steaming in ballast voyages, and they are reporting savings in bunker costs of up to 50%.
- **Hanjin Shipping experience:** They have implemented a number of CO_2 emission reduction measures/technologies applied on their ships including turbocharger cut-off, application of low-friction paints, use of fuel additives, route optimisation and vessel performance monitoring systems (Hanjin, 2010). Although no specific figures are available for each measure, the

overall emissions of the company's shipping sector in 2010 were reduced by 12% (expressed in g-CO_2/teu-km) compared to 2008 levels.

- **Cosco Group experience:** In their 2008 report, they list a variety of operational measures including fuel homogenisation and use of additives, engine temperature control, speed reduction and speed optimisation, vessel performance monitoring, cargo heating optimisation and hull cleaning. Again, no specific figures are available for each measure but fuel consumption (expressed in kg/kilotons per sea mile) has consistently reduced[4] across all shipping sectors the company is engaged in (containerships, bulk carriers, tankers and general cargo).
- **Cruise shipping:** Similar experiences are reported in the cruise sector.

  - Holland America Line reports an increase in efficiency (expressed in kg fuel per km travelled per available lower berth) of 6% between 2007-2009 by employing operational practices such as voyage optimisation, performance monitoring and reporting, and onboard energy conservation.
  - RCCL (Royal Caribbean Cruise Lines) reported a reduction of 4% in fuel consumption (expressed in terms of available passenger cruise days). Although some of these savings are attributed to the introduction of more efficient ships on the fleet, operational and management practices such as ship speed, hull maintenance, deployment (itinerary planning of individual sailings), heating, ventilation and air conditioning usage, lighting, water management and behavioural changes among passengers and employees are cited.
  - Princess Cruises also list a number of operational measures, such as participation in a voluntary speed reduction programme, use of low-friction silicone paint, use of engine waste heat for fresh water production, use of low energy bulbs, HVAC optimisation and use of shore side electricity but with no reported figures as to the effect of these measures.
- **Class Societies:** A number of class societies have been promoting operational energy efficiency practices and have reported significant saving potentials from operational and technical best-practice viewpoints.

10 Based on the above experiences, it could be concluded that the potential for energy saving is high and some companies are already taking advantage of this potential, primarily for cost cutting. Therefore, if SEEMP regulation could spread the use of energy saving practices widely within the industry, its impact is expected to be high especially if fuel cost pressure persists.

Increased awareness and culture change

11 The effectiveness of the SEEMP will be driven to a large extent via increasing familiarity of the industry with advantages of energy efficiency and promotion of awareness and cultural change. The mandatory nature of the SEEMP will ensure to a certain degree that the above mentioned awareness and cultural change are achieved in the short to medium term.

[4] The company has reported reductions of 6% for the containership sector, 6% for the bulk carrier sector, 60% for the tanker sector and 13% for the general cargo sector in 2007 compared to 2004 levels, in terms of kg/kilotons per sea mile

12 In the longer term, the following aspects need to be ensured for a good and effective SEEMP uptake:

- Company energy policy and management commitment to reducing fuel consumption are in place at strategic levels.
- Measures in the SEEMP are specific and applicable to the ship and its operation.
- Clear objectives and goals for energy saving are set.
- Roles and responsibilities are clearly assigned and there are enough resources available for their implementation.
- Training is continuously provided.
- A quantitative performance monitoring system is in place and records showing alignment with the goals are made available.
- Compliance with the SEEMP requirements is evaluated in some detail by periodical audits and management reviews.

SEEMP and Fuel price

13 There is a clear linkage between fuel prices and operational energy efficiency practices. Studies on the first and second global oil crises during 1970s indicate that shipping transport efficiency increased after the oil price hikes; primarily via slow steaming. The same has happened after the 2008 worldwide economic crisis due to banking system. Despite these linkages, there are no well documented studies relating to possible uptake of SEEMP measures with fuel price. In this Study, it is assumed that uptake of SEEMP will be affected by marine fuel and carbon prices.

Conclusions

14 Based on this analysis, it may be concluded that the mandatory use of SEEMP based on current IMO regulations will provide a procedural framework for shipping companies to recognise the importance of the operational energy saving activities. It will significantly boost the level of awareness and, if implemented properly, will lead to a positive cultural change. However, and in view of lack of regulatory requirements for target setting and monitoring, SEEMP effectiveness will need to be stimulated / incentivised via other initiatives.

15 Some drivers for more effective use of the SEEMP are:

- High fuel and carbon prices.
- More vigorous awareness building and cultural change on board ships.
- More collaboration between industry stakeholders and a solution to issue of split-incentives.
- Effective monitoring of SEEMP implementation via rigorous audits and reviews.

16 In view of the above, the uncertainty of the SEEMP's effectiveness as a regulatory measure in its current form will persist in the future. Further action beyond current regulations may be needed to encourage wider uptake of SEEMP measures in the future.

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Appendix 5

Method of calculation of CO_2 reduction due to EEDI reduction factor

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 reference line expressed by a standard deviation. The reference lines for different ship types were presented in MEPC 62/24/Add.1 [A1]. The standard deviations presented in Table A5.1 for the different ship types were not presented in [A1], but were retrieved from the background data.

3 While the standard deviation from the fleet average (or 'reference line') 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	Standard deviation in reference lines	Standard deviation used in this study
Bulk carrier	0.13	0.15
Tanker (incl. gas)	0.23 (0.19 for gas)	0.20
Container ship	0.18	0.20
Coastal ships	0.28 – 0.38	0.30

Table A5.1 Standard deviation for the reference lines

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. The closest figure the real standard deviation was chosen: 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 A5.2 Figure A5.3 shows the results expressed in terms of the required EEDI in relation to the current fleet average or 'reference line'. A negative value indicates a required EEDI above the current fleet average value.

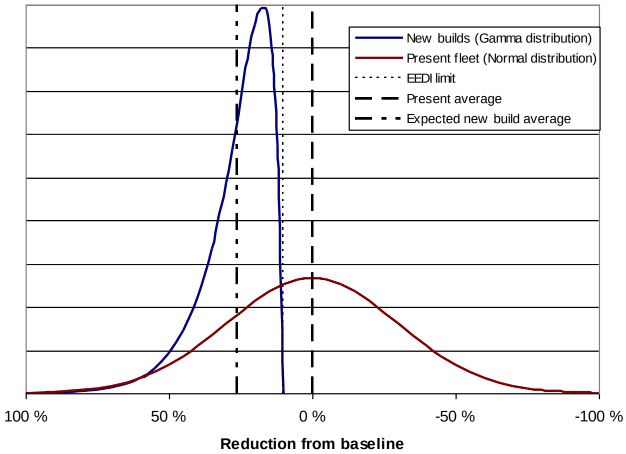
5 Setting a mandatory limit on the EEDI for future ships will lower the average EEDI for all new builds. However, the new average will not be equal to the set EEDI limit. This appendix explains the relationship between the set EEDI limit and the average EEDI.

6 The estimated EEDI values are calculated for every ship in the fleet, and plotted against the capacity in order to create a reference line. The EEDI values can be shown to be normally distributed around the regression line [A2]. 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 reference line 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 cost of compliance with 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.



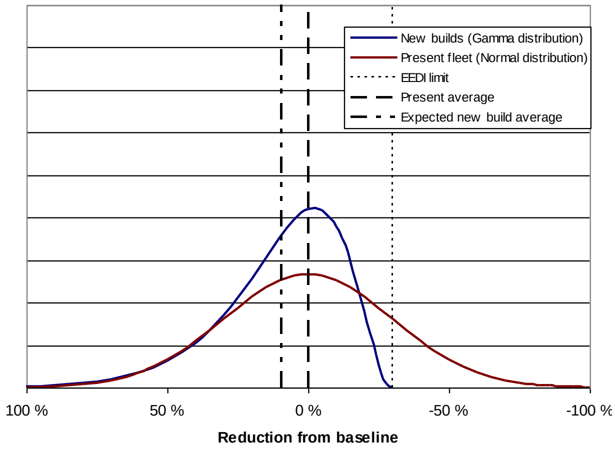


Figure A5.2: Setting the limit below (left) and above (right) the reference line

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 A5.2) 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 A5.2) 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 less energy efficient 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 A5.3. 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.

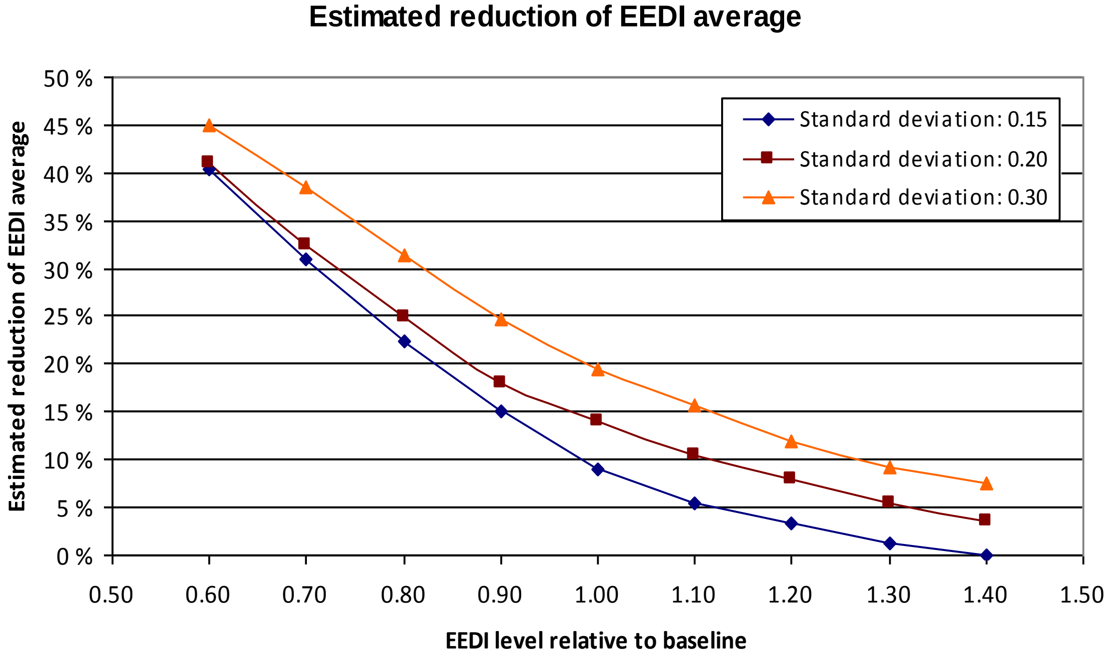


Figure A5.3: Estimated average reduction as a function the limit relative to reference line for three different standard deviations

11 The different ships types have different variance. Bulk carriers generally are very uniform vessels and the standard deviation of individual ships compared to the regression line is low, except for very small ships. For tankers, container vessels and, especially, general cargo 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) has little or no effect as all existing designs already comply. Generally, the effect of the 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, this number is rounded up to 0.20. The middle line (0.20) in Figure A5.3 can then 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 'reference line'.

Appendix V References

A1 International Maritime Organization, Marine Environment Protection Committee, *Report of the marine environment protection committee on its sixty-second session,* MEPC 62/24/Add.1, 26 July 2011.

A2 International Maritime Organization, Marine Environment Protection Committee, *A mandatory CO_2 Design Index for New Ships*, MEPC 57/INF.12, 2008.

Appendix 6

Projected CO_2 Emissions Reduction Attributable to EEDI and SEEMP

Year	Growth scenario	A1B				B2				A1B
	SEEMP uptake scenarios	Low		High		Low		High		High
	Fuel price scenario	Reference	High	Reference	High	Reference	High	Reference	High	Reference
	Scenario	A1B-1	A1B-2	A1B-3	A1B-4	B2-1	B2-2	B2-3	B2-4	30 % waiver
2010	Estimated BAU CO2 emissions [mill tonnes]	866				866				866
	EEDI - estimated CO2 emission reduction [mill tonnes]	0				0				0
	SEEMP - estimated CO2 emission reduction [mill tonnes]	0	0	0	0	0	0	0	0	0
	Total estimated CO2 emission reduction [mill tonnes]	0	0	0	0	0	0	0	0	0
	Total estimated CO2 emission reduction [% of total]	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %
2013	Estimated total CO2 emissions [mill tonnes]	944				913				944
	EEDI - estimated CO2 emission reduction [mill tonnes]	0				0				0
	SEEMP - estimated CO2 emission reduction [mill tonnes]	22	22	42	43	21	22	41	42	42
	Total estimated CO2 emission reduction [mill tonnes]	22	22	42	43	21	22	41	42	42
	Total estimated CO2 emission reduction [% of total]	2 %	2 %	4 %	5 %	2 %	2 %	5 %	5 %	4 %
2020	Estimated total CO2 emissions [mill tonnes]	1 165				1 040				1 165
	EEDI - estimated CO2 emission reduction [mill tonnes]	42				31				33
	SEEMP - estimated CO2 emission reduction [mill tonnes]	80	81	154	158	72	73	138	142	155
	Total estimated CO2 emission reduction [mill tonnes]	122	123	196	200	103	104	169	173	189
	Total estimated CO2 emission reduction [% of total]	10 %	11 %	17 %	17 %	10 %	10 %	16 %	17 %	16 %
2030	Estimated total CO2 emissions [mill tonnes]	1 599				1 271				1 599
	EEDI - estimated CO2 emission reduction [mill tonnes]	224				155				216
	SEEMP - estimated CO2 emission reduction [mill tonnes]	100	103	192	199	82	83	156	161	193
	Total estimated CO2 emission reduction [mill tonnes]	324	327	416	423	237	238	312	316	409
	Total estimated CO2 emission reduction [% of total]	20 %	20 %	26 %	26 %	19 %	19 %	25 %	25 %	26 %
2040	Estimated total CO2 emissions [mill tonnes]	2 242				1 584				2 242
	EEDI - estimated CO2 emission reduction [mill tonnes]	538				351				533
	SEEMP - estimated CO2 emission reduction [mill tonnes]	125	130	238	250	90	93	172	180	239
	Total estimated CO2 emission reduction [mill tonnes]	662	667	776	788	441	444	523	531	772
	Total estimated CO2 emission reduction [% of total]	30 %	30 %	35 %	35 %	28 %	28 %	33 %	34 %	34 %
2050	Estimated total CO2 emissions [mill tonnes]	3 215				2 014				3 215
	EEDI - estimated CO2 emission reduction [mill tonnes]	995				603				995
	SEEMP - estimated CO2 emission reduction [mill tonnes]	162	168	311	325	103	106	197	205	311
	Total estimated CO2 emission reduction [mill tonnes]	1 158	1 164	1 306	1 320	706	709	800	808	1 306
	Total estimated CO2 emission reduction [% of total]	36 %	36 %	41 %	41 %	35 %	35 %	40 %	40 %	41 %

Table A6-1 Projected emission reductions attributable to EEDI and SEEMP

Estimated CO2 emissions [mill tonnes]. Scenario/Option:									
Year	A1B-1	A1B-2	A1B-3	A1B-4	B2-1	B2-2	B2-3	B2-4	A1B-3WL
2010	866	866	866	866	866	866	866	866	866
2013	944	944	944	944	913	913	913	913	944
2020	1 165	1 165	1 165	1 165	1 040	1 040	1 040	1 040	1 165
2030	1 599	1 599	1 599	1 599	1 271	1 271	1 271	1 271	1 599
2040	2 242	2 242	2 242	2 242	1 584	1 584	1 584	1 584	2 242
2050	3 215	3 215	3 215	3 215	2 014	2 014	2 014	2 014	3 215

World fleet: EEDI - estimated CO2 emission reduction [mill tonnes]									
Year	A1B-1	A1B-2	A1B-3	A1B-4	B2-1	B2-2	B2-3	B2-4	A1B-3WL
2010	-	-	-	-	-	-	-	-	-
2013	-	-	-	-	-	-	-	-	-
2020	42	42	42	42	31	31	31	31	33
2030	224	224	224	224	155	155	155	155	216
2040	538	538	538	538	351	351	351	351	351
2050	995	995	995	995	603	603	603	603	995

World fleet: SEEMP - estimated CO2 emission reduction [mill tonnes]									
Year	A1B-1	A1B-2	A1B-3	A1B-4	B2-1	B2-2	B2-3	B2-4	A1B-3WL
2010	-	-	-	-	-	-	-	-	-
2013	22	22	42	43	21	22	41	42	42
2020	80	81	154	158	72	73	138	142	155
2030	100	103	192	199	82	83	156	161	193
2040	125	130	238	250	90	93	172	180	
2050	162	168	311	325	103	106	197	205	311

World fleet: Total estimated CO2 emission reduction [mill tonnes]									
Year	A1B-1	A1B-2	A1B-3	A1B-4	B2-1	B2-2	B2-3	B2-4	A1B-3WL
2010	-	-	-	-	-	-	-	-	-
2013	22	22	42	43	21	22	41	42	42,49
2020	122	123	196	200	103	104	169	173	188,63
2030	324	327	416	423	237	238	312	316	409,22
2040	662	667	776	788	441	444	523	531	-
2050	1 158	1 164	1 306	1 320	706	709	800	808	1 306,30

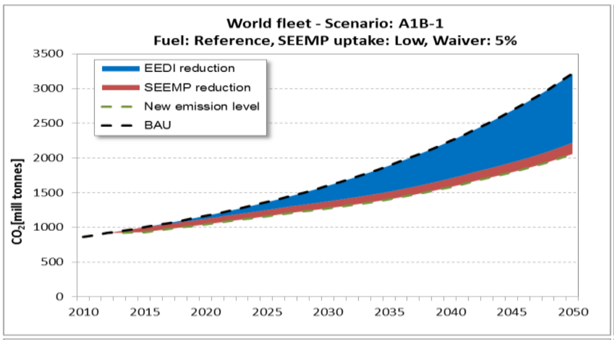
A1B-3WFuel: Reference, SEEMP uptake: High, Waiver: 30%

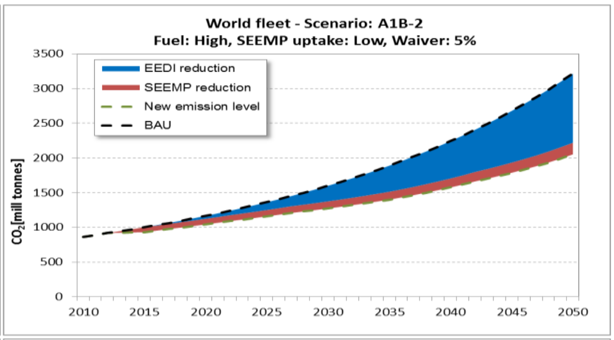
World fleet: Relative estimated CO2 emission reduction [%]									
Year	A1B-1	A1B-2	A1B-3	A1B-4	B2-1	B2-2	B2-3	B2-4	A1B-3WL
2010	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %	0,0 %
2013	2,3 %	2,4 %	4,5 %	4,6 %	2,3 %	2,4 %	4,5 %	4,6 %	4,5 %
2020	10,5 %	10,6 %	16,8 %	17,2 %	9,9 %	10,0 %	16,3 %	16,7 %	16,2 %
2030	20,3 %	20,4 %	26,0 %	26,4 %	18,6 %	18,8 %	24,5 %	24,9 %	25,6 %
2040	29,5 %	29,8 %	34,6 %	35,1 %	27,8 %	28,0 %	33,0 %	33,5 %	34,4 %
2050	36,0 %	36,2 %	40,6 %	41,1 %	35,0 %	35,2 %	39,7 %	40,1 %	40,6 %

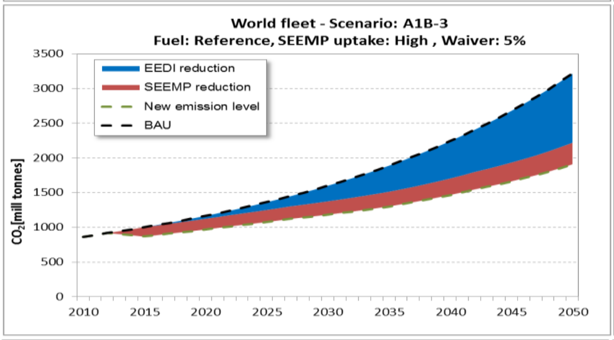
Table A6-2 - Estimated Emissions Levels with Alternative Scenarios

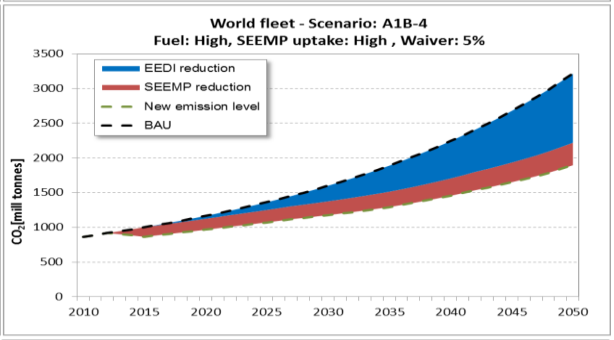
Appendix 7 -Projected emissions trends

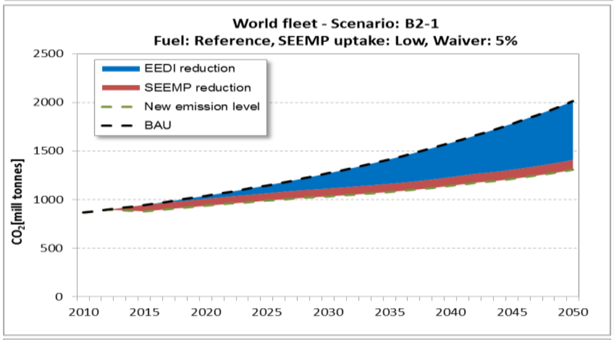
Projection of CO_2 emissions reduction by EEDI and SEEMP for alternative scenarios

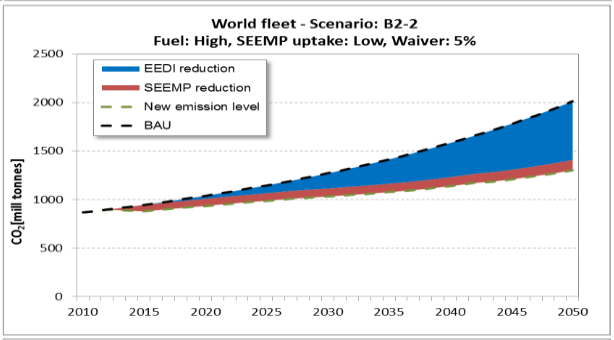


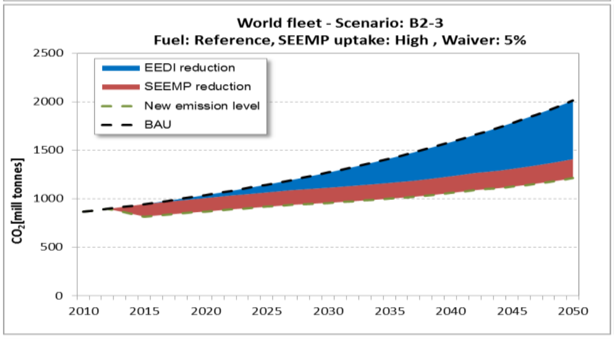


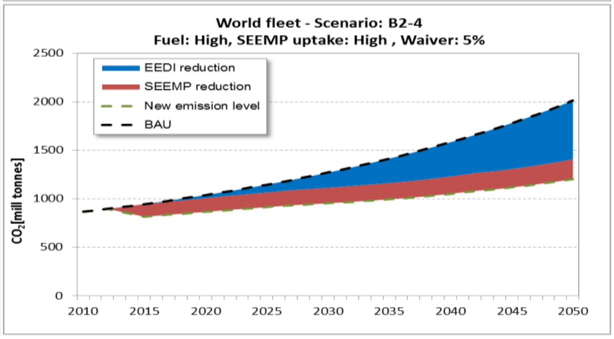


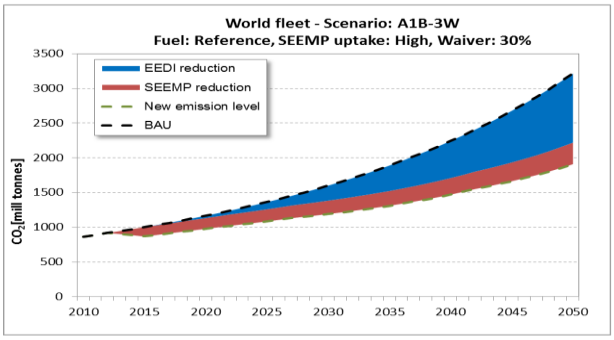












Appendix 8

Transport efficiency trends