

# Study on methods and considerations for the determination of greenhouse gas emission reduction targets for international shipping

Final Report: Short-term Measures

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# **Study on methods and considerations for the determination of greenhouse gas emission reduction for international shipping**

Final Report

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## Executive summary

The Marine Environment Protection Committee (MEPC) of the International Maritime Organization (IMO) has adopted the Initial IMO Strategy on reduction of greenhouse gas (GHG) emissions from ships which envisages to 'reduc[e] GHG emissions from international shipping and (...) phase them out as soon as possible in this century'. It also expresses the ambition to:

- reduce CO<sub>2</sub> emissions per transport work, as an average across international shipping, by at least 40% by 2030 compared to 2008; and
- to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO<sub>2</sub> emissions reduction consistent with the Paris Agreement temperature goals.

The Initial Strategy also includes a list of candidate short-, mid- and long-term measures, defined respectively as measures that will be agreed by the MEPC before 2023, between 2023 and 2030, and after 2030. Given these timelines, the level of ambition for 2030 will have to be achieved by short- and possibly also mid-term measures. The short-term measures could also be instrumental in achieving a peak in emissions as soon as possible and setting them on a downward course. However, the Strategy recognises that in order to meet the 2050 Level of Ambition, the global introduction of alternative fuels and/or energy sources will be required.

Within the context of the Initial Strategy, this report has designed short-term measures on the basis of the list comprised in the initial strategy and assessed their impacts on emissions in 2030.

### Short-term measures

The Initial Strategy contains a list of 13 candidate short-term measures. Of these, five can be considered to have a direct impact on CO<sub>2</sub> emissions from ships. These are (using the numbering of the Initial Strategy):

- Further improvement of the existing energy efficiency framework with a focus on Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), taking into account the outcome of the review of EEDI regulations.
- Develop technical and operational energy efficiency measures for both new and existing ships, including consideration of indicators in line with the three-step approach that can be utilized to indicate and enhance the energy efficiency performance of shipping, e.g. Annual Efficiency Ratio (AER), Energy Efficiency per Service Hour (EESH), Individual Ship Performance Indicator (ISPI) and Fuel Oil Reduction Strategy (FORS).
- Establishment of an Existing Fleet Improvement Programme.
- Consider and analyse the use of speed optimization and speed reduction as a measure, taking into account safety issues, distance travelled, distortion of the market or trade and that such measure does not impact on shipping's capability to serve remote geographic areas.
- Encourage the development and update of national action plans to develop policies and strategies to address GHG emissions from international shipping in accordance with guidelines to be developed by the Organization, taking into account the need to avoid regional or unilateral measures.

Some of these measures, like the Existing Fleet Improvement Programme, have been described in detail in various submissions to the MEPC. On others, little more information is available than is contained in the list above. This report has developed more detailed designs of the measures which are presented in summary below.

### Further improvement of the EEDI

This report presents two policies to further improve the EEDI. The first is to bring forward the implementation date of Phase 3 of the EEDI from 2025 to 2022 and introduce a fourth phase in 2027.

The second is a policy to apply the EEDI to existing ships, which requires a more elaborate description. Under this policy, each ship would need to have an attained measure of its design efficiency, similar to the EEDI for new ships, but potentially calculated on the basis of existing documentation. A target would be set, e.g. 10%, 20% or 30% above the applicable reference line, and within a certain timeframe, ships would need to meet the new standard through retrofits of energy technologies or reducing engine power.

### Further improvement of the SEEMP

This report analyses three options for further improve the SEEMP.

First, the SEEMP could be aligned with other energy efficiency management plans by mandating companies to set a goal for the energy efficiency of a ship. This has proven in other sectors to improve the impact of the policy. A shipping company would need to adopt an energy efficiency metric which it considers to represent the efficiency of the ship well and set a target. In addition, progress towards the target would need to be monitored and the target would need to be updated regularly. SEEMPs would have a limited validity in order to ensure that targets will indeed be updated.

Second, the SEEMP could mandate ships to regularly establish a speed-fuel curve following a standardised method. This could facilitate the communication on efficiency between ship owners and charterers and help reduce the split incentive (whereby ship owners don't reap the benefits of investments in energy efficiency because charterers benefit from the lower fuel costs).

Third, mandating ships to install cost-effective technologies. This is the most complicated improvement of the SEEMP as it would change the nature of the SEEMP from a management plan that has to be developed on the basis of guidelines into a regulation that requires ships to change their design efficiency. Under this policy, a group of experts would establish a list of technologies that are generally cost-effective to implement. Examples of such technologies could be advanced hull coatings, propeller upgrades like ducts or counter-rotating propellers. Ships would have to apply these technologies at their next drydocking, unless they can prove to their administration that the technology is not cost-effective for the ship in question.

### Operational efficiency standards

This measure would entail that ships monitor their operational efficiency using an indicator that needs to be agreed by the IMO. The IMO would also set reference lines and targets for ships. Ships would then be required to meet the applicable operational efficiency target.

### Existing Fleet Improvement Programme

The existing fleet improvement programme would require ships to set aside a certain amount of money each year, related to the fuel consumption of the ship. This money would need to be invested in Energy Efficiency Bonds, which can only be used to purchase energy efficiency technologies for ships. Shipping companies would be allowed to convert the Bonds for any ship, and would thus have an incentive to invest it in the improvement of the ship for which it is most cost-effective.

### Speed limitation

This regulation would introduce a ship-type and –size specific maximum speed which ships would not be allowed to exceed.

### National or regional measures

This report presents three possible national or regional measures and focusses on how the IMO could facilitate States or Regions to adopt them.

First, IMO could offer a platform for developing a standard for ship-shore communication that could inform ships well in advance on the availability of pilots and berths and allow them to approach ports at an optimal speed.

Second, the IMO could offer a platform for the development of a standard for port incentive schemes.

Third, the IMO could develop a framework to allow incentivising the uptake of renewable fuels on short-haul routes.

### Impacts of the short-term measures on emissions

The measures presented and analysed in this report can be grouped into three categories:

- Measures that can help remove barriers to the implementation of cost-effective technologies or operational practices:
  - Strengthening the SEEMP – mandatory goal-setting;
  - Strengthening the SEEMP – mandatory periodic efficiency assessment;
  - Develop a standard for ship-shore communication for voluntary use;
  - Develop a standard for port incentive schemes for voluntary use;
  - Create a framework for incentivising the uptake of renewable fuels;
- Measures that mandate ships to improve their technical or design efficiency:
  - Strengthening the EEDI for new ships;
  - Applying the EEDI to existing ships;
  - Strengthening the SEEMP – mandatory retrofits of cost-effective technologies;
  - Existing fleet improvement programme;
- Measures that mandate operational carbon intensity improvements:
  - Setting mandatory operational efficiency standards;
  - Speed regulation.

The first category of measures in general has a limited impact on emissions because the many cost-effective measures will be implemented anyway over time in most Business as Usual (BAU) scenarios and because some barriers will remain. Although the emission reductions vary per measure, they are typically a few percent. These measures are not able to ensure that the shipping sector meets the 2030 level of ambition of the IMO GHG Strategy, which is to improve the CO<sub>2</sub> intensity of maritime transport by at least 40% relative to 2008.

The second category of measures has a slightly larger impact on emissions because they can also mandate the adoption of measures that are not cost-effective from a private perspective. The measure that applies only to new ships has a limited impact on emissions by 2030, but the impact will increase in later years. However, the measures that apply to the existing fleet can have larger impacts, depending on the stringency applied. Emission reductions by 2030 are typically several percent. Moreover, measures that exclusively incentivise improvements in technical/design efficiency show a risk of a rebound effect. That is to say that savings in technical efficiency are diminished because of an economic incentive created to operate at higher speeds. The results suggest that the rebound effect could approximately halve the benefit of CO<sub>2</sub> emissions reduction gained from the technical efficiency improvements. These measures by themselves are not able to ensure that the shipping sector meets the 2030 level of ambition.

The third category of measures has the highest impact on emissions because they apply to all ships, can ensure that ship owners have to meet a certain efficiency target, and/or because they incentivise speed reduction which is the measure that has the greatest potential to reduce emissions. This category of measures has the ability to meet or exceed the minimum level of ambition for 2030.

The operational efficiency can be calculated annually for individual ships on the basis of data available within shipping companies and reported to the Flag State in the IMO Data Collection System. Average annual speeds can also be calculated from the Data Collection System. The difference between the measures is that the definition of the average annual speed is straightforward, while there is no agreement yet on what a suitable operational efficiency indicator would be.

Both speed limits and operational efficiency standards will require most ships to reduce their speed if the 2030 CO<sub>2</sub>-intensity ambition is to be met. There is a difference, however. At equivalent CO<sub>2</sub> reduction outcomes, operational efficiency standards allow ships more ways to comply than to reduce speed: improving the design efficiency, switching fuels, improving the management or logistics of the ship, et cetera. As a consequence, the resulting speed in 2030 will be somewhat higher than under equivalent speed reduction measures. Table 1 summarises the projected impact of the measures on GHG emissions.

Table 1 - Projected impact of measures on 2030 GHG emissions

Measure	Impact on 2030 annual CO <sub>2</sub> emissions relative to BAU
Strengthening the SEEMP: mandatory goal setting	0% - 2%
Strengthening the SEEMP: mandatory periodic efficiency assessment	0% - 2%
Strengthening the EEDI for new ships	1% - 3%
Strengthening the SEEMP: mandatory retrofits of cost-effective technologies	2% - 4%
Existing Fleet Improvement Programme	2% - 4%
Applying the EEDI to existing ships	1% - 6%
Operational efficiency standards: AER 20% below 2008	5%
Speed reduction: cap average speed at 2012 level	13%
Required to meet the 2030 level of ambition on the CO <sub>2</sub> intensity	21%
Operational efficiency standards: AER 40% below 2008	21%
Speed reduction: cap average speed at 20% below 2012 level	24% - 34%
Operational efficiency standards: AER 60% below 2008	43%

Note: In order to achieve a 40% carbon intensity reduction on 2008 carbon intensity, we estimate that a CO<sub>2</sub> emissions reduction of approximately 21% in 2030 relative to the BAU will be required.

# 1. Introduction

## 1.1. Policy background

The Paris Agreement of the UNFCCC aims to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C. To that end, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible and to undertake rapid reductions thereafter. In the second half of the century, the net emissions of greenhouse gases should become zero.

The Paris Agreement does not set specific targets for countries or sectors, but relies on 'nationally determined contributions' (NDCs). International shipping emissions are generally not covered by NDCs (and neither are the emissions of international aviation) but given their share in the total emissions and their projected increase, they risk increasing the costs of reaching the Paris Agreement goals if unabated or even put reaching the temperature goal at risk.

In April 2018, the MEPC adopted the Initial IMO Strategy on reduction of GHG emissions from ships (Resolution MEPC.304(72)). It aims to 'reduc[e] GHG emissions from international shipping and (...) phase them out as soon as possible in this century'. It also sets three Levels of Ambition:

- carbon intensity of the ship to decline through implementation of further phases of the energy efficiency design index (EEDI) for new ships to review with the aim to strengthen the energy efficiency design requirements for ships with the percentage improvement for each phase to be determined for each ship type, as appropriate;
- carbon intensity of international shipping to decline to reduce CO<sub>2</sub> emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and
- GHG emissions from international shipping to peak and decline to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO<sub>2</sub> emissions reduction consistent with the Paris Agreement temperature goals.

The Initial Strategy also includes a list of candidate short-, mid- and long-term measures, defined respectively as measures that will be agreed by the MEPC before 2023, between 2023 and 2030, and after 2030. Given these timelines, the level of ambition for 2030 will have to be achieved by short- and possibly also mid-term measures.

Climate scientists have developed the concept of a carbon budget, which indicates the amount of anthropogenic CO<sub>2</sub> emissions that will result in a certain global average temperature increase. The most recent estimate indicates that the budget to limit the global average temperature increase to 1.5°C is about 420 – 570 Gt of CO<sub>2</sub> which can be emitted from 2018<sup>1</sup>; if an additional 50% of that amount of CO<sub>2</sub> is emitted, the global average temperature increase will reach 2°C.

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<sup>1</sup> These estimates result in a 66% probability of keeping the temperature increase to 1.5°C; the first estimate relates to the global mean surface air temperature, the second to the global mean surface temperature. IPCC 2018, summary for policymakers C1.3.

There is no scientific way to divide the remaining carbon budget over countries or sectors. One way to do so is to start from the current share in annual emissions and allocate proportional shares of the carbon budget to sectors or countries.

In order for the shipping emissions to be reduced in a way that is consistent with the Paris Agreement temperature goals, as called for in the Initial Strategy, it is necessary to estimate how the emissions will develop, and what the impact of short-term measures will be on emissions up to 2030.

## **1.2. Aims and scope of the study**

This report aims to support informed decision making related to the implementation of the initial IMO GHG strategy on GHG emissions from ships. Against the policy background described in the preceding chapter, this report aims to identify and design short-term measures that can reduce emissions in the short-term. It will estimate their impact on 2030 emissions and the 2030 level of ambition in the Initial Strategy.

An accompanying report calculates the carbon budget for shipping as well as the share that will remain after implementation of the short-term measures and lays out technological pathways towards decarbonisation and identify areas in which further research would be needed in order to phase out emissions completely.

Specifically, the research questions of this report are:

- Which short-term measures have the ability to reduce GHG emissions from international shipping in the short term?
- What will their impact be on:
  - 2030 emissions; and
  - The 2030 level of ambition included in the initial strategy?

The associated report answers the following questions:

- What does this mean for the remaining budget after 2030:
  - What is a proportionate climate budget for international shipping; and
  - Which share of the budget will be left in 2030?
- Which technological pathways can result in staying within the carbon budget as well as meeting the 2050 level of ambition?

Following from the context provided in Section 1.1, this report focusses on measures included in the Initial IMO Strategy. Its scope is limited to CO<sub>2</sub> emissions, which account for over 98% of the GHG emissions of shipping, expressed in CO<sub>2</sub> equivalents (IMO, 2015).

The project was initiated in 2017. The policy measures analysed in this study were based on a draft version of the Initial Strategy contained in MEPC 72/7 and are interpretations of the short-term measures included in that draft, which are deemed to directly reduce GHG emissions from ships. Since then, the Initial Strategy has been further developed, adopted, and various Parties have submitted new proposals for short-term measures to the MEPC. These proposals may resemble policy measures analysed in this report, but can have different features which may result in different impacts on GHG emissions.

## **1.3. Methodology**

This study employs a diverse suite of methods and models. The design of the short-term measures in Chapter 2 is based on desk studies as well as on interactions with stakeholders, both bilaterally and in two workshops organised over the course of the project. The emissions modelling in Chapter 2 is done with two models that are introduced in the chapter as well as by ad-hoc modelling.

#### **1.4. Outline of the report**

Chapter 2, the most extensive of this report, presents short-term measures that are able to reduce emissions before 2030 and analyses their impacts on emissions. Chapter 3 summarises and concludes.

## 2. Short-term measures and their impacts on emissions

### 2.1. Introduction

The Initial IMO Strategy on reduction of GHG emissions from ships (Resolution MEPC.304(72)) contains a list of 13 candidate short-term measures, defined as measures that will be agreed by the MEPC before 2023. The list, which is non-exhaustive, offers predominantly high-level indications of measures, like 'further improvement of the existing energy efficiency framework with a focus on EEDI and SEEMP, taking into account the outcome of the review of EEDI regulations' or 'incentives for first movers to develop and take up new technologies'. As indicated in the Strategy, measures can be grouped into measures that directly reduce GHG emissions from ships and measures that support action to reduce emissions.

This report considers the following measures to have a possible direct impact on CO<sub>2</sub> emissions from ships:

- further improvement of the existing energy efficiency framework with a focus on EEDI and SEEMP, taking into account the outcome of the review of EEDI regulations;
- develop technical and operational energy efficiency measures for both new and existing ships, including consideration of indicators in line with the three-step approach that can be utilized to indicate and enhance the energy efficiency performance of shipping, e.g. Annual Efficiency Ratio (AER), Energy Efficiency per Service Hour (EESH), Individual Ship Performance Indicator (ISPI) and Fuel Oil Reduction Strategy (FORS);
- establishment of an Existing Fleet Improvement Programme;
- consider and analyse the use of speed optimization and speed reduction as a measure, taking into account safety issues, distance travelled, distortion of the market or trade and that such measure does not impact on shipping's capability to serve remote geographic areas;
- encourage the development and update of national action plans to develop policies and strategies to address GHG emissions from international shipping in accordance with guidelines to be developed by the Organization, taking into account the need to avoid regional or unilateral measures.

Some of these measures, like the Existing Fleet Improvement Programme, have been described in more detail in various submissions to the ISWG-GHG and the MEPC. Others have not. The latter measures have been developed further in this chapter. In some cases, we came up with several possible designs of the measures.

Thus, this chapter contains possible designs of the following policy measures:

- improvement of the EEDI and SEEMP:
  - improvement of the EEDI:
    - strengthening the EEDI for new ships;
    - applying the EEDI to existing ships.
- improvement of the SEEMP:
  - mandatory goal setting;
  - mandatory periodic efficiency assessment;
  - mandatory retrofits of cost-effective technologies.
- operational efficiency standards;
- existing Fleet Improvement Programme;
- speed regulation;
- national or regional action plans:
  - development of a standard for ship-shore communication;
  - development of a standard for port incentive schemes;
  - development of a framework for the uptake of renewable fuels on short-haul routes.

Note that the project was initiated in 2017. The policy measures analysed in this study were based on a draft version of the Initial Strategy contained in MEPC 72/7 and are interpretations of the short-term measures included in that draft, which are deemed to directly reduce GHG emissions from ships. Since then, the Initial Strategy has been further developed, adopted, and various Parties have submitted new proposals for short-term measures to the MEPC. These proposals may resemble policy measures analysed in this report, but can have different features which may result in different impacts on GHG emissions.

In the next sections of this chapter, a design of each of these measures is presented. In addition, the impacts of these measures on emissions are quantified with the GloTraM model. The quantification is relative to a BAU scenario that is described in the next subsection.

### **2.1.1. GHG emissions under the BAU scenario**

In order to assess the impact of different policy measures on reducing GHG emissions from shipping, it is important to first establish the future developments of shipping's GHG emissions under a Business as Usual (BAU) scenario. This enables the comparison between a scenario in which a new policy measure has been put in place and one without any additional policies. For example, the relative impact on GHG emissions of a speed reduction measure depends on the development of operational speed in the BAU scenario. Similarly, the impact of measures that improve ships' technical energy efficiency depends on the improvement of the fleet's technical energy efficiency in the BAU scenario.

In the GloTraM model, the emission projections for the BAU scenario are based on:

- Transport work projections (as a function of the historical relation between GDP and fossil energy consumption -see Annex).
- Projections of ships' design efficiency (EEDI and market-driven).
- Projections of fleet developments (ship size, fleet renewal).
- Projections of ships' operating speed.

The investment and operational (speed) decisions are projected for each ship type, size and age category, by maximising a shipowner's profits under a given regulatory and macroeconomic environment (see Annex 0 for more details). This means that in the BAU scenario, the GloTraM model allows shipowners to optimise ships' operating speed to suit market conditions (most ships currently operate at lower speeds than design speed, therefore, there is scope for speeding up as well as for slowing down).

Under the specified conditions in the BAU scenario, ships' average operating speed would increase (almost continually) from 2020 onwards and by 2030, would be close to 2008 speed levels (see Figure 1). This is related to the model's assumption that over the period to 2030, there will be a gradual reduction in the general overcapacity in shipping that has persisted since after the financial crisis, and that this return to a closer balance between capacity/supply and demand will return freight rates to their long-run average values.

At the same time, due to expected continued growth in transport demand (the scenario applied in this modelling is from the Third IMO GHG Study, RCP 2.6 SSP1), the number of active ships grows steadily and by the year 2030, will then be nearly twice as high as in 2016 (see Figure 2). As a consequence of the increase in ships' operating speed, fleet growth and the other factors considered in GloTraM (see above), CO<sub>2</sub> emission in the BAU scenario approximately double in 2030 relative to the value in 2008 (as shown in

Figure 4). We conducted a sensitivity scenario for the BAU with a different transport demand (RCP 4.5 and SSP3 transport demand, which has a higher level of transport demand for oil tankers and lower levels of demand for the other ship types relative to the demand scenario used in BAU) which leads to a lower level of CO<sub>2</sub> emission (about 7% in 2030 relative to the BAU) (see Annex A, Figure 22), but otherwise does not significantly modify the general findings of this study. Overall, in 2030 RCP4.5 and SSP3 transport demand is lower than RCP2.6 and SSP1 by 5.2%.

Figure 1 - Weighted average operational speed for a subset of the global fleet

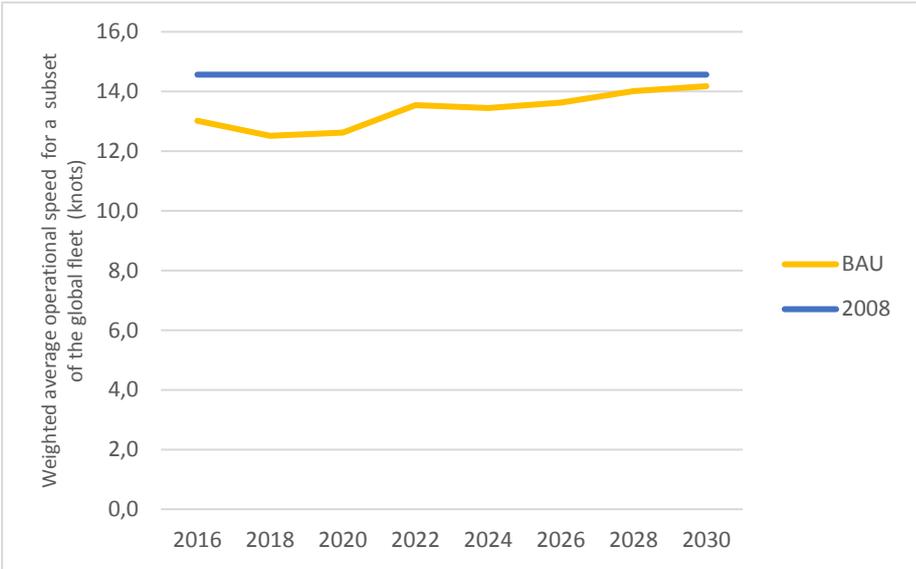
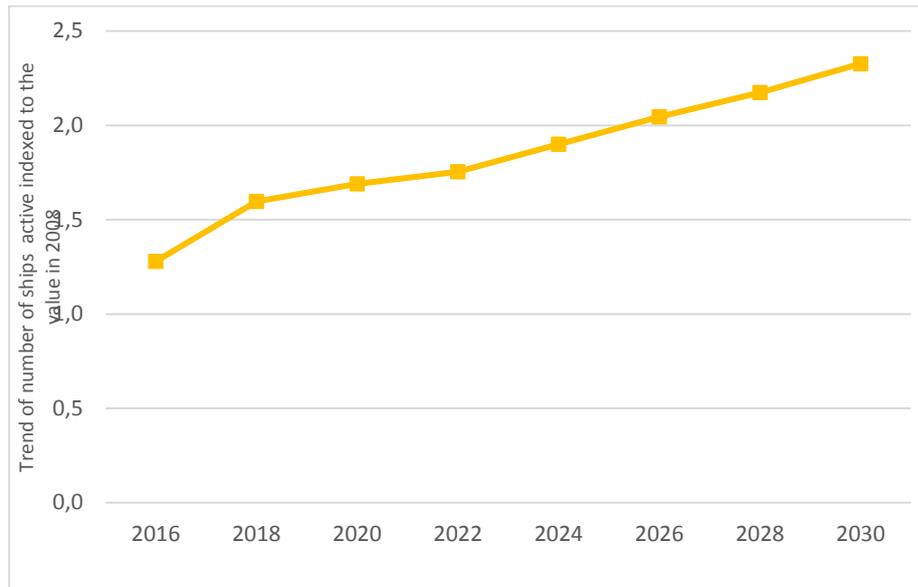


Figure 2 - Trend of number of ships active indexed to the value in 2008



The BAU scenario shows a considerable improvement of the technical efficiency between 2008 and 2016 as shown in Figure 3. This improvement incorporates both the reduced EEDI of newbuild ships over this period, and also the improvement to the existing fleet (e.g. through retrofit) and the change in the composition of the fleet (proportions of different ship types and the underlying trend of increasing ship size). For ships that entered the fleet in this period, this improvement is plausible and also reflected in Estimated Index Values (EIVs, a simplified form of the EEDI) of these ships. During the modelled period 2016 to 2030 the EIV continues to improve, approximately 6%. This is based on two aspects: the first aspect is that the new ships will need to comply with the EEDI Phase 3 requirements (the model ensures that new ships are compliant with the existing regulation including the EEDI limits). The second aspect is the expectation that shipping companies would retrofit, to some extent, cost-effective technologies like propeller and rudder upgrades, bulbous bow improvements, advanced hull coatings, etc. under the projected market conditions. The sensitivity of this BAU scenario's efficiency improvement to the conclusions drawn on the different measures is discussed throughout the report, including the impact on the findings that would arise in the event of a lower reduction in EIV over the period 2008 to 2016.

Figure 4 also shows the least ambitious interpretation of the 2030 carbon intensity objective of the Initial IMO GHG Reduction Strategy, i.e. "to reduce CO<sub>2</sub> emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008" (Resolution MEPC.304(72)). In order to achieve a 40% carbon intensity reduction on 2008 carbon intensity, we estimate that a CO<sub>2</sub> emissions reduction of approximately 21% in 2030 relative to the BAU will be required. This is based on the assumptions used for the BAU scenario (e.g. transport demand) and the resulting technical (e.g. efficiency) and operational changes (e.g. speed).

Figure 3 - Weighted average design efficiency for a subset of the global fleet

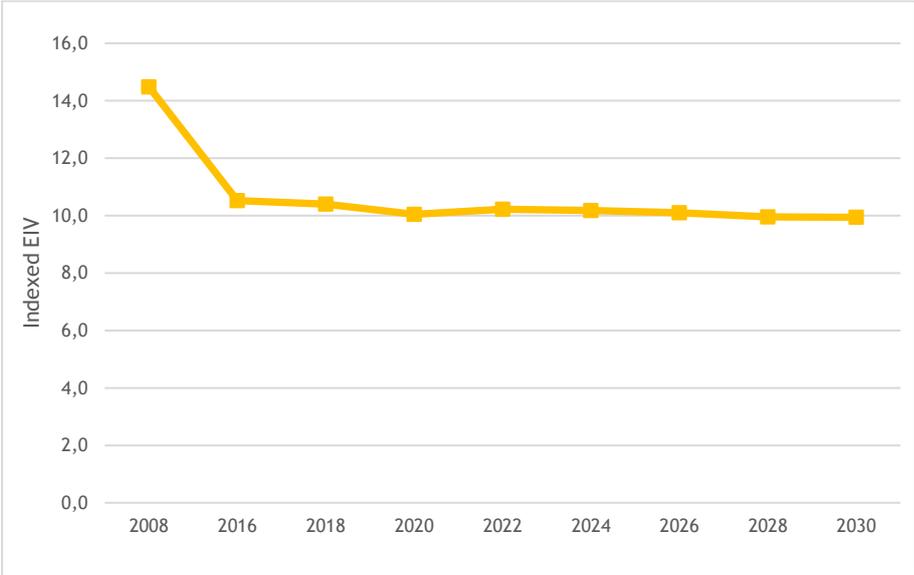
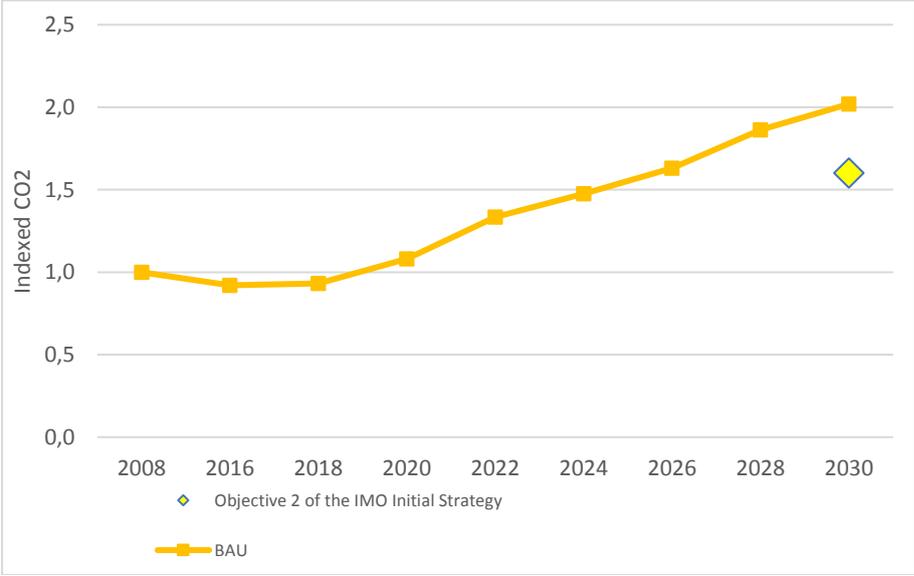


Figure 4 - Trend of CO<sub>2</sub> emissions relative to the value in 2008 in a BAU scenario



## 2.2. Strengthening the EEDI for new ships

### 2.2.1. Introduction

Regulation 21 of MARPOL Annex VI that entered into force in January 2013, requires the attained Energy Efficiency Design Index (EEDI) of certain categories of ships not to exceed the required EEDI.

The required EEDI is thereby determined according to ship's size and ship type by using a reference line value, which represents an average EEDI value of ships delivered in the preceding 10 years (from 1 January 1999 to 1 January 2009). And the attained EEDI is calculated according to the formula as laid down in the *2014 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships* (Resolution MEPC.245(66); MEPC 66/21/Add.1, Annex 5).

The CO<sub>2</sub> reduction level for the first phase that started in 2015 has been set to 10% and will be tightened every five years (see Table 2).

Table 2 – Reduction factors (in percentage) for the EEDI relative to the EEDI Reference line

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 and onwards
Bulk carrier	20,000 DWT and above	0	10	20	30
	10,000–20,000 DWT	n/a	0-10*	0-20*	0-30*
Gas carrier	10,000 DWT and above	0	10	20	30
	2,000–10,000 DWT	n/a	0-10*	0-20*	0-30*
Tanker	20,000 DWT and above	0	10	20	30
	4,000–20,000 DWT	n/a	0-10*	0-20*	0-30*
Container ship	15,000 DWT and above	0	10	20	30
	10,000–15,000 DWT	n/a	0-10*	0-20*	0-30*
General Cargo ships	15,000 DWT and above	0	10	15	30
	3,000–15,000 DWT	n/a	0-10*	0-15*	0-30*
Refrigerated cargo carrier	5,000 DWT and above	0	10	15	30
	3,000–5,000 DWT	n/a	0-10*	0-15*	0-30*
Combination carrier	20,000 DWT and above	0	10	20	30
	4,000–20,000 DWT	n/a	0-10*	0-20*	0-30*
LNG carrier	10,000 DWT and above	n/a	10**	20	30
Ro-ro cargo ship (vehicle carrier)***	10,000 DWT and above	n/a	5**	15	30

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 and onwards
Ro-ro cargo ship***	2,000 DWT and above	n/a	5**	20	30
	1,000 –2,000 DWT	n/a	0-5* **	0-20*	0-30*
Ro-ro passenger ship***	1000 DWT and above	n/a	5**	20	30
	250 –1,000 DWT	n/a	0-5* **	0-20*	0-30*
Cruise passenger ship*** having non-conventional propulsion	85,000 GT and above	n/a	5**	20	30
	25,000–85,000 GT	n/a	0-5* **	0-20*	0-30*

Source: Resolution MEPC.203(62) (MEPC 62/24/Add.1, Annex 19); MEPC 251(66) (MEPC 66/21, Annex 12).

\* Reduction factor to be linearly interpolated between the two values dependent upon ship size. The lower value of the reduction factor is to be applied to the smaller ship size.

\*\* Phase 1 commences for those ships on 1 September 2015.

\*\*\* Reduction factor applies to those ships delivered on or after 1 September 2019, as defined in paragraph 43 of regulation 2.

n/a: no required EEDI applies.

The measure incentivizes the improvement of the technical efficiency of new ships.

Regulation 21.6 of MARPOL Annex VI requires the IMO to review the EEDI w.r.t the status of technological developments to implement the energy efficiency design index at the beginning of Phase 1 (1 January 2015) and at the midpoint of Phase 2 (1 July 2022), and, if proven necessary, amend the time periods, the EEDI reference line parameters for relevant ship types and the reduction rates.

The first review has already been carried out with the outcome (MEPC 70/18) that the Committee agreed to retain the reduction rates, time periods and EEDI reference line parameters in the Phase 2 requirements for ship types other than ro-ro cargo and ro-ro passenger ships. And that the Committee agreed to consider a proposal by the United States to bring forward the time periods for Phase 3 to 2022 and to include a Phase 4 in the EEDI framework, and instructed the working group to consider the submitted documents, as well as comments and decisions made in plenary, and examine proposals and options for EEDI reduction rates and dates beyond Phase 2.

The 'Correspondence group on EEDI review beyond Phase 2' is reviewing whether and if so, how the EEDI can be strengthened. It will submit a final report to MEPC 74 in 2019 and interim reports to earlier MEPCs.

### 2.2.2. Current performance of new ships

Many ships that have entered the fleet in recent years have an EEDI that is significantly better than their required EEDI. Table 3 shows that most ship types already meet Phase 2 requirements *on average*, whereas the best performing ships in all ship types except for bulkers already exceed Phase 3 requirements. However, large tankers (over 225,000 dwt) and bulk carriers (over 175,000 dwt) are closer to the reference line than smaller vessels (MEPC 72/INF.12, Annex 11).

Table 3 – EEDI of new ships

Ship type	Average distance of the EEDI to the reference line	Average distance of the EEDI to the reference line of 10% best performing ships
Bulk carriers	19.7%	27%
Tankers	23.3%	35%
Container ships	37.9%	58%
General Cargo	28.3%	57%
Gas Carrier	25.1%	42%

Note: The average distance of the EEDI to the reference line is taken from the IMO EEDI database, version 5 February 2019. The average performance of the 10% best performing ship is from Transport & Environment, 2017 (T&E, 2017).

For the vast majority of ships, EEDIs have been attained without recourse to innovative technologies such as wind propulsion and without reducing the design speed (CE Delft, 2016; CE Delft, 2017a). Wind assisted propulsion is especially attractive for large slow ships with sufficient deck space, which are precisely the types that appear to have improved the least in recent years. MEPC 72/INF.12, Annex 14 provides two examples where flettner rotors improve the EEDI by 5 percentage points.

### 2.2.3. Proposals for strengthening the EEDI for new ships

Two options have been selected for further strengthening of the EEDI. Both are currently studied by the correspondence group.

The first option would be to implement Phase 3 in 2022 instead of 2025. For most ship types and size categories this appears to be a viable option as ships have already been built that exceed Phase 3 requirements.

The second option is to tighten the reduction factors for some ship types. Container ships and general cargo ships appear to be the best candidates for this.

### 2.2.4. Impacts on ship design, equipment, operations and fuel consumption

We do not expect that a decision to move the implementation date for Phase 3 to 2022 will have a major impact on ship design, equipment, operations and fuel because ships are already sailing today that exceed Phase 3 requirements. Perhaps large bulk carriers or tankers would need to be fitted with less powerful engines (and hence have lower design speeds) or with innovative technologies. The other ship types would have fewer challenges in meeting Phase 3 requirements.

A further increase in the stringency could have an impact on ship design, equipment, operations and fuel, especially for bulk carriers and tankers. MEPC 72/INF.12, Annex 9, 10 and 14 show that there are a number of technologies that these ships could choose from to meet a more stringent EEDI requirement:

- using LNG or other low-carbon fuels;
- installing less powerful engines and lowering the design speed;
- installing wind-assisted propulsion;
- installing energy saving devices.

### 2.2.5. Safeguarding sufficient propulsion power in adverse weather conditions

For some ship types, a further strengthening of the EEDI could result in underpowered ships which cannot manoeuvre safely in adverse weather conditions. This appears to be the case in particular for large tankers and bulkers beyond Phase 2 of the EEDI (see Annex B).

However, if not by using more innovative design, the problem could be resolved by limiting the shaft power under normal conditions, while allowing ships to lift the limitation in adverse weather conditions if properly documented. This has been proposed by Germany, Norway and Spain in MEPC 73/5/1. By doing so, ships would have more installed power than they would be permitted to use under normal conditions. For many ships, this means that they would sail below their design speed most of the time. However, in adverse weather conditions, the ships would be able to use the excess power for save manoeuvring. This opens the way to strengthening the EEDI and ensuring that ships are sufficiently powered in adverse weather conditions.

### 2.2.6. Impact on GHG emissions

In order to model the impacts on GHG emissions of a strengthened EEDI for new ships, we introduced in the GloTraM model the following elements to the existing EEDI regulation:

- Early implementation of Phase 3: 2022 instead of 2025.
- Phase 4 starting from 2027 (five years after 2022) with a uniform reduction factor of 40% for all ship types.

The modelling simulation suggests that strengthening the EEDI for new ships would reduce the global fleet's CO<sub>2</sub> emissions by about 2% in the year 2030 compared to the BAU scenario. This measure by itself is therefore estimated to be insufficient to meet the 2030 level of ambition included in the IMO initial strategy; a further CO<sub>2</sub> emissions reduction of about 19% would be required.

Strengthening the EEDI for new ships would have a delayed effect on overall CO<sub>2</sub> emissions, as it takes several decades for the fleet to turnover and for new ships built after the period of implementation of new EEDI stringencies to be a significant portion of the overall fleet.

This measure is only expected to result in a 2% emissions reduction because the savings achieved in practice are expected to be lower than those of the technical efficiency increase. Technical efficiency improvements stimulated under this measure would reduce a ship's fuel consumption at a given speed which in turn would reduce the cost and marginal cost of increased speed. Assuming all else being equal (including design speed), a ship has a commercial incentive to operate at a higher than average speed if its technical energy efficiency is better than the average and if there is sufficient market demand. These incentives are included in the model and explain why the actual saving can be lower than the technical efficiency increase.

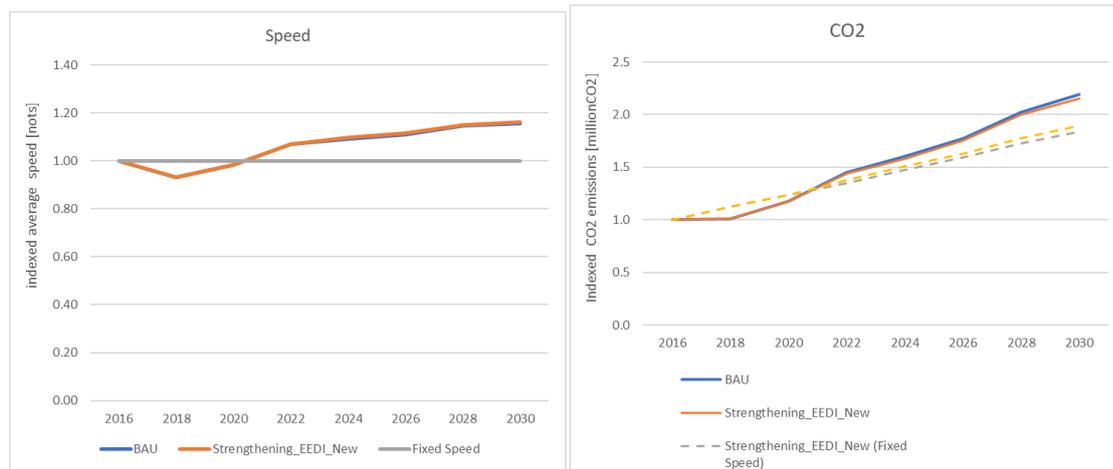
Note that this modelling result assumes that the EEDI can be met without lowering the design speed of a vessel. If instead the EEDI results in lower design speeds, the rebound effect may not occur, or may occur to a lesser extent.

To assess the potential impact of the rebound effect, we have artificially constrained the UMAS model to keep operating speeds fixed, and compared the results with the model as usual (allowing shipowners to optimise speed to suit market conditions). Figure 5 shows the sensitivity for this policy scenario with and without fixed speed. The results suggest that the rebound effect could approximately halve the benefit of CO<sub>2</sub> emissions reduction gained from the technical efficiency improvements, therefore, we estimated that this measure, without rebound, would result in an approximately 3% emissions reduction in 2030 (the difference between the dotted grey line and dotted yellow line in the right hand plot). This means that even without a rebound effect, this measure would not

achieve the IMO’s level of ambition for the year 2030 and a further 18% CO<sub>2</sub> emissions reduction would be required.

Future transport demand is important for this measure as it drives the number of new ships that will enter the fleet and therefore the potential impact on emissions reduction. For example, if the transport demand growth slows relative to the projection, and fewer new more efficient ships are built, the fleet’s composition and emissions will be more dominated by the existing fleet. This results in a lower emission reduction of this measure. If, on the other hand, trade grows more than projected, there would be more efficient ships added to the fleet and the measure would have higher results.

Figure 5 - Sensitivity for this policy scenario with and without fixed speed



We further examined this measure using the CE Delft emission projection model, which projected a 1% reduction in emissions in 2030. That model also allowed to assess the impacts of different trade projections–10% less trade in 2030 would result in a 10% lower impact of the measure, relative to BAU (i.e. approximately 0.9% emission reduction).

The results from the CE Delft model are comparable with the GloTraM result of 1.6% (rounded at 2%) confirming the limited impact of the measure.

### 2.2.7. Conclusions

There appears to be scope for a further strengthening of the EEDI: studies show that designs with EEDIs more than 30% below the reference line are possible; several ships have already achieved such an EEDI; and the use of innovative technologies or less powerful engines is very limited to date.

Strengthening of the EEDI for new ships can be done as indicated in Table 4.

Table 4 - Strengthening the EEDI for new ships

Responsible entity	The responsible entity would be the ship
Requirement that the entity has to fulfil	Each ship built after 2022 and 2027 would need to have an attained EEDI that is respectively 30% and 40% below the reference line. This requirement would only apply for ship types that are subject to the EEDI.
Monitoring and reporting requirements	Current EEDI requirements apply.
Competent authority	The flag state has to ascertain that a ship has complied with the regulation.
Legal instrument	MARPOL Annex VI Regulation 21 would need to be amended.

However, our modelling of this measure shows consistently that the impact on GHG emission reduction in 2030 is limited to 1% to 2% below the baseline, even in cases when the fleet grows rapidly and the share of new ships in the fleet is relatively large. The predominant reason is that the EEDI for new ships only affects a small share of the fleet in 2030 (the impact of the measure will increase over time) and that the actual CO<sub>2</sub> saving are lower than the technical efficiency increase due to a commercial incentive to operate at a higher than average speed.

A correspondence group is studying further increases and will report to MEPC 74.

## 2.3. Applying the EEDI to existing ships

### 2.3.1. Introduction

Ships with a building contract placed on or after 1 January 2013 or delivered on or after 1 July 2015, have to comply with the Energy Efficiency Design Index (EEDI)–a technical efficiency standard for new ships.

For existing ships, a technical efficiency standard could be implemented as a short term measure too.

An EEDI for existing ships (referred to in the following as 'ES-EEDI') has been discussed in the IMO before, however, most of the proposals are related to a measure that combines the technical standard with a monetary instrument, like e.g.:

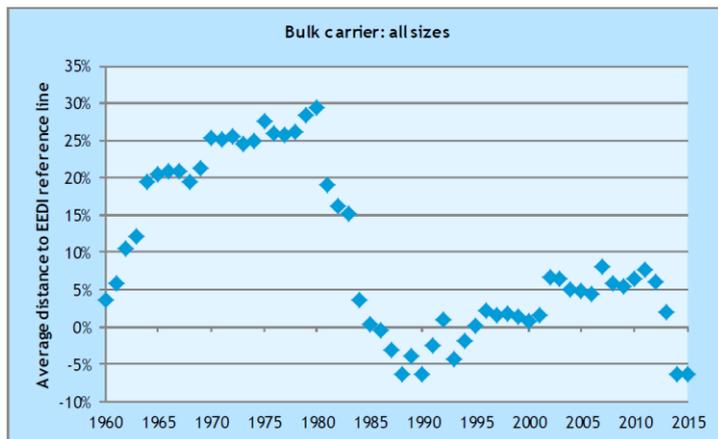
- MEPC 60/4/39: Vessel efficiency system (VES) proposed by the WSC: EEDI for existing ships in combination with charges for those who do not comply based on fuel consumption.
- MEPC 61/INF. 24: SETC as proposed by the US: credit and baseline trading scheme based on a technical efficiency benchmark;
- MEPC 63/5/3: Efficiency Incentive Scheme (EIS) as proposed by Japan and the WSC: a technical efficiency standard combined with a fee for those who do not comply based on fuel consumption and the relative efficiency of the vessel.

### 2.3.2. Current performance of existing ships

The EEDI of existing ships is not known. An indication of the design efficiency of existing ships is available, however, from studies into the Estimated Index Value, which is a simplified form of the EEDI. CE Delft & UCL (2016) have shown that the average design efficiency of new ships was at its best around 1990, deteriorated afterwards and has recently improved significantly.

Figure 6 shows how the average design efficiency of bulk carriers has varied over time as a function of their year of entry in the fleet. Tankers and container ships show similar patterns.

Figure 6 –The design efficiency of new bulkers as a function of the year of entry in the fleet



Source: CE Delft & UCL (2016).

Note: A negative value indicates a relatively efficient fleet, a positive value a relatively inefficient fleet.

### 2.3.3. How the EEDI could be applied to existing ships

#### Metric

The ES-EEDI could be based on the attained EEDI metric, i.e.  $g/(t\ nm)$ , calculated as specified in the 2014 guidelines MEPC.1/Circ.866, since the technical efficiency of an existing ship is in principle determined by the same factors as the technical efficiency of a new ship.

This is a major advantage compared to an operational efficiency standard where no consensus on a metric has been reached yet.

The different parameters used to calculate the attained ES-EEDI may however deviate from the parameters used to calculate the attained EEDI, since they may change over time and with the state of maintenance. For the calculation of the attained EEDI for example, the SFC as specified in the NO<sub>x</sub> technical code is used, but for a 10 year old ship the SFC may be higher if the ship's engine is not maintained on a regular basis.

#### Reference line

The ES-EEDI could be based on the reference lines that have been determined for the EEDI that has already been implemented for new ships. Working with the EEDI reference lines has advantages and disadvantages.

An advantage is that it would allow a relatively quick implementation of the measure.

A disadvantage of working with the EEDI reference lines is that they do not reflect the entire existing fleet—the underlying EIV values have been calculated for ships that have been built in the period 1999 to 2009 which makes target setting and an assessment of the impacts rather difficult.

If using the existing EEDI reference lines is considered problematic, reference lines could be recalculated using data of ships built in earlier periods. To nevertheless be able to move on rather quickly, the existing reference lines could be used temporarily in combination with a rather soft target so that only the worst designed ships are affected at the date of implementation. Once real data of ES-EEDIs become available, reference lines can be recalculated for and a more stringent target can be set, based on an analysis of the share of the fleet that would be affected.

Worth mentioning in this context: the EIV data have to be reported and published in the context of the EU MRV regulation (2015/757) (EU, 2015). According to the regulation (Article 11 (3a), Article 21 (2b)), ships not covered by the EEDI have to report their EIV,

at least if the according ship type is covered by EEDI. (see also Guidance/Best practices document on monitoring, reporting and verification emissions from maritime transport).

Working with the EEDI reference lines would also mean that ship types not covered by the EEDI would also not be covered by the EEDI for existing ships. These ship types are, for example, fishing vessels, yachts, tugs, and dredgers. Collectively, these ship types accounted for 13% of CO<sub>2</sub> emissions in 2012 (Third IMO GHG Study 2014).

### Target

The EEDI for new ships requires the ships' technical efficiency to be x% better than the reference efficiency.

The EEDI for existing ships could require the existing ships to improve their efficiency such that their efficiency is not more than x% worse than the reference efficiency.

As discussed above, the EEDI reference lines may not provide sufficient data to base a target decision on. This could be solved by choosing a conservative target in the first instance and by applying a—in general—pre-specified target after real EEDI data for existing ships becomes available after Phase 1 of the EEDI for existing ships.

Just like the EEDI for new ships has a less stringent target for small ships (the definition of 'small' varies across ship types), the ES-EEDI could also have differentiated treatment of small ships.

New ships are not in general more efficient than old ships (see Section 2.3.2). That is why old ships do not have to be exempted from an EEDI for existing ships. On the other hand, technical reduction measures even with a relative short payback time, might not pay off if applied to ships that are scrapped in the foreseeable future. For this reason it could make sense to exempt very old ships from an EEDI for existing ships. However, the EEDI for existing ships should not incentivize that very old ships are kept longer in the fleet and are later replaced by an EEDI compliant ship than in the baseline. This could for example be solved by not fully exempting very old ships but by giving very old ships the choice between an efficiency improvement and a fee to be paid, dependent on the deviation from the target, with the revenue being used to reduce emissions elsewhere.

Since ships flagged in developing economies are on average 10 years older than those flagged in developed countries (UNCTAD, 2017), there may be a call for age-differentiated targets. This option could help to increase the political acceptability of the retroactive measure.

### How ships can be required to meet the obligation

The EEDI for new ships requires the parameters that are necessary for the calculation of a ship's EEDI to preliminary be determined and verified at the design stage of the ship and to finally be determined and verified in a sea trial.

Enforcement of an EEDI for existing ships does not necessarily require a new sea trial since the documentation of a ship will always contain the speed-fuel curve or the speed-power curve of the delivery sea trial. The attained ES-EEDI can be calculated from this document. If improvements are made to the energy-efficiency of the ship, the efficiency improvements of the different efficiency measures could be determined without each ship having to demonstrate their impact on the attained ES-EEDI. Compliance could be demonstrated by substantiated and verified calculations.

The period in which ships will be required to improve their efficiency, could account for the ships' dry dock periods, to avoid unnecessary costs and ship yard capacity bottlenecks.

The International Energy Efficiency Certificate (IEEC) could, just as for the EEDI for new ships, serve as proof that a ship complies<sup>2</sup>.

#### **2.3.4. Impacts on ship design, equipment, operations and fuel consumption**

If the EEDI is applied to existing ships it will incentivize the uptake of measures with which the attained ES-EEDI can be improved.

Ship design elements that cannot be changed or only against extremely high costs on an existing ship, like for example its hull form, will not be incentivized by the measure.

An ES-EEDI could however incentivize the uptake of retrofit technical energy efficiency measures, including the de-rating of engines or shaft-power limitation, with the latter improving the ship's fuel efficiency if the ship reduced its speed. A shaft power limit could be installed with an option to bypass the option in adverse weather conditions, so that safety would not be compromised.

If parameters like the SFC would be determined not based on documents issued at the time the ship was built, but at the time of the calculation of the attained ES-EEDI, then maintenance could be stimulated at least once, i.e. before a new measurement would take place.

#### **2.3.5. Safeguarding sufficient propulsion power in adverse weather conditions**

The propulsion power in adverse weather conditions could be maintained in the same way as for new ships, as explained in Section 2.2.5.

#### **2.3.6. Impact on GHG emissions**

Assessing the impact of this measure in particular on emissions requires an accurate estimate of the design-efficiency of the current fleet (at the point when the regulation enters into force) as well as reliable projections of the expected specifications of scrapped ships in BAU circumstances. The model that is used for the other measures contains both an estimate of the BAU design-efficiency trend (6% improvement in design efficiency from 2016 to 2030), and of how ships are scrapped (ships are scrapped on the basis of their age, when they have been in service 30 years), however there is no empirical quantification of the model's uncertainty in these respects. Acknowledging the sensitivity of the measure's impacts to these uncertainties, we have therefore analysed the possible impacts in two different ways.

The first way to estimate the impact of this measure is by estimating how the design efficiency of the current fleet would change if ships that are worse than a certain level would be upgraded to the average efficiency or replaced by more efficient ships (as a simplified way of modelling the effect of improving design efficiency, which could be achieved in any way possible, to a given target). Using a database of the Estimated Index Value (EIV) of tankers, bulk carriers and container ships, we estimated how the average EIV would change if ships that are 30%, 20% or 10% or just above the reference line would be removed from the fleet. A detailed analysis is presented in Annex 0. The summary results are presented in Table 5.

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<sup>2</sup> "An International Energy Efficiency Certificate for the ship shall be issued after a survey in accordance with the provisions of regulation 5.4 to any ship of 400 gross tonnage and above, before that ship may engage in voyages to ports or offshore terminals under the jurisdiction of other Parties. The certificate shall be issued or endorsed either by the Administration or any organization duly authorized by it. In every case, the Administration assumes full responsibility for the certificate." [MEPC Resolution 203(62)].

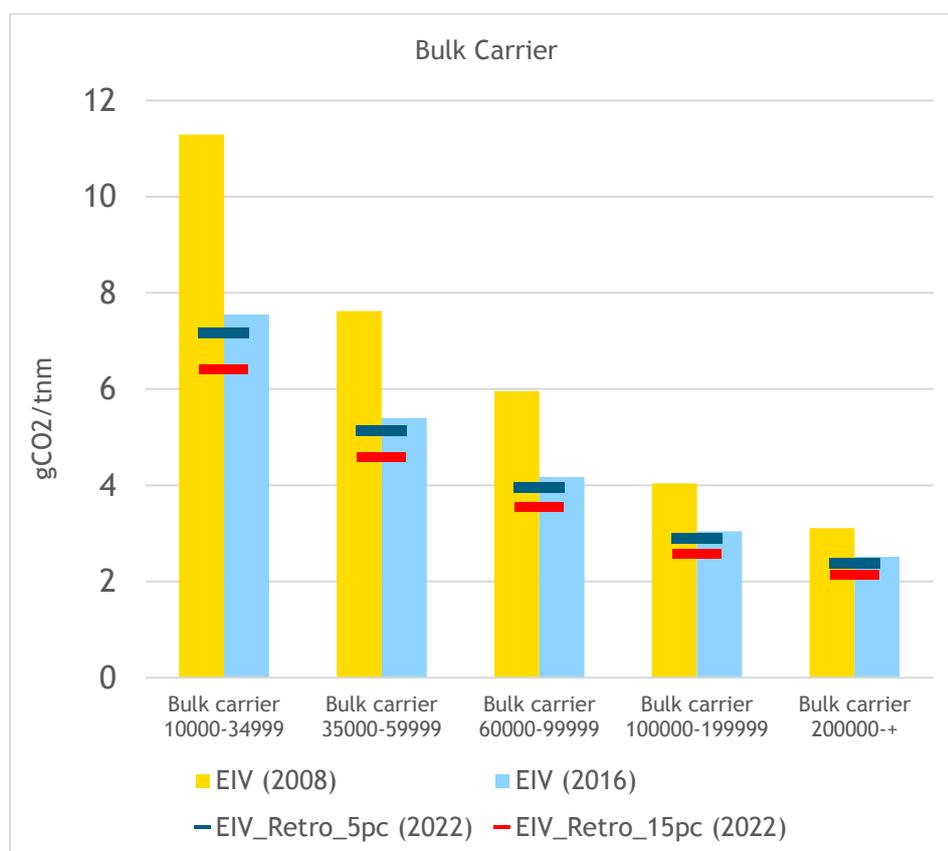
Table 5 - Improvement of the design efficiency of the fleet if the least efficient ships are removed

Cut-off value	% improvement	% non-compliant ships
0% above the reference line	-14%	52%
10% above the reference line	-9%	24%
20% above the reference line	-6%	8%
30% above the reference line	-4%	4%
No cut-off	0%	0

Table 5 shows that if ships that have an EIV 30% or more above the reference line would be upgraded to the average efficiency or replaced by averagely efficient ships, the average design efficiency of the fleet would improve by 4%. If ships that are more than 20% above the reference line would be removed, the average design efficiency would be improved by 6%. If these ships would be replaced by ships below the reference line, the gains would be even larger.

A second way to estimate the impact of this measure is to model the impact on GHG emissions of applying two different EIV stringency levels in a dynamic model. We examined two options in which the EIV is set to 5% and 15% below the baseline EIV in 2016 calculated across ship types and sizes. As an example, Figure 7 shows the levels of stringency used for bulk carriers as well as the EIV estimates in 2008 and 2016.

Figure 7 - EEDI levels of stringency used for bulk carriers. EIV (2008) and EIV (2016) show the mean EIV in their respective years.



The modelling simulations estimate that applying the EEDI to existing ships (listed in Annex A.3) for the 5 and 15% stringencies, would reduce CO<sub>2</sub> emissions between 1% to 3% in 2030, relative to BAU. There are three explanations for why this is a relatively small change even though this is a policy that could be applied to the whole fleet:

- The stringency (5 and 15%) is necessarily quite low, to ensure that all ships would be able to meet the reduction targets (we did not model the potential for design speed reduction as a means to meet the reduction requirement).
- The BAU scenario against which this policy's change in emissions is calculated, already estimates some retrofitting of the existing fleet due to market forces (e.g. fuel price). This means that to close the gap to the 5-15% improvement in 2008 average EIV, the change is smaller than if this stringency were applied to the same ships in 2008 (e.g. before they had been retrofitted).
- Similar to the measure of strengthening the EEDI for new ships, the model reflects the potential rebound effect. That is that for the ships that improve their EIV, they are estimated to increase operating speeds relative to the BAU scenario, due to the incentive to increase operating speed in response to the improved technical energy efficiency. This effect therefore reduces impacts.

By removing speed optimisation from the modelling and artificially constraining the fleet to maintain a constant speed, this policy option is estimated to reduce CO<sub>2</sub> emissions between 2% to 6% in 2030, but realising this upper bound limit of CO<sub>2</sub> emission reduction in practice is unlikely.

This policy's estimated emissions reductions are sensitive to GloTraM's estimate of what has happened to the existing fleet over the last ten years e.g. the estimate that market forces have already driven some EIV improvement in the existing fleet in BAU, but this is limited to approximately 6% improvement between 2016 and 2030. If the amount of retrofitting and EIV improvement is significantly less than estimated, this policy measure's GHG reduction would increase moderately, but it would still be unlikely to achieve levels of GHG reduction sufficient to meet the 2030 IMO Objective.

Increasing the stringency of the policy measure beyond what has been applied in these scenarios may result in certain ships being prematurely scrapped, e.g. because they cannot be economically retrofitted to comply with the policy. Assuming that these scrapped ships were like-for-like replaced with newbuild ships built to achieve either the current regulated minimum EEDI stringencies, or even enhanced stringencies (as in "strengthening the EEDI for new ships", the impact would be greater than estimated in these results.

At these levels of stringency, therefore, this measure by itself is estimated to be insufficient to meet the 2030 Objective included in the IMO initial strategy; a further absolute emissions reduction of about 15-20% would be required.

An approach that could be used to reduce the EEDI of existing ships that was not considered in this analysis, is to reduce the shaft power and therefore the design/reference speed of existing ships. If significant reductions in shaft power were applied, and in such a way that there were no impacts on safety in operation, it is conceivable that a more stringent version of this regulation could be applied, which could achieve greater CO<sub>2</sub> reductions. This higher stringency could be achieved because a greater number of the existing fleet should be able to achieve a greater amount of efficiency improvement. CO<sub>2</sub> reductions achieved could still be subject to some degree of rebound effect, because the design speed reduction implied by the shaft power reduction could not be assumed to correspond to an equivalent reduction in operating speed.

### **2.3.7. Conclusions**

An EEDI for existing ships (ES-EEDI) could mainly use design elements like the metric and the reference lines of the EEDI for new ships. This classifies the measure as a short term measure, although more lead time is necessary for the adoption of incentivized technical reduction measures compared to operational reduction measures.

Regarding the attained ES-EEDI, certain parameters necessary to calculate the measure would have to be checked for their validity for existing ships. And since the EEDI

reference lines have not been determined based on the entire fleet, but on the ships that entered the market in the period 1999 and 2009, an ES-efficiency target might have to be chosen rather generous in the first instance to, if necessary, be tightened after ES-EEDI data of the entire fleet is available. Predefined targets, depending on the actual efficiencies, could help to manage the expectations here.

The ES-EEDI targets would, just as under the EEDI, be differentiated by ship type and size, but would probably be above the requirements for new ships, since existing ships have fewer technical efficiency improvement options compared to new ships and retrofitting is in general more expensive than if measures are installed at the building stage of ship.

It could be considered to allow very old ships, for which most of the measures will not pay off, to use flexibility mechanisms to comply. As an alternative, ship age differentiated are conceivable too.

An ES-EEDI would incentivize technical retrofit measures that contribute to the improvement of the attained ES-EEDI, like for example de-rating of engines.

As a retroactive measure, an ES-EEDI might not be easy to implement, but it would not be the first retroactive measure implemented by the IMO. Ballast water management requirements and sulphur requirements are examples for this.

Applying the EEDI to existing ships can be summarised as indicated in Table 4.

Table 6 - Applying the EEDI to existing ships

Responsible entity	The responsible entity would be the ship.
Requirement that the entity has to fulfil	Each ship would need to have an attained EEDI that is less than the required EEDI. The stringency would need to be decided, for example 10%, 20% or 30% above the applicable reference line. This requirement would only apply for ship types that are subject to the EEDI.
Monitoring and reporting requirements	Ships would need to verify their EEDI according to the existing regulation, e.g. at the first dry docking.
Competent authority	The flag state has to ascertain that a ship has complied with the regulation.
Legal instrument	MARPOL Annex VI Regulations 21 would need to be amended.

The policy measure’s estimated GHG reduction potential in 2030 of 1-6%, depending on the stringency. This means that on its own, it would be very unlikely to be sufficient to achieve the 2030 objective. A variant of the measure that reduces or limits the shaft power may be able to be applied with higher stringency and achieve greater reduction potential, but was not analysed in this study.

## 2.4. Strengthening the SEEMP: Mandatory Goal Setting

### 2.4.1. Introduction

Mandatory goal-setting in the SEEMP is not a new idea. When the SEEMP was proposed by Japan in 2009, it comprised setting both a short- and a long-term goal for the EEOI (GHG-WG 2/4) that would be regularly reviewed by the management. However, this requirement was not taken up in the Regulation or the Guidelines.

Since 2009, several metrics for ship-efficiency have been proposed (CE Delft ; Öko-Institut ;Tim Bäuerle, 2014) and much experience has been gained with different measures (China et al., 2017, (ISWG-GHG, 2017), CE Delft 2015, (MEPC, 2015) (SSPA, 2016), (MEPC, 2018). From this it is clear that the EEOI is not a suitable metric for every ship in all circumstances and that other metrics may show large fluctuations from year to year. Allowing the company to choose the indicator could be a solution for this.

#### 2.4.2. Design of the policy

The policy would entail:

- requiring that a performance indicator for energy efficiency is chosen for each ship;
- requiring that a goal is set for the performance indicator for the next year and for a 3- or five year period; and
- requiring that the goals are updated regularly.

The paragraph on goal setting in the SEEMP Guidelines currently reads:

*The last part of planning is goal setting. It should be emphasized that the goal setting is voluntary, that there is no need to announce the goal or the result to the public, and that neither a company nor a ship are subject to external inspection. The purpose of goal setting is to serve as a signal which involved people should be conscious of, to create a good incentive for proper implementation, and then to increase commitment to the improvement of energy efficiency. The goal can take any form, such as the annual fuel consumption or a specific target of Energy Efficiency Operational Indicator (EEOI). Whatever the goal is, the goal should be measurable and easy to understand.*

This could be changed to:

*Goal setting is an essential element of energy management and directly linked to the performance of the management plan. The company should choose one or more energy-efficiency indicators. For each of these indicators, the company should set a short-term goal (for the current or next year) and a long-term goal (for three to five years ahead). The goals and indicators should be listed in the SEEMP.*

Moreover, in order to mandate regular evaluation of the goals, an additional clause could be added to the regulation: "the validity of the SEEMP shall be one year. The SEEMP can be renewed if conditions specified in the guidelines are met".

We assume that setting a goal would be a top-management decision. Thus, mandatory goal setting would remedy several weaknesses of the SEEMP that were identified by Johnson et al. in their comparison of the SEEMP with the ISM code and the ISO 50001 standard for energy management, namely:

- the establishment of a goal in itself is linked to performance of any management system;
- goal setting usually involves upper management; and
- goals setting and the choice of an energy efficiency metric as a key performance indicator (KPI) facilitates management review of the policy.

Since the design of this measure, proposals have been made to IMO whereby the IMO would set a target which shipping companies would be obliged to meet. Note that the measure designed here does not have this feature and that therefore the analysis in the subsequent sections does not relate to those proposals.

### 2.4.3. Impacts on ship design, equipment, operations and fuel consumption

Because in this design of the measure, shipping companies are free to choose which goal they set, we expect most shipping companies to set goals that are achievable without raising the operational costs of the ship. This means that typically, cost-effective options will be implemented. These are measures like propeller polishing, hull cleaning or coating, weather routing (ICCT, 2011); speed optimisation, trim optimisation and, occasionally, redesigning the bulbous bow (Betram & Tasdemir, 2016).

As an example of what could be achieved, the Green Marine Environmental Program can give an indication. This Program is a voluntary initiative for shipowners and other maritime stakeholders that addresses key environmental issues through 12 performance indicators. Under the program, participants must benchmark their annual environmental performance through the program's exhaustive self-evaluation guides, have their results verified by an accredited external verifier and agree to publication of their individual results. One element of the program for shipowners is that they set a quantified efficiency improvement target as part of an energy performance plan (Green Marine, 2016).

In the past years, shipowner participants in the Green Marine Environmental Program have improved their efficiency by an average rate of 1.4% per year (Green Marine, 2017). Green Marine does not report which changes shipping companies made to achieve these improvements.

The results of Green Marine participants cannot be directly extrapolated to the world fleet for various reasons, including:

- Participation in the Green Marine Program is voluntary. The participants can be expected to attach greater value to environmentally friendly behaviour than the average shipping company.
- The energy performance plan comprises more elements than only goal setting, such as assigning responsibility for the execution of the energy performance plan to a staff member. This is one element that is lacking in the SEEMP and that is expected to increase its effect (Johnson, Johansson, Andersson, & Södahl, 2012).

### 2.4.4. Impact on GHG emissions

We modelled the effect of introducing mandatory goal setting by changing the 'investment parameters' and the 'market barriers' (as described in Annex A The market barriers are included in the model through a 'barrier factor' that represents the proportion of a charterer's fuel cost savings that are returned to the shipowner. The higher the barrier factor, the fewer market barriers exist, e.g. a 100% barrier factor means that all of the charterer's fuel cost savings are returned to the shipowner and that hence, no market barrier exists. For the investment parameters, we assumed that this measure would impact the payback period and interest rate.

For this measure, we assumed that there are fewer market barriers than in the BAU scenario and hence we increased the market barrier factor by 20% (for example for bulk carrier from 32% in the BAU scenario to 38% in this scenario). We have furthermore assumed that the payback period acceptable for the shipowner would be longer (6 years instead of 5 years in the BAU scenario) and set the interest rate (representing the cost of capital) at 5% instead of 10% in the BAU. The 10% in the BAU is based on an analysis of Weighted Average Cost of Capital of shipping companies which on average was calculated to be 10.5% (MEPC 62/INF.7).

This measure was applied from 2022 onwards.

In addition, if the mandatory goal is expressed in an operational efficiency indicator, not a design efficiency indicator, we do not expect a rebound effect to occur.

The modelling simulation suggests that strengthening the SEEMP by making it mandatory for shipowners to set a goal would reduce CO<sub>2</sub> emissions by less than 1% in 2030 (the impact on the fleet’s technical efficiency can be seen in Annex A.4 and the section on technical efficiency, Table 24). This measure by itself is estimated to be insufficient to meet the 2030 level of ambition included in the IMO initial strategy. The main reason for the relatively small impact on emissions is that in the BAU scenario, many cost-effective measures will already be taken, and since it is up to the shipowner to decide at what level to set the goal, we do not expect shipping companies in competitive market to install technologies that are not cost-effective. Since the design of this measure, proposals have been made to IMO whereby the IMO would set a target which shipping companies would be obliged to meet. Depending on the stringency of the target set by IMO, the impact on GHG reductions would be more in line of those achieved by mandatory operational efficiency targets and could achieve the IMO’s 2030 level of ambition (see Section 2.7 for more information).

Because it is uncertain to what extent this type of measure would affect investment decision making and parameters as well as market barriers, the values used in this study are estimates based on an expert judgment. However, even if market barriers to technology take-up were much lower than those assumed in this analysis, the impact of this measure on GHG emissions reductions is not expected to be significantly higher because the policy measure is reliant on voluntary stringency and does not mandate achievement of a certain improvement.

**2.4.5. Conclusions**

Mandatory goal-setting in the SEEMP would probably have a positive impact on its effectiveness in reducing emissions because goal-setting has been proven to have this effect in energy management in other sectors. Moreover, goal-setting may help to involve senior management, which is also a success factor of energy efficiency plans in general.

Mandatory goal-setting can be summarised as indicated in Table 7.

Table 7– Mandatory goal setting summary

Responsible entity	Regulation 22 specifies that the ship has to have a SEEMP on board. The Guidelines place the responsibility with ‘the company and/or the ship’.
Requirement that the entity has to fulfil	Select an energy efficiency metric; Set a goal on a regular basis.
Monitoring and reporting requirements	There are implicit requirements to monitor the selected indicator. There are no requirements to report to entities outside the shipping company.
Competent authority	The flag state has to ascertain that a ship has a SEEMP that has been developed taking into account the Guidelines. It will enforce against ships in its registry that do not comply. In addition, Port States have the right to inspect a ship and its SEEMP.
Legal instrument	There is a requirement to have a SEEMP. Regulation 22 of MARPOL Annex VI specifies that the SEEMP shall be developed taking into account Guidelines adopted by the IMO. Hence, the change required is a change in the guidelines, which should specify that a KPI shall be selected and a goal shall be set.

The impacts of this measure on emissions are difficult to model because of lack of empirical data. However, in the design of this measure chosen in this study, they are likely to be small because the most this measure can likely achieve is to increase the share of cost-effective measures that are

implemented because the goal can be set at will by the shipping company and meeting the goal is not mandatory. Using expert judgement on the likely share, our modelling points to an emissions reduction of a few percent at most.

**2.5. Strengthening the SEEMP: Mandatory Periodic Efficiency Assessment**

**2.5.1. Introduction**

In the current chartering market, energy efficiency appears to be only partially reflected in charter rates (Adland, Alger, Justina, & Jia, 2017). This is odd, because a more energy-efficient ship has lower costs to the charterer. One of the possible reasons cited in the literature is a lack of information about the energy efficiency of a ship (Rehmatulla & Smith, 2015 ).

A potential remedy could be that the SEEMP requires ships to regularly monitor the fuel efficiency in a speed trial and process the data in a standardised way so that charterers can use the speed-power curves when selecting vessels.

**2.5.2. Design of the policy**

Such a policy would be a new requirement in the SEEMP. It could be implemented as a new chapter in the SEEMP Guidelines or as an addition to Section 4.3 of the Guidelines, which is on monitoring. For example a new paragraph stating that the speed-power curve of a ship shall be measured annually in conformity with certain guidelines and that the information shall be available at all times. That would provide the possibility for charterers to request the speed curve in the chartering process, because they would know that it is available (even when ships are not required to publish it).

The speed-power curve can change over time as a result of changes in the condition of a ship, such as hull and propeller fouling, wear of bearings, et cetera. Hence, it needs to be updated regularly. In order to mandate the regular updating of the speed-power curve, the validity of the SEEMP should be limited and renewal could be made conditional on having a recently measured speed-power curve. This would probably require a change in the SEEMP regulation, for example a clause stating that “the validity of the SEEMP shall be one year. The SEEMP can be renewed if conditions specified in the guidelines are met”.

There are several standards for the establishment of speed-power curves. ISO 15016:2015, Guidelines for the assessment of speed and power performance by analysis of speed trial data, provides a standardised way to establish a speed-power curve in a speed trial. It is currently primarily aimed to be used for new ships for which tow-tank data are available and that can sail under standardised trim conditions. There are several commercial companies that develop speed-power curves without these restrictions, using real-time data in combination computer models to standardise the impacts of weather, sea conditions, load and trim (e.g. Propulsion Dynamics, We4Sea).

Table 8 – Mandatory periodic energy-efficiency assessment summary

Responsible entity	Regulation 22 specifies that the ship has to have a SEEMP on board. The Guidelines place the responsibility with ‘the company and/or the ship’.
Requirement that the entity has to fulfil	Establish a speed-power curve on a regular basis, e.g. annually, according to a standard.
Monitoring and reporting requirements	Establish a speed-power curve annually and keep records on the ship and on shore.
Competent authority	The flag state has to ascertain that a ship has a SEEMP that has been developed taking into account the Guidelines. It will enforce against ships in its registry that do not comply.

	In addition, Port States have the right to inspect a ship and its SEEMP.
Legal instrument	There is a requirement to have a SEEMP. Because the speed-power curve can change over time as a result of e.g. hull and propeller fouling, the SEEMP should have a limited validity, and renewal should be conditional on the establishment of a speed-power curve. Regulation 22 of MARPOL Annex VI specifies that the SEEMP shall be developed taking into account Guidelines adopted by the IMO. Hence, the change required is a change in the guidelines, which should specify that a speed-power curve shall be established regularly.

### 2.5.3. Impacts on ship design, equipment, operations and fuel consumption

The mere requirement to regularly establish speed-power curves will not change ship design, equipment, operations and fuels used, although it is intended that such a requirement could potentially result in implementation of operational measures e.g. hull fouling paint, hull cleaning, etc. (pre-trial in order to optimise the trial results) and if it is really used by charterers than it could even lead to implementation of technical measures to improve the speed-power curves. An impact on emissions could also arise from a market preference for fuel-efficient ships. If this preference is translated in higher chartering rates for fuel-efficient ships, this could remove one of the market barriers for retrofitting technologies to improve the fuel-efficiency. It could indirectly result in a higher uptake of cost-effective technical measures.

### 2.5.4. Impact on GHG emissions

Similar to the mandatory goal setting measure, the same input parameters (barrier factor, payback period and interest rate) have been changed to model the impact on GHG emissions of a mandatory periodic efficiency assessment. However, for this measure it is assumed that barrier factor would increase (and hence market barriers would be reduced) by 50% (for example for bulk carrier from 32% in the BAU scenario to 47%), the payback period extends to 7 years from 5 years and the interest rate reduce from 10% to 4%.

It is assumed that barriers would be reduced to a larger extent in a mandatory periodic efficiency assessment measure than in the mandatory goal setting measure (that requires shipowners to decide on and set a target as opposed to newer proposals made to IMO whereby IMO would set a target which shipping companies would be obliged to meet) because the former improves the market circumstances for efficient ships by increasing the availability and therefore hopefully the use across the markets of transparent and reliable performance data. Whereas the latter focusses only on the management of the shipping company, so is assumed to have a more limited effect. As with the mandatory goal setting measure, there are uncertainties related to the values for the three input parameters so we had to use expert judgment to estimate by how much they would change.

The modelling simulation suggests that strengthening the SEEMP with a mandatory periodic efficiency assessment would reduce CO<sub>2</sub> emissions by up to 1% in 2030. The emissions reduction is higher than the previous measure but still less than 1%. This measure by itself is estimated to be insufficient to meet the 2030 level of ambition included in the IMO initial strategy.

As with the other measures, the model reflects the expected dynamic of a rebound effect. By removing this dynamic, it is possible to identify an upper bound limit of CO<sub>2</sub> emissions reduction. Although in practice unlikely, without the rebound effect this measure could reach less than 2% CO<sub>2</sub> emission reduction in 2030 and would thus still be insufficient on its own to achieve the IMO's 2030 level of ambition.

## 2.5.5. Conclusions

Mandatory periodic assessment of ship efficiency would remove one of the barriers to selecting efficient ships for chartering and help reduce the split incentive.

Mandatory periodic energy-efficiency assessment can be summarised as indicated in Table 9.

Table 9 – Mandatory periodic energy-efficiency assessment summary

Responsible entity	Regulation 22 specifies that the ship has to have a SEEMP on board. The Guidelines place the responsibility with 'the company and/or the ship'.
Requirement that the entity has to fulfil	Establish a speed-power curve on a regular basis, e.g. annually, according to a standard.
Monitoring and reporting requirements	Establish a speed-power curve annually and keep records on the ship and on shore.
Competent authority	The flag state has to ascertain that a ship has a SEEMP that has been developed taking into account the Guidelines. It will enforce against ships in its registry that do not comply. In addition, Port States have the right to inspect a ship and its SEEMP.
Legal instrument	There is a requirement to have a SEEMP. Because the speed-power curve can change over time as a result of e.g. hull and propeller fouling, the SEEMP should have a limited validity, and renewal should be conditional on the establishment of a speed-power curve. Regulation 22 of MARPOL Annex VI specifies that the SEEMP shall be developed taking into account Guidelines adopted by the IMO. Hence, the change required is a change in the guidelines, which should specify that a speed-power curve shall be established regularly.

The impacts of this measure on emissions are difficult to model because of the uncertainty in exactly how the sector would respond. However, in the design of this measure chosen in this study, they are likely to be small because the most this measure can likely achieve is to increase the share of cost-effective measures that are implemented because it lessens the impact of the split incentive on the ability of ship owners to recoup their investment. Using expert judgement on the likely share, our modelling points to an emissions reduction of a few percent at most.

## 2.6. Strengthening the SEEMP: Mandatory Retrofits

### 2.6.1. Introduction

Another way to strengthen the SEEMP would be to mandate ships to install technologies that are known to have a payback period of less than 2 or 3 or 5 years unless they can prove that the payback period for that particular ship would be longer. Similar policies have been targeted for land-based installations. For example, under Dutch law, SMEs with an energy consumption within a certain range are obliged to implement all technical and operational measures that have a payback period of 5 years or less<sup>3</sup>.

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<sup>3</sup> The requirement is in Article 2 of the [Activiteitenbesluit \(Activities Decree\)](#) under the Wet Milieubeheer (Environmental Act). It has led, amongst other things, to supermarkets installing doors on their fridges and freezers.

## 2.6.2. Design of the policy

The requirement would need to take into account that the payback period of a certain technology can vary from ship to ship as it depends on the type and size of the ship, the type of fuel used, and how the ship is operated.

One way to introduce this requirement in the SEEMP would be to agree on a list of technologies that often have a payback period of less than 2, 5 or 10 years and require ships to install these technologies as a condition to renewal of their SEEMP unless they can prove that the payback period for the ship in question would be considerably longer. The list should only contain technologies that are sufficiently mature.

The list could be compiled by an expert group that is appointed by MEPC. It should be possible for technology providers to submit technologies to the expert group for consideration. The group can review the evidence presented and decide whether or not to include the technology to the list and if so, for which ship types and size categories.

In MEPC 58/INF.7, ICS and other organisations proposed to include a list of technologies in the SEEMP (see Figure 8). The difference between this proposal and the proposal by ICS et al. is that this proposal obliges ships to install cost-effective technologies, whereas MEPC 58/INF.7 only required ships to note whether and if so, when they had installed certain technologies.

Figure 8 – Table of technologies for insertion in SEEMP as proposed by ICS et al., in MEPC 58/INF.7 (excerpt)

<b>Energy Saving Option</b> Technical or Equipment Modification	<b>Date of Implementation</b> <i>Insert: Relevant date/Under consideration</i>	<b>Energy Saving</b> <i>Insert: unit/time</i>	<b>Energy Saving Potential</b> <i>Insert: unit/time</i>
Thermal Heat Recovery (WHR-systems) <i>Remarks: Mainly applicable for newbuildings</i>			
Advanced hull coatings systems <i>Remarks: Can increase hull smoothness and decrease drag</i>			

Source: MEPC 58/INF.7

As many of these retrofits require dry-docking, it makes sense to require that ships comply with the regulation every five years, and that they submit a plan on the measures prior to the main class survey and implement the measures during the survey when the ship is in dry-dock.

This method to strengthen the SEEMP implies that the SEEMP has a limited validity and that renewal is conditional on the installation of cost-effective technologies. This would probably require a change in the SEEMP regulation, for example a clause stating that “the validity of the SEEMP shall be five years. The SEEMP can be renewed if conditions specified in the guidelines are met”. The Guidelines should specify that cost-effective technologies have to be installed when the ship undergoes a major survey.

## 2.6.3. Impacts on ship design, equipment, operations and fuel consumption

The regulation will result in a wide uptake of cost-effective technologies. Several studies have shown that many measures have a payback period of less than five years. These include, for example [DNV GL Efficiency Finder](#):

- installing a high-efficiency propeller;
- bulbous bow redesign;
- engine de-rating;
- auxiliary engine optimisation; and
- energy saving devices such as pre-swirl or ducts.

In addition, ABB (2013)<sup>4</sup> lists:

- variable frequency drive pumps for HVAC and cooling.
- variable frequency drive for shaft generator;
- waste heat recovery systems;
- azipod propulsion;
- et cetera.

Marginal abatement cost curves suggest that cost-effective efficiency improvements are possible of about 10-20% (TNO, Marintek, ISL, & TML, 2015; CE Delft, 2012a).

#### **2.6.4. Impact on GHG emissions**

Similar to the mandatory goal setting and periodic efficiency assessment measures, we have changed the market barrier factor, the payback period and the interest rate to model the impact of this measure on GHG emissions. However, for this measure, it is assumed that market barriers would be eliminated, the payback period is set to 10 years instead of 5 years in the BAU scenario and the interest rate at 2% instead of 10% in BAU. In contrast, with the previous two SEEMP-strengthening measures, market barriers restricting take-up are assumed to disappear because the retrofits are mandated.

The modelling simulation using GloTraM suggests that strengthening the SEEMP with a mandatory retrofit would reduce CO<sub>2</sub> emissions by approximately 2% in 2030 relative to BAU. This measure by itself is therefore estimated to be insufficient to meet the 2030 level of ambition included in the IMO initial strategy.

The model reflects the expected dynamic of a rebound effect. By removing this dynamic, it is possible to identify an upper bound limit of CO<sub>2</sub> emissions reductions. Although in practice unlikely, this measure could result in approximately 4% emission reduction in 2030 without the rebound effect.

The estimated savings are dependent on the accurate estimation in the model of the extent to which energy efficiency options have already been fitted to the fleet, and the difference between this and the level of energy efficiency that could be deemed cost-effective. If the modelling either overestimates what the existing fleet has been fitted with, or underestimates what could be deemed cost-effective, then the GHG abatement potential of the policy would increase.

We therefore also examined this measure's impact on GHG emissions using the CE Delft model which has slightly different assumptions on the BAU take-up of energy efficiency options. Using this model, the estimate of CO<sub>2</sub> emissions reduction are around 3% in 2030.

Hence, despite different model setups, the results are very similar, which increases the confidence in the findings.

#### **2.6.5. Conclusions**

Mandatory installation of cost-effective technologies could be implemented as a way to strengthen the SEEMP. It can be summarised as indicated in Table 10.

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<sup>4</sup> ABB (2013): [Energy Efficiency: the other alternative fuel](#), Helsinki

Table 10 – Mandatory retrofits summary

Responsible entity	Regulation 22 specifies that the ship has to have a SEEMP on board. The Guidelines place the responsibility with 'the company and/or the ship'.
Requirement that the entity has to fulfil	Implement technologies that have a pay-back time of less than 2, 3 or 5 years.
Monitoring and reporting requirements	After each drydocking, the responsible entity has to submit a report on technologies that have been installed. If certain technologies have not been installed, the list should demonstrate that they have a payback period longer than the limit.
Competent authority	The flag state has to ascertain that a ship has a SEEMP that has been developed taking into account the Guidelines. It will enforce against ships in its registry that do not comply. In addition, Port States have the right to inspect a ship and its SEEMP.
Legal instrument	There is a requirement to have a SEEMP. The Regulation should be changed so that the SEEMP has a limited validity; renewal should be conditional on the installation of cost-effective technologies.  Regulation 22 of MARPOL Annex VI specifies that the SEEMP shall be developed taking into account Guidelines adopted by the IMO. Hence, the change required is a change in the guidelines, which should specify that cost-effective technologies should be implemented.

Mandatory installation of cost-effective technologies could have a significant impact on the technical energy efficiency of the existing fleet in the short-term. However, the impact would diminish over time because in most plausible business-as-usual scenario's, many cost-effective emission reduction options would be implemented over the course of more than a decade. This is consistent with the observation that in recent years, many ships have retrofitted energy efficiency devices. Hence, our modelling points to an emissions reduction of a few percent by 2030.

## 2.7. Setting mandatory operational efficiency standards

### 2.7.1. Introduction

Several operational efficiency metrics have been proposed and discussed at the IMO. The most recent proposals are the following:

1. Energy Efficiency per Service Hour (EESH) (MEPC 65/4/19).
2. Annual Efficiency Ratio (AER) (MEPC 66/4/6, MEPC 67/5/4).
3. Individual Ship Performance Indicator (ISPI) (MEPC 66/4/6).
4. Fuel Oil Reduction Strategy (FORS) (MEPC 66/4/6).

A number of publications have discussed the strengths and weaknesses of each measure.

The latest submission proposing a policy based on one of these metrics is ISWG-GHG 1/2/1–submitted by Norway. The submission demonstrates that it is possible to calculate reference lines for all of the metrics, but that the spread of empirical annual values around the reference line is large. Norway evaluates the different metrics in ISWG-GHG 1/2/1 and finds that the AER scores best in terms of robustness, feasibility, reduction potential and applicability, at least for cargo ships. It also suggests some improvements, like replacing deadweight by displacement in order to account for variance in carbon density. For non-cargo ships, other indicators may be more suitable.

A number of other submissions have evaluated the four metrics. MEPC 68/INF.29 found that the spread in operational efficiency values is very large and that that the same ship may have very different values in different years, even when it is owned and operated by the same shipping company. The same study shows that ships that appear to be relatively efficient in one indicator are not necessarily relatively efficient in another. Both the spread and the variability could hamper the possibility of setting reference lines that are both ambitious and effective. Another study, presented in ISWG-GHG 2/2/7, had similar findings and concluded that setting operational efficiency metrics are not suitable to set targets for individual ships, but should be used instead to assess the efficiency of segments of the fleet.

A study on the operational efficiency of 11 sister ships found that the variations were large, and that over 40% of the variations could be attributed to environmental conditions during voyages, the climate in which the ship operates (e.g. cold climate), the condition for the transportation of the cargo (e.g. heated), the calorific value of fuel used and the maintenance and technical specifics of the different ships (MEPC 72/INF.5). With the exception of the latter, these factors are not under control of the shipowner. The study developed a metric that has a lower variability, but in order to do so, variation in speed had to be adjusted for. If this metric were to be used in an operational efficiency standard, one of the most prominent operational measures to improve the efficiency would be discarded.

### **2.7.2. Design of the policy**

A mandatory operational efficiency standard could be developed in a way that is outlined by the United States in their MEPC submission MEPC 65/4/19 and later taken up by other countries in MEPC 66/4/6.

Based on empirical data collected in the IMO Data Collection System (Resolution MEPC.278(70)), baseline curves of operational efficiency would be established for different ship types. Examples in MEPC 66/4/6 suggest that these curves would be best-fit curves of empirical values of operational efficiency indicators plotted against the capacity of ships.

As mentioned in Section 2.7.1, four different indicators of operational efficiency have been discussed at MEPC. It is planned that these will be evaluated in the second step of the so-called three step approach: data collection, data analysis, followed by decision-making on what further measures, if any, are required (MEPC 68/21). For one or more of the indicators, baseline curves would be established. In the next step, ships would have to meet or exceed minimal operational efficiency standards.

### **2.7.3. Impacts on ship design, equipment, operations and fuel consumption**

The impacts on ship design, equipment, operations and fuel consumption depend on the indicator chosen (CE Delft ; Öko-Institut ; Tim Bäuerle, 2014). They differ in the types of measures that are incentivised and the relative strength of the incentives given.

All indicators will incentivise the improvement of the design efficiency of ships, e.g. by retrofitting energy saving devices.

All indicators also incentivise speed reduction, although not all to the same extent. FORS incentivises slow steaming in a technology-neutral way: emission reductions resulting from slow steaming result in the same improvement of FORS as equivalent technical or operational emission reductions. In contrast, the AER and ISPI reward slow steaming to a lesser extent, because slow steaming not only reduces the annual CO<sub>2</sub> emissions (numerator of indicator) but also results in a decrease in the distance covered in that year (part of the denominator of the indicator). The EESH rewards speed reduction more than equivalent measures because slow steaming not only reduces fuel energy consumption (numerator of the indicator) but also leads to an increase in the hours in which a ship is in service (denominator of indicator).

The EESH in its current form does not incentivise the use of low-carbon fuels because it is expressed in units of energy per unit of time, and not in emissions per unit of time. The other metrics will incentivise the use of low-carbon fuels since they are expressed in terms of units of CO<sub>2</sub> emissions rather than units of energy.

The extent to which the measures are taken depends on the stringency of the operational efficiency standard.

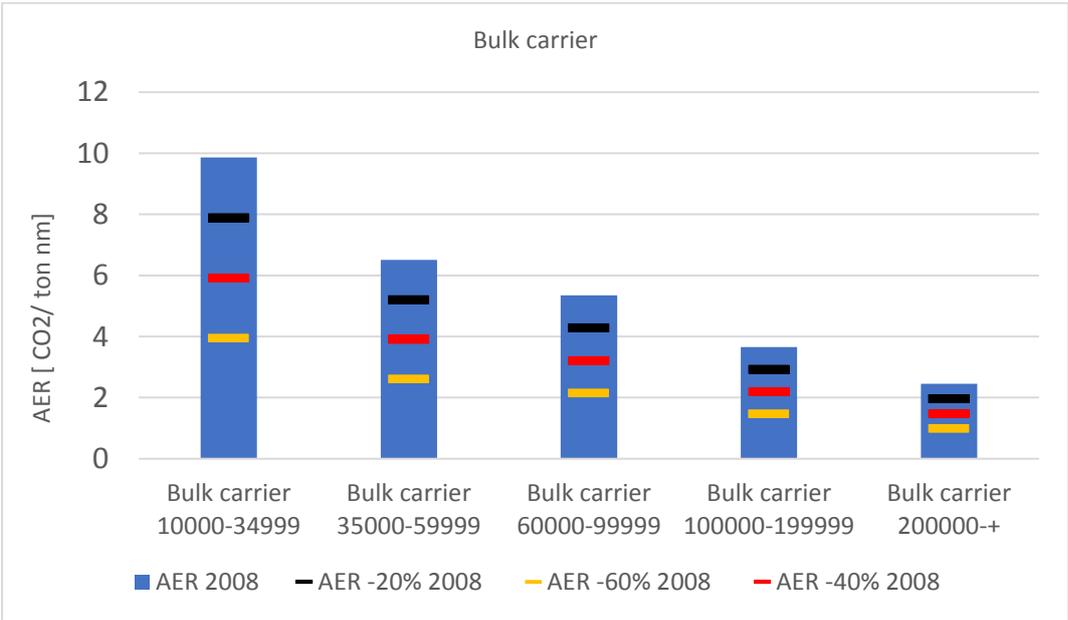
**2.7.4. Impact on GHG emissions**

In order to model the impact of a mandatory operational efficiency standard in GloTraM, an operational energy efficiency indicator is needed. While there are a number of different options for indicators, due to data availability and the way the model has been set up, this study has used the Annual Efficiency Ratio (AER; metric: CO<sub>2</sub> per year/ (dwt\*distance sailed in a year)). Note that this is not intended to prejudge the outcome of discussions at the IMO on the different options for indicators.

We examined three different scenarios with varying stringency levels, requiring an improved operational efficiency of 20%, 40% and 60% by 2030 respectively, in which 40% and 60% meet the level of ambition of the Initial Strategy.

As an example, Figure 9 shows the estimated 2008 AER level for bulk carriers for different size categories and the three associated levels of stringency for this measure.

Figure 9 - AER levels of stringency used for bulk carriers. AER (2008) shows the average AER within that size category

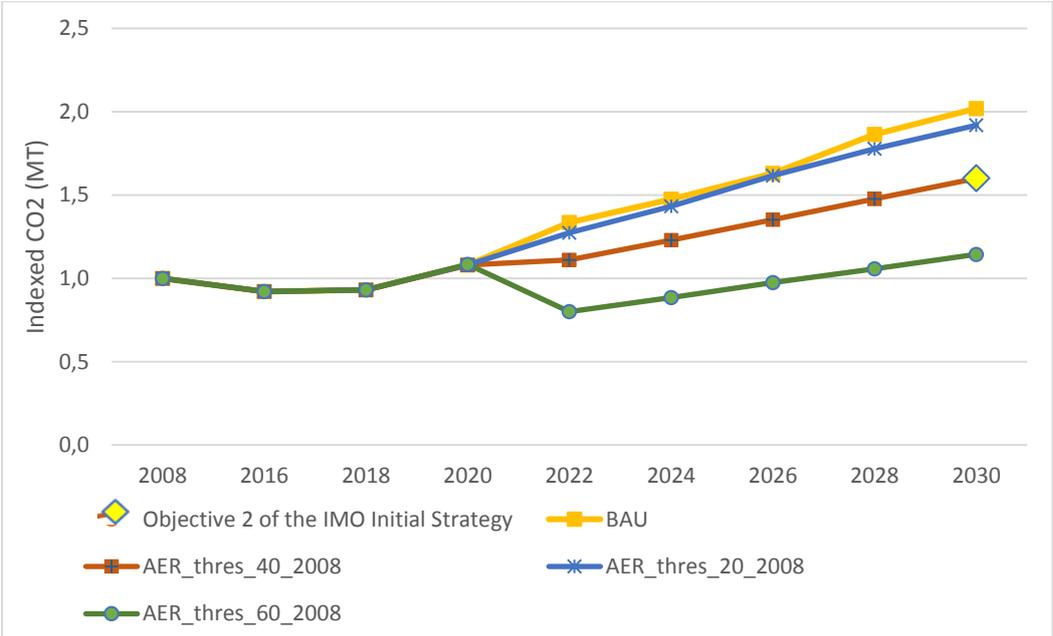


Increasing the level of stringency of this measure has a direct effect on reducing CO<sub>2</sub> emissions, up to the limit of what can be achieved with available technology and operation interventions. This direct effect is not evident in many other measures especially those that focus on technical efficiency, due both to the rebound effect, and the fact that speed is such an important parameter for the operational efficiency the associated consequence on the number of active ships (which are taken into account in the model) and emissions of ships.

The modelling simulation suggests that setting mandatory AER standards would reduce CO<sub>2</sub> emissions in 2030 by about 5%, 21%, and 43% respectively for the three different stringency levels. Depending on the level of stringency, this measure has the potential to achieve carbon intensity reductions in line with Objective 2 of the IMO Initial Strategy (at

least 40% reduction in carbon intensity by 2030)–this is the case for the scenarios requiring an operational energy efficiency improvement of 40% and 60% compared to the 2008 AER baseline (see Figure 10).

Figure 10 - CO<sub>2</sub> emissions trends for the three scenarios of setting mandatory operational efficiency standards



This measure has an impact also on the average EIV, and choice of operating speed, depending from the stringency levels and the optimum trade-off between reducing speed and improving the EIV to comply with the regulations. Table 10 shows the impact on speed and EIV for the three scenarios and it includes the changes observed in the BAU scenario. It is important to note that in all cases most of the impact is originating from speed changes.

Table 11 - Impacts on speed and EIV and comparison against the BAU scenario

	% CO <sub>2</sub> reduction in 2030 relative to the BAU	% difference relative to speed in 2008	% difference relative to EIV in 2008
BAU	-	-3%	-31%
AER_thres_20_2008	-5%	-5%	-31%
AER_thres_40_2008	-21%	-14%	-29%
AER_thres_60_2008	-43%	-33%	-34%

**2.7.5. Conclusions**

Most mandatory operational efficiency standards incentivise all measures that ships can take to reduce the carbon intensity of shipping: technical and operational measures as well as changes in fuels. However, they rely on acceptance of an operational efficiency indicator which is by no means an easy task because each indicator creates different winners and losers. Moreover, several studies have raised questions about whether the indicators are a consistent reflection of the operational efficiency.

If the discussion on the suitability of the different indicators can be resolved, an operational standard would be an effective way to meet the level of ambition of the IMO GHG Strategy.

Table 12 summarises the operational efficiency standards.

Table 12 – operational efficiency standards summary

Responsible entity	The responsible entity is the ship.
Requirement that the entity has to fulfil	The ship has to meet or exceed a minimum operational efficiency each year.
Monitoring and reporting requirements	In addition to the data collected under MARPOL Annex VI Regulation 22A, ships would need to calculate their annual operational efficiency and report it to their flag state.
Competent authority	The flag state has to ascertain that a ships operational efficiency meets or exceeds the required value for that ship and issue a certificate of compliance. In addition, Port States have the right to inspect a ship and its certificate of compliance.
Legal instrument	This would require a new regulation in MARPOL Annex VI.

Because the 2030 level of ambition of the IMO GHG Strategy is expressed in CO<sub>2</sub> intensity of the fleet, i.e. the same indicator as several operational efficiency standards, the ambition could be met by setting the stringency of the target. If the operational efficiency were to be expressed in AER, the stringency would need to be at least 40% improvement relative to 2008.

## 2.8. Existing fleet improvement programme

### 2.8.1. Introduction

BIMCO, IPTA and WSC invited MEPC 71 to consider setting up an Existing Fleet Improvement Programme (EFIP) under the Comprehensive IMO Greenhouse Gas Strategy (MEPC 71/7/4). The EFIP would be 'a positive and concrete mechanism to improve efficiency across the existing fleet while avoiding the major shortcomings, inequities, and complexity that operational standards invite'.

The proposed EFIP requires ship owners to set aside a certain amount of money in proportion to the amount of fuel a ship has consumed in a certain year. The ship owners would be required to spend this money on 'recognized mechanisms for improving ship efficiency', such as propeller upgrades, advanced hull coatings and so on. Ship owners would have some flexibility on the timing of the investment. If the ship owner has a fleet of ships, she would be allowed to pool the money and spend it on one or a few ships in a certain year. If she owns one ship, she could save the money until the ship goes into drydock and make improvements then.

The EFIP proposal is an outline; many details have to be developed. This section discusses:

- which sums would be required for a meaningful EFIP;
- how the obligation to invest can be structured;
- how the obligation to invest can be monitored and enforced;
- how technologies in which to invest can be selected.

### 2.8.2. Structure of the obligation to invest

The obligation to invest can be structured in several ways, e.g.:

- an obligation to invest in certain technologies;
- an obligation to invest until a certain efficiency-goal has been reached;
- an obligation to invest a specified amount of money.

These obligations are not mutually exclusive. All these obligations have advantages and disadvantages, which are discussed below.

An obligation to invest in certain technologies has the advantage that shipping companies will know which investments to make and that the increased demand for the selected technologies may result in innovation. Recognizing that technologies that are cost-effective on one ship may not be so on another, the programme should allow improvements to be made by applying any technology or technologies selected from a suite of technologies recognized (i.e., “approved”) by experts as known technologies for improving the technical efficiency of a ship.

An obligation to invest until a certain efficiency-goal has been reached has the advantage that it allows shipping companies to invest in the most cost-effective technologies, i.e. in the technology or combination of technologies that result in the required efficiency improvement against the lowest costs. This will also drive innovation. However, there is not a good efficiency metric available at the moment. Operational efficiency metrics have been demonstrated to be very sensitive to types of cargo, region where the ship is active, as well as contractual arrangements on speed, so that they are not suited to demonstrate compliance. The EEDI could perhaps be used as a measure, as discussed in Section 2.3, but that would imply a diversion from the line the MEPC has hitherto taken.

An obligation to invest a certain amount of money has the advantage that shipping companies can choose the most cost-effective technologies suited for the ship they control. The amount can also be unequivocally specified and monitored. The disadvantage, however, is that the environmental result cannot be assessed in advance. Moreover, strict safeguards and possibly expensive monitoring programmes are needed to minimise the risk that shipping companies will invest in technologies that barely impact the fuel efficiency. The monitoring and the safeguards are analysed in more detail in Sections 2.8.4 and 2.8.5, respectively.

The EFIP has opted for an obligation to invest a certain amount of money. The exact amount can be based on several parameters, e.g.:

- the size of the ship;
- the age of the ship;
- the revenues a ship makes, its value, or its charter-rate;
- the fuel-efficiency of a ship; or
- the amount of fuel a ship consumes.

The remainder of this section will discuss the advantages and disadvantages of these options.

Calculating the amount of money to the size of the ship, her age, type or other fixed attributes has the disadvantage that they are not related to the fuel use and emissions of the ship nor to her efficiency.<sup>5</sup> Hence shipping companies may be required to invest in ships that are laid up, idle or in use as floating storage. This would diminish the overall cost-effectiveness of the policy.

Relating the obligation to the commercial value of a ship would ensure that companies have the means to invest. However, the sometimes complicated structure of ownership and operational control in shipping can make it difficult to establish what the commercial value of a ship is. Moreover, monitoring compliance would require companies to disclose commercially sensitive information. Hence, this does not appear to be a feasible way forward.

Calculating the obligation on the basis of the fuel-efficiency of a ship is attractive because it could target the least efficient ships first, which could probably achieve the largest improvements. However, this option is less feasible because of lack of universally applicable efficiency metrics.

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<sup>5</sup> New ships are not always more efficient than older ships, as shown in CE Delft; UCL, (2016).

Determining the contribution on the basis of the fuel consumption of a ship has the advantage that fuel consumption is already reported and that it requires ships that emit more CO<sub>2</sub> to invest more in efficiency improvements. Moreover, by allowing flexibility to shipping companies that have control over more than one ship on where to invest, facilitates choosing for the most cost-effective options available.

### **2.8.3. Existing ship retrofit costs**

The costs associated with retrofitting a ship to make it more energy efficient can vary widely, depending on the type of ship, its original design, and the specific technologies retrofitted.

A project to improve the efficiency of a tanker or bulker or similarly designed ship by 10-15% can include the retrofitting of flow ducts, new propeller blades, shifted gearboxes and new coating. For a panamax-sized ship, the associated costs would be between USD 1 million and USD 1.5 million, according to information confidentially received by the authors. The investments are higher for larger ships, but the cost-effectiveness improves for larger ships because the fuel savings increase more than the investments.

Assuming that the retrofit would be carried out once in a ship's lifetime and the costs would be amortised over a 25-year lifetime, the additional annual costs would amount to USD 40,000-60,000.

### **2.8.4. Monitoring and reporting of obligation to invest**

The obligation to invest needs to be structured in a way that balances several requirements:

- The amount of money to be invested will be determined annually for each ship individually.
- The timing of the investment can be chosen so as to coincide with the drydocking cycle or other times when a ship has to be taken out of service. This means that the money needs to be set aside annually.
- Funds raised for several ships can be pooled to invest in one ship or multiple ships.
- The investments need to be secured when ships change ownership or flag. The administrative burden should be manageable even when shipping companies have ships registered in different states.

One way to meet these requirements would be to create Ship Energy Efficiency Bonds (EEBs) that shipping companies have to purchase in order to meet their obligation. Each EEB can for example represent a value of USD 1,000. Shipping companies would need to report annually to the Flag State on the amount of units purchased in that year and on the total amount of units accumulated for that ship over time. This should not exceed a certain limit in order to ensure that the investments are actually made.

EEBs can be taken out of the account of a ship for two purposes: either to invest in energy efficiency measures for that ship, or to invest in energy efficiency measures of another ship.

In both cases, shipping companies would need to report to the flag state of the ship in which the investment has been made which technologies they have invested in and how many units they have exchanged. This report would need to be accompanied by a statement of the classification society that the investment has indeed been made. If the EEBs are drawn from accounts of other ships, the shipping company would need to inform the registries of all the ships from which EEBs have been used that the investment has been made and that the amount of EEBs of the ships is reduced. That report should be accompanied by a statement from the auditor of the shipping company that the total

number of EEBs exchanged matches the investment made in order to avoid double counting.

Flag States should issue two documents of compliance. The first would state that ships have purchased EEBs in a certain year. The second would state that the total number of EEBs in the account of the ship does not exceed a certain limit value and that subtractions from the account have been made in conformity with the requirements, i.e. either to invest in the ship or in another ship.

Port States would be allowed to inspect both documents of compliance and take action against ships that do not possess one or more documents.

#### **2.8.5. Selection of eligible technologies**

The investments under EFIP should improve the energy efficiency of a ship. This can be done in many ways and whether an investment is sensible depends on the original design of the ship, where it will be put into service, the type of cargo it carries, et cetera. This suggests that the range of eligible technologies should be wide.

Still, it is clear that not all technologies should be eligible. Technologies that barely have an impact on energy efficiency, for example, should not be used for compliance with EFIP. Hence, in order to ensure that the investments are indeed made in energy-efficiency, a list of eligible technologies would be necessary.

An open question is whether technologies should be eligible that are widely, yet not universally used and are generally considered to be cost-effective, such as energy-efficient lighting. In addition, the EFIP may aim to speed up the deployment of proven technologies that are not yet widely used in order to increase the rate of innovation in the shipping industry. Both these arguments support having a list that is regularly amended and updated.

The selection of technologies on the list could be entrusted to a group of experts who could determine procedures for how new technologies can be added to the list. They could propose amendments to the list every few years to the Parties (through the MEPC), which could authorise the list.

If more flexibility is needed, e.g. to allow very innovative technologies, the possibility could be given to shipping companies to make a case for a certain investment and have it approved by the experts, even when the investment is not, or not fully, in approved technologies.

#### **2.8.6. Minimising the risk of fraud**

In order for the policy to be effective and not to distort the competitive market, the risk of fraud should be minimised. Some types of fraudulent behaviour are constrained by the above design of the policy. For example, external auditors would need to certify that the money was set aside and/or invested. A class society would need to declare that the new technologies have been installed. And the Flag State can inspect the ship.

However, it will be hard, if not impossible, to make sure that technologies invested in are sold at normal market prices, and not at an inflated price in exchange for lower prices on other works or investments.

### 2.8.7. Impacts on ship design, equipment, operations and fuel consumption

We expect shipping companies to have a preference for investing in the most cost-effective technologies. These vary from ship to ship. Probably, the following would often be included<sup>6</sup>:

- hull coatings;
- propulsion Improving Devices (ABS, 2013);
- retrofitted propellers; and
- retrofitted bulbous bows.

### 2.8.8. Impact on GHG emissions

The impact on GHG emissions of the existing fleet improvement programme (EFIP) is difficult to model because of the many flexibilities of the system. It is assumed to result in similar CO<sub>2</sub> emissions reductions as mandatory retrofits, i.e. CO<sub>2</sub> emissions reductions between 1% to 3% in 2030, and reductions in the range of 2% to 4% in 2030 if there is no rebound. This depends, however, on the amount of money that ships are required to invest in energy efficiency. If this amount is large, the measure may result in the uptake of technologies that are not cost-effective, in which case the impact could be larger.

Regardless of the impact of the rebound effect, this measure on its own is estimated to be insufficient to meet the 2030 level of ambition included in the IMO initial strategy.

### 2.8.9. Conclusions

The existing fleet improvement programme would require ships to set aside a certain amount of money each year, related to the fuel consumption of the ship, which can only be invested in improving the operational efficiency of the ship or any other ship that the shipowner controls. A summary of the measure is presented in Table 13.

Table 13 - Existing Fleet Improvement Programme summary

Responsible entity	The responsible entity would be the ship. In practice, the owner or anybody who has control over the ship can fulfil the obligations.
Requirement that the entity has to fulfil	Each ship needs to set aside a certain amount of money per year and invest it once every few years in energy-efficiency improvements of the ship or of another ship.
Monitoring and reporting requirements	<i>The owner or somebody acting on his behalf needs to report annually to the Flag State that the funds have been set aside and/or spent. The report has to be audited by an accredited auditor.</i> <i>In case investments are made, a class society needs to ascertain that the investments have been made in technologies that are on the list.</i>
Competent authority	The flag state has to ascertain that a ship has set aside the required amount of money and/or invested it in improving efficiency. It will enforce against ships in its registry that do not comply. In addition, Port States have the right to inspect a ship.
Legal instrument	<i>MARPOL may be amended, either as an additional regulation in MARPOL or as a new Annex. The need for a new convention is unlikely.</i>

<sup>6</sup> [GloMEEP energy efficiency portal, Technical solutions](#)

The impact of the existing fleet improvement programme on GHG emissions is difficult to model because of the many flexibilities of the system. Because the measure incentivises investments in improvement of the operational efficiency, the impacts are likely to be similar to those of mandatory retrofits (see Section 2.6), i.e. 2-4% in 2030.

## **2.9. Speed regulation**

### **2.9.1. Introduction**

The last decade has shown that a very effective way to reduce the energy consumption of ships is to reduce their speed, also called slow steaming (IMO, 2015).

If a ship lowers its speed, the ship's energy consumption decreases more than proportionally, even though the ship needs more time to provide the same transport work, and when taking into account that more ships are required to provide the same amount of transport work. Note that the benefits of slow steaming diminish at very low speeds because boilers and auxiliary generators need to run longer hours, but even at 30% below 2012 average speeds, there are benefits of further speed reduction (CE Delft, 2017b).

Depending on the implied cost changes (depends highly on bunker fuel prices) and the opportunity costs (depends highly on freight rates), slow steaming can be a cost efficient measure from the perspective of the ship owner/operator.

But even if the measure is cost effective from the ship owner's/operator's point of view, it is often not implemented due to conditions as laid down in standard charter contracts. And also the competition in the sector can lead to high opportunity costs for a ship sailing at the lower speed if the faster ship is gaining the trade at its expense.

Regulatory slow steaming might thus be solution to overcome these barriers.

### **2.9.2. Current slow steaming**

The operational speed of ships has decreased as a result to the oversupply of ships from 2007 onwards (IMO, 2015).

In principle, the EEDI encourages lower design speeds: the installation of an engine with relative low power contributes to an improvement of the attained EEDI compared to the baseline EEDI. However, to date there is no evidence that ships are reducing their design speeds (CE Delft, 2017a). Rather EEDI improvements appear to have been realised through better ship designs, which allowed yards to build ships with smaller engines without reducing the design speed.

### **2.9.3. Design of the policy**

Regulatory slow steaming can be designed in different ways regarding the geographic scope, the metric, the target and target level(s).

Regulatory slow steaming can be implemented on a global or regional level. If implemented on a regional level, the scope of the measure has to be refined in terms of the voyages that fall within/outside the scope of the measure.

The metric used can either be the ships' average speed over a predefined distance or it can be the ships' speed as such. In either case, a target would be defined as a maximum allowed value.

The following four design combinations—two on global and two on regional/national level - have been selected for further analysis, with the voyages to and from the regional or national ports falling within the scope of the regionally/nationally implemented measure (in which case the role of the IMO could be to develop guidelines for regional implementation):

- a global speed limit, differentiated by ship type and size;
- a global maximum average speed, differentiated by ship type and size;
- a speed limit for ships sailing to and/or from regional or national ports, differentiated by ship type and size; and
- a maximum average speed of ships sailing to and/or from regional or national ports, differentiated by ship type and size.

### Baseline

Setting a baseline on the basis of historical speed data would ensure that each ship type contributes proportionally to the overall effort of the fleet and would introduce the minimal distortion of the competitive market between ship classes.

AIS data have a good global coverage since 2012 (IMO, 2015), (ICCT, 2017). These data can be used to calculate the average speed of vessels while at sea, differentiated by ship type and size.

### Implementation and enforcement: legal aspects

#### *Global regulatory slow steaming*

A legal analysis of regulatory slow steaming (CE Delft, 2012b) has come to the following conclusions with regards to regulatory slow steaming on a global level:

- Regulatory slow steaming can be imposed by a State on the ships flying its flag. For such ships the flag State has prescriptive and enforcement jurisdiction.
- Enforcement of global regulated slow steaming would be organised using flag State obligations and port State rights. Flag States that would be a party to a convention would take on the obligation to enforce the speed restriction on ships flying their flag. In addition, port States which are party to a convention would have the right to inspect any ship in their port for compliance. MARPOL, SOLAS, contain the 'no more favourable' treatment of ships of non-contracting States which in essence obliges foreign ships of non-contracting States to follow the rules of the port State or face the same consequences as if they were non-compliant ships of a contracting State.
- A general agreement on maximum speeds for each type of vessel approved by the IMO's navigation committee (NCSR) and the MEPC would give global consent to such measures.

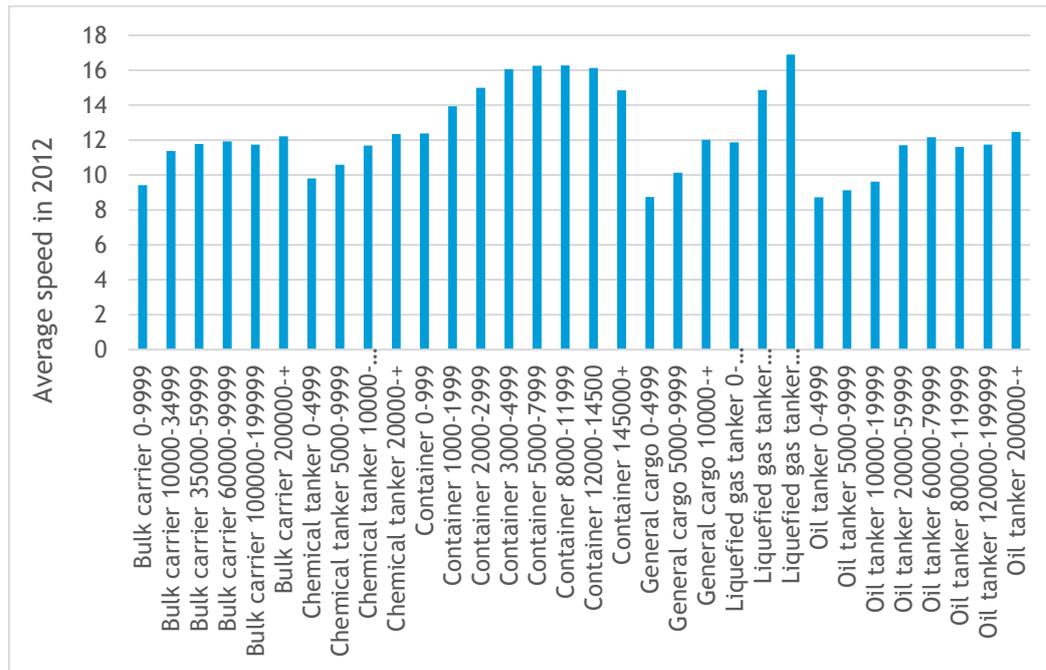
#### *Monitoring compliance and enforcement: practical issues*

Based on the baseline and an agreed speed reduction, each ship could be assigned with a maximum allowable speed. A ship would need to report annually to its Flag State that it has complied with the speed regulation. In addition, before entering a port, a ship could be required to submit a speed profile of the voyage to the port to demonstrate compliance. This would make it possible for Port States to ensure that ships comply.

### **2.9.4. Impact on GHG emissions**

In order to estimate the impact of a speed reduction measure on GHG emissions, we examined two different speed reduction scenarios. Due to modelling constraints, the two variants of the speed reduction measure are based on regulating average ship operating speed rather than maximum ship operating speed. This also means that a reference line for the average in-service speed of different ship types and size categories is needed. We have used 2012 as a reference line, as shown in Figure 11.

Figure 11 - Estimated average in-service speed of ships in 2012 across type and size



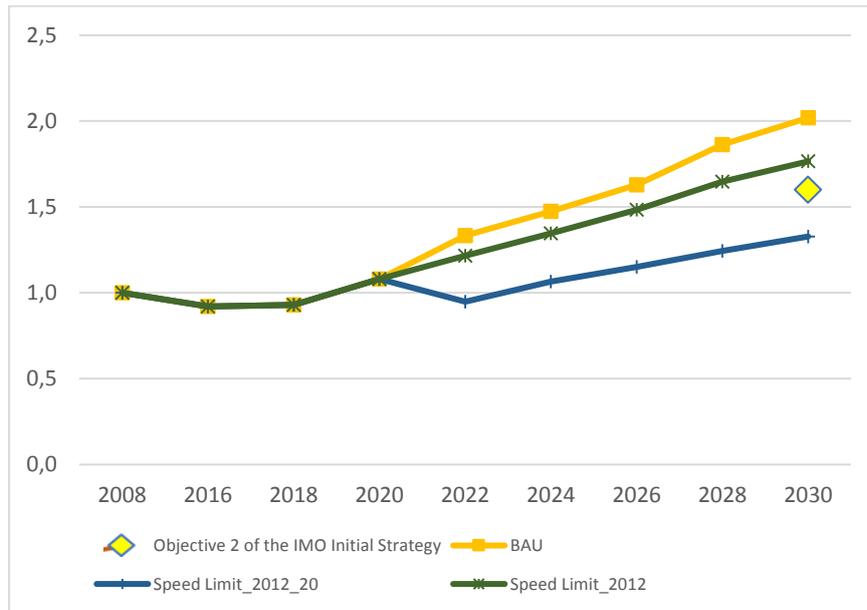
The following assumptions have been used for the two scenarios:

- Scenario 1: The average in-service speed for the different ship types and sizes is capped at their respective 2012 values.
- Scenario 2: The average in-service speed for the different ship types and sizes is set at 20% below their respective 2012 values.

The speed regulation is assumed to enter into force in 2022.

The modelling simulation suggests that limiting speed would reduce CO<sub>2</sub> emissions in 2030 by 13% in Scenario 1 and by 34% in Scenario 2. This means that the speed regulation variant in scenario 2 (i.e. limiting speed to 20% below the 2012 value) has the potential to achieve carbon intensity reductions in line with Objective 2 of the IMO Initial Strategy (at least 40% reduction in carbon intensity by 2030). In fact, the results suggest that this level of stringency would exceed the minimal IMO level of ambition (see Figure 12). In contrast, limiting the speed at the average 2012 in-service speed would be insufficient to meet the IMO target; a further CO<sub>2</sub> emissions reduction of approximately 10% would be required.

Figure 12 - CO<sub>2</sub> emissions trends for the two scenarios of speed regulation



It is important to highlight that both speed reduction scenarios take into account that a larger fleet is needed to meet transport demand. They both result in CO<sub>2</sub> emission reductions, even though the number of active ships is higher.

We have also conducted a fuel price sensitivity analysis which accounts for a fuel price “spike” in 2020 for LSHFO due to the incoming IMO sulphur cap (our default fuel price projections do not assume a LSHFO price spike in 2020). The fuel price spike would incentivise ships to slow down or switch to other fuels which in turn would impact CO<sub>2</sub> (and other) emissions. In this scenario, operating speed decreases by 10% in 2020 relative to the scenario without the spike, even without speed regulation. As a consequence, we observe a lower impact of speed regulation on CO<sub>2</sub> emissions in 2020 when there is a price spike. By 2030, supply and demand of low sulphur fuels is assumed to be balanced, so that the CO<sub>2</sub> emissions reductions in 2030 are approximately the same in both scenarios. Overall, the modelled cumulative emissions reduction (from 2016 to 2030) changes from 23% to 25%, with the latter representing the scenario with the spike. Please see Annex A.3 and A.4 for more details.

Furthermore, we examined the same speed regulation scenarios using the CE Delft model. It shows that a 20% speed reduction (relative to 2012 average speeds) would result in 24% lower CO<sub>2</sub> emissions in 2030. This is different from the GloTraM estimate of 34% CO<sub>2</sub> emissions reductions in 2030. As described in Section 2.6.4, the two models treat speed differently which has implications for the BAU scenario. In the CE Delft model, speed is set exogenously with most ship types in the BAU scenario operating at a speed that is 10% lower than the 2012 average speed. GloTraM, on the other hand, models speed as a function of the marginal costs of increased speed (as explained in Section 2.2.6. and in the Annex), which means that in GloTraM’s BAU scenario, ship speeds are determined as a function of both the projected freight rates and fuel prices and the model chooses the optimal speed in a given year, given these market forces. Because by 2030, freight rates in the BAU scenario are assumed to return to long-run averages, GloTraM estimates that speed will increase by 12% in 2030 relative to the average 2012 speeds (in contrast to the 10% speed decrease in CE Delft’s scenario). This means that the estimated CO<sub>2</sub> emissions reductions in 2030 for the speed reduction scenarios are higher in GloTraM because there is a larger gap between the BAU and the policy scenario than in the CE Delft model.

## 2.9.5. Conclusions

Slow steaming is a short term measure with relative small lead time at least regarding the ships, and provided it can be implemented under an existing convention (e.g. by adding a chapter to MARPOL Annex VI). A summary of the measure is presented in Table 14.

Table 14 - Speed regulation summary

Responsible entity	The responsible entity would be the ship.
Requirement that the entity has to fulfil	Each ship needs to sail at a speed less than or equal to the maximum allowable speed for the given ship type and size.
Monitoring and reporting requirements	<i>The ship needs to report annually to the Flag State that it has not sailed a speeds higher than the maximum allowable speed. Before entering a port, a Port State could require ships to submit evidence on the speed during the last voyage. This evidence can be based on AIS records or other methods.</i>
Competent authority	The flag state has to ascertain that a ship has complied with the regulation. It will enforce against ships in its registry that do not comply. In addition, Port States have the right to refuse entry to ships that have exceeded their maximum allowable speed.
Legal instrument	<i>A new legal instrument is needed, either as an additional regulation in MARPOL or as a new Annex to it or as a new convention.</i>

Speed regulation as designed in this study is estimated to have a greater impact on CO<sub>2</sub> emissions reductions compared to the technical efficiency measures investigated in this study because:

- the measure has a larger scope than some of the other measures (it is applicable to all ships, rather than just new or existing ships);
- it has a high emissions reduction potential (power is proportionate to the cube of speed); and
- it would help prevent possible future speed increase.

However, on the downside, this measure:

- does not distinguish between ships that have already invested significantly in technology and those that have not;
- can diminish the returns on some technologies (e.g. waste heat recovery);
- may increase the payback time on energy efficiency technologies and disincentivise investment in retrofits and R&D.

Speed regulation could be combined with operational efficiency standards, which would offer the potential to overcome these downsides. A speed limit could be explicitly equated with an equivalent carbon intensity improvement, and ships given a choice to comply with either parameter (speed or AER) to suit their circumstances.

## 2.10. National or regional measures

### 2.10.1. Introduction

Next to the global measures discussed in the previous chapters, there are measures that are better applied nationally or regionally because they require the involvement of ports and other national actors, each of which has a specific economic and regulatory

environment. Because of the different circumstances, these measures cannot be implemented globally. Still, they could benefit from global alignment as that would make compliance by ships easier and enhance the effectiveness of the measures.

All the measures discussed here could be elements of national action plans.

This chapter focusses on action that could be taken at a global level to support the implementation of these measures in national action plans. It describes a standard for ship-port communication (Section 2.10.2), harmonisation of port incentive schemes (Section 2.10.3) and frameworks for incentivising the uptake of renewable fuels (Section 2.10.4).

### **2.10.2. Develop a standard for ship-shore communication about the availability of pilots and berths**

Ships sail at times at high speeds to ports even when no pilots or berths are available and they have to idle outside the port. Emissions could be reduced if ships could set their speed at a level where they would arrive just in time to pick up a pilot and proceed to berth. Although such behaviour raises the fuel costs for the ship, it is rational when ports and terminals process the ships on a first come, first serve basis (Jia, Ådland, Prakash, & Smith, 2017). Moreover, charter parties have traditionally required ships to proceed at the normal speed.

If ships would be informed in advance about the availability of berths and could optimise their speed accordingly, they could reduce their emissions considerably. Quantification of the savings range from 2-10% (Jia, Ådland, Prakash, & Smith, 2017; Alvarez, Longva, & Engebretsen, 2010; TNO ; CE Delft, 2010).

In recent years, several barriers have been overcome to the concept of optimising speed to arrive just in time in port. For example, BIMCO has developed slow steaming clauses which have been included in standard charter parties (Allan, 2012). OCIMF and Intertanko have developed and tested the concept of Virtual Arrival which allows tankers to proceed at the optimal speed when they are informed about the availability of berths (INTERTANKO, 2010).

Still, many ships are still sailing above the speed that would see them arrive just in time in port. The reason for slow adoption of this innovation is that it requires coordinated changes in regulations and practices of several parties (Römers, 2013):

- terminal operators need to inform ships and the harbour master about the availability of berths and ensure that personnel and equipment are available in time.
- the harbour master needs to inform the terminal operators and ships about the nautical port information, availability of pilots and tugboats so that the ship can proceed swiftly from the pilot station to berth and vice versa.
- ships need to be updated constantly and adjust their speed, while also informing terminal operators and the port about changes in its estimated time of arrival.

Better coordination of information flows between port authorities and terminals is preferably organised at a local level because each port is different. And more generally, better exchange of information can be part of a national action plan or a regional measure. However, because ships visit many ports, better information exchange between the ship on the one hand and the terminal operator and harbour master on the other would benefit from global standardisation. This is something that IMO could organise.

The standard could cover the following topics:

- type of information exchanged between ship, port and terminal:
  - planned availability of berths;
  - expected nautical situation of the port;
  - planned availability of pilots and tugs;
  - position, draught, speed and ETA of the ship.
- frequency and timing of information;
- actors involved in information exchange;
- data format for information exchange.

### **2.10.3. Develop a standard for port incentive schemes**

Many ports and maritime infrastructure providers have implemented environmental incentive schemes (see e.g. Cogea, et al., 2017; MEPC 70/7/1; MEPC 71/7/10/Rev.1) with the aim to encourage green shipping and reduce both local and global impacts on the environment. A recent evaluation of port incentive schemes concludes that there are many different schemes with different indicators and aims (Cogea, Glintt, VUB, & KLU, 2017). Although some convergence has taken place, e.g. with the widespread use of the Environmental Ship Index (ESI) as one of the indicators, further harmonisation of the schemes could enhance their effectiveness as it would improve the financial incentive provided to ships.

One of the reasons why environmental incentive schemes diverge is that different ports face different environmental challenges and may therefore want to incentivise different types of green performance. For many ports, for example, local air pollution is a more pressing problem than climate change, which may be a reason why many port incentive schemes reward ships with low NO<sub>x</sub> and SO<sub>x</sub> emissions.

Nevertheless, several ports have demonstrated a willingness to contribute to reducing GHG emissions from shipping by including energy efficiency or CO<sub>2</sub> emissions as one of the indicators in their incentive schemes. For example, the Vancouver Fraser Port Authority's EcoAction Program offers discounts to ships that have an EEDI that is 5%, 10% or 15% better than required, as well as discounts to ships that demonstrate a good operational efficiency (VFPA, 2016)<sup>7</sup>. The Environmental Ship Index which is used by a large number of ports under the auspices of the IAPH awards points to ships that improve their operational efficiency year-on-year (NRDC, 2017).

One of the constraints in developing a policy on port incentive schemes is that the IMO does not regulate ports and in many countries, ports are private entities with much autonomy on how to set port dues. However, the IMO could develop guidelines for indicators and offer them to ports to be used when port authorities wish to incentivise energy efficiency or GHG mitigation.

It should be noted that incentive schemes do not necessarily feature rebates on port dues. The Panama Canal, for example, offers priority to green ships instead of a financial reward. However, faster handling may be worth more than a rebate.

A recent evaluation of port incentive schemes in Europe concluded that although in the short run environmental charging may not necessarily lead to altered behaviour of ship owners, the incentive may be effective when it comes to the development of new ships. One area that would be worthwhile to explore further is whether port incentive schemes can be used to reward ships that go beyond standards, e.g. ships that have a significantly better EEDI than required. Such schemes can increase the rate of innovation, especially when adopted widely.

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<sup>7</sup> As an indicator of operational efficiency, the Green Marine GHG level is used.

In short, the IMO could organise a process with full stakeholder participation in order to develop indicators of energy efficiency that ports can use when they want to reward the best performing ships. A unification of indicators could provide a strong signal to the market.

#### **2.10.4. Create framework to allow incentivising the uptake of renewable fuels on short-haul routes**

It is clear that the reduction of emissions will require zero-carbon fuels or energy sources. On a small scale, experiments are being conducted with fuels or energy sources that are or could become carbon neutral (e.g. battery powered vessels, hydrogen, ammonia, bio-HFO and methanol). Many of these experiments require dedicated infrastructure and dedicated ships; they are therefore best conducted on ships that frequently visit the same ports or are active in one area where the fuel or installations are available.

One of the things that the IMO could do is to create a framework to allow for incentivising the uptake of renewable fuels or power sources, focussing especially on short-sea routes.

The framework could cover topics like:

- conditions that have to be met;
- how safety aspects should be taken into account;
- platform for exchanging information.

#### **2.10.5. Impact on GHG emissions**

We assumed that the national and regional measures would have an effect on certain input assumptions within the model. In particular, we assumed that:

- the development of a standard for ship-shore communication about the availability of pilots and berths would increase the number of active days (+1% from 2020 excluding liner services);
- the development of a standard for port incentive schemes would reduce the investment costs for energy efficiency technologies (-20% from 2025 for new ships only);
- creating a framework for incentivising the uptake of renewable fuels on short-haul routes would affect the price of renewable fuels (-1% from 2025).

The modelling simulations suggest that:

- developing a standard for ship-shore communication would reduce CO<sub>2</sub> emissions by about 1% in 2030;
- developing a standard for port incentive schemes as well as creating a framework to incentivise the uptake of renewable fuels would reduce CO<sub>2</sub> emissions by less than 1% in 2030.

These measures by themselves are estimated to be insufficient to meet the 2030 level of ambition included in the IMO initial strategy.

It is uncertain to what extent these measures would affect the model's input assumptions, so the values used in this study are estimates based on an expert judgment. Using different values for the input assumptions could lead to different CO<sub>2</sub> emissions reductions estimates. For example, we estimated that creating a framework to incentivise the uptake of renewable fuels on short-haul routes would reduce the price of renewable fuels by 1% from 2025, however, such a framework could lead to greater reductions in renewable fuel prices depending on the characteristics of specific locations. However, we think that choosing a higher level of price reduction at global level is in

contrast with the infrastructure development required for renewable fuels during the period up to 2030. In addition, renewable fuels would be generally used for new ships, so the relative impact on GHG emissions would remain small.

We also consider a reduction in investment costs for energy efficiency technologies by 20% from 2025 (due to the development of a standard for port incentive schemes) as optimistic and would consider greater levels of reduction as unrealistic. Even though we use a different level of reduction in investment costs, the results of other measures that mandate technical/design efficiency improvements suggest that the impact on GHG emissions would remain limited and not sufficient to meet the objective 2 of IMO initial strategy.

#### **2.10.6. Conclusions**

Several measures could be developed by States acting alone or in collaboration, either as an element of a National Action Plan or as stand-alone measures. This section has explored three options in which IMO could play a role by offering a platform on the exchange of information or for voluntary co-ordination of measures, so that the impacts of the measures is increased.

The options explored in this section are the development of a standard for ship-shore communication about the availability of pilots and berths; a standard for port incentive schemes and a framework to allow incentivising the uptake of renewable fuels on short-haul routes.

The impacts of these measures on emissions is hard to model because it depends on the number of participating States or ports or routes. It is however unlikely to be more than a few percent.

#### **2.11. Conclusion**

The measures presented and analysed in this chapter can be grouped into three categories:

- Measures that can help remove barriers to the implementation of cost-effective technologies or operational practices:
  - strengthening the SEEMP-mandatory goal-setting with a self-chosen goal;
  - strengthening the SEEMP-mandatory periodic efficiency assessment without a goal;
  - develop a standard for ship-shore communication for voluntary use;
  - develop a standard for port incentive schemes for voluntary use;
  - create a framework for incentivising the uptake of renewable fuels;
- Measures that mandate ships to improve their technical or design efficiency:
  - strengthening the EEDI for new ships;
  - applying the EEDI to existing ships;
  - strengthening the SEEMP-mandatory retrofits of cost-effective technologies;
  - existing fleet improvement programme.
- Measures that mandate operational carbon intensity improvements:
  - setting mandatory operational efficiency standards;
  - speed regulation.

The first category of measures in general has a limited impact on emissions because the many cost-effective measures will be implemented anyway over time in most BAU scenarios and because some barriers will remain. Although the emission reductions vary per measure, they are typically a few percent. These measures are not able to ensure that the shipping sector meets the 2030 level of ambition of the IMO GHG Strategy, which is to improve the CO<sub>2</sub> intensity of maritime transport by 40% relative to 2008.

The second category of measures has a slightly larger impact on emissions because they can also mandate the adoption of measures that are not cost-effective from a private perspective. The measure that applies only to new ships has a limited impact on

emissions by 2030, but the impact will increase in later years. However, the measures that apply to the existing fleet can have larger impacts, depending on the stringency applied. Emission reductions by 2030 are typically several percent. Moreover, measures that exclusively incentivise improvements in technical/design efficiency show a risks of a rebound effect. That is to say that savings in technical efficiency are diminished because of an economic incentive created to operate at higher speeds. The results suggest that the rebound effect could approximately halve the benefit of CO<sub>2</sub> emissions reduction gained from the technical efficiency improvements. These measures by themselves are not able to ensure that the shipping sector meets the 2030 level of ambition.

The third category of measures has the highest impact on emissions because they apply to all ships, because they incentivise speed reduction which is the measure that has the greatest potential to reduce emissions. This category of measures has the ability to meet or exceed the minimum level of ambition for 2030.

Both speed limits and operational efficiency standards will require ships to reduce their speed if the 2030 CO<sub>2</sub> intensity ambition is to be met. There is a difference, however. At equivalent CO<sub>2</sub> reduction outcomes, operational efficiency standards allow ships more ways to comply than to reduce speed: improving the design efficiency, switching fuels, improving the management or logistics of the ship, et cetera. As a consequence, the resulting speed in 2030 will be somewhat higher than under equivalent speed reduction measures.

Table 15 summarises the projected impact of the measures on GHG emissions.

Table 15 - Projected impact of measures on 2030 GHG emissions

Measure	Impact on 2030 annual CO <sub>2</sub> emissions relative to BAU
Strengthening the SEEMP: mandatory goal setting	0-2%
Strengthening the SEEMP: mandatory periodic efficiency assessment	0-2%
Strengthening the EEDI for new ships	1-3%
Strengthening the SEEMP: mandatory retrofits of cost-effective technologies	2-4%
Existing Fleet Improvement Programme	2-4%
Applying the EEDI to existing ships	1-6%
Operational efficiency standards: AER 20% below 2008	5%
Speed reduction: cap average speed at 2012 level	13%
<b>Required to meet the 2030 level of ambition on the CO<sub>2</sub> intensity</b>	<b>21%</b>
Operational efficiency standards: AER 40% below 2008	21%
Speed reduction: cap average speed at 20% below 2012 level	24-34%
Operational efficiency standards: AER 60% below 2008	43%

Apart from the impact on emissions, there are other considerations for the choice of an instrument. Table 16 indicates whether measures are susceptible to a rebound effect and whether they drive the uptake of energy efficiency technologies. Measures are susceptible to a rebound effect when they improve the design efficiency of a ship without limiting the speed or the engine power. It has been demonstrated that more efficient ships, on average, sail faster while there are also observations that suggests that ships that have invested in improving their design efficiency through retrofits tend to sail at higher speeds (see Annex A, Section A.1.1).

Table 16 - Susceptibility of measures to rebound effect

Measure	Potential to achieve IMO Objective 2 Target?	Susceptible to rebound effect?
Strengthening the EEDI for new ships	N	Y
Applying the EEDI to existing ships	N	Y
Strengthening the SEEMP: Mandatory Goal Setting	N	Y
Strengthening the SEEMP: Mandatory Periodic Efficiency Assessment	N	Y
Strengthening the SEEMP: Mandatory Retrofits	N	Y
Setting mandatory operational efficiency standards	Y	N
Existing fleet improvement programme	N	Y
Speed regulation	Y	N
National or regional measures	N	Y

### 3. Conclusions

The Initial IMO GHG Strategy contains a list of candidate short-term measures (defined as measures that can be agreed before 2023). This report shows that these measures can have a significant impact on emissions and meet the 2030 level of ambition of the Initial Strategy if they induce operational changes in the shipping sector. Of the measures analysed in this report, operational efficiency standards and mandatory speed reduction are able to induce operational changes.

Other measures, i.e. measures that can help remove barriers to the implementation of cost-effective technologies or operational practices and measures that mandate ships to improve their technical or design efficiency will not meet the 2030 level of ambition and will also not prolong the time available for the transition to an emissions-free shipping sector.

The overall aim of the Initial Strategy is to phase out GHG emissions from shipping as soon as possible in this century. This requires a switch from fossil fuels to low- or zero-carbon fuels, some of which require new ways to convert energy on-board ships, such as fuel cells.

None of these technologies are currently available on the market at a scale that enables a transformation of the industry. Most technologies are already used on land, or separately, but much development is needed to scale up the technologies to the requirements of the maritime sector, to integrate components into systems and test them in maritime environments.

The technology needs to be developed urgently. The time available for a transition to zero-carbon shipping can be prolonged somewhat by implementing the short-term measures to reduce GHG emissions from shipping.

Apart from meeting the levels of ambition of the strategy, there are other advantages of improving the energy-efficiency of shipping in the short term. New fuels are projected to be substantially more expensive than fossil fuels, partly because the damage that fossil fuels do to the climate and the environment is not reflected in their price. If ships improve their efficiency, and lower the amount of energy they require to perform a unit of work, the price increase of using zero-carbon fuels will be smaller.

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## A Modelling of the impact of measures on emissions

### A.1 UMAS shipping model: GloTraM theory and architecture of the model

UMAS' Global Transport Model (GloTraM) enables a holistic analysis of the global shipping system, including of how shipping might change in response to developments in economic drivers such as fuel prices and to changing environmental regulation.

The model comprises different modules which ensures that the analysis and any algorithms are robust, and connected together in order to consider the dynamics at a 'whole system' level. It is possible to identify at least 8 modules:

- Transport demand module that estimates for a given year the total mass of freight multiplied by the distance it is transported.
- Ship stock module that maintains a database of the ships that make up fleets of ship type/size which is updated every time-step simulated.
- Transport supply module; once the transport demand for each ship type is estimated, the characteristic of the actual fleet in the stock is used to calculate the transport supply.
- Ship evaluation module that assesses the profitability of any specified ship.
- Ship fuel consumption module that calculates the annual fuel consumption and different emissions species emitted per year for each specified ship.
- Regulatory module that applies all the existing and upcoming regulations.
- Ships impact module that assesses any change due to the adoption of a technology (CO<sub>2</sub> abatement and new machinery technologies) for each specified ship.
- Emissions apportionment and climate module that provides national and regional statistics for CO<sub>2</sub> emissions according to different allocation philosophies as well as specify different level of carbon budget constraint.

A key feature of the model is that investment and operational (speed) decisions are modelled for each ship type, size and age category in a way which maximises a shipowner's profits under a given regulatory and macroeconomic environment. The model is therefore based on a profit maximization approach.

#### A.1.1 Rebound effect explained

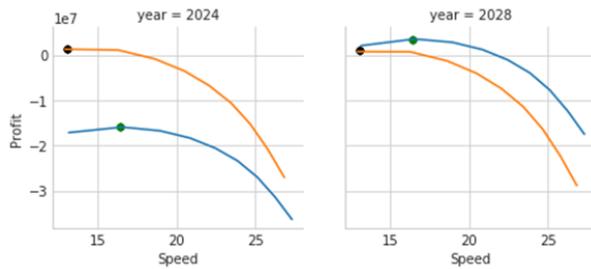
Technical efficiency improvements reduce a ship's fuel consumption at a given speed and the gradient of the speed/fuel curve. This reduces the cost and marginal cost of increased speed. If all else is equal, a ship has a commercial incentive to operate at a higher than average speed if it has better than average technical efficiency. If the technically more efficient ship operates at an increased speed, the cost savings achieved in practice are lower than those of the technical efficiency increase (a form of rebound effect).

In separate research, we investigated the average speeds of a cohort of ships (Suezmax) with a mewis duct retrofit. Operating speeds were increased relative to ships which were not retrofitted and the operational efficiency gain was significantly lower than the technical efficiency increase.

Figure 13 shows the profit/speed curve for a selected cohort for container vessels. The effect of the technical efficiency improvements results in higher annual costs (ie. the blue curve on the left hand side is below the orange BAU curve). The additional capital costs are then paid off by 2028, resulting in the curve moving above the BAU curve. The effect of the new technology is also to change the shape of the profit/speed curve by shifting the optimal speed to the right. The change in annual costs between 2024 and 2028 has

no effect on this shape, simply shifting the curve vertically, whilst maintaining the same optimal speed.

Figure 13 - profit/speed curve for a selected cohort for container vessels



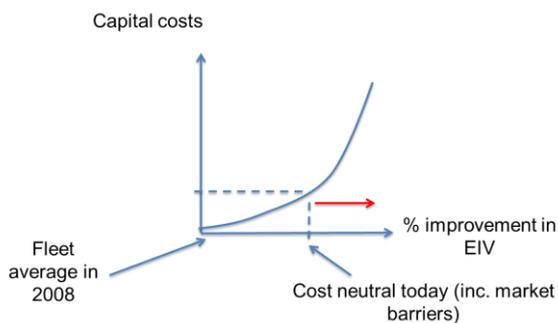
## A.2 Introducing the short-term measures into GloTraM model

The short-term policy measures identified in this study were introduced into the GloTraM model. We can group the different measures into:

- policies that mandate technical/design efficiency improvements: EFIP, EEDI for existing ships, strengthening the EEDI for new ships;
- policies with no mandated stringency levels, but that can help remove market barriers: Further improvement of the SEEMP (goal setting and periodic efficiency assessment) and national action plans;
- policies that mandate operational carbon intensity improvements: operational energy efficiency standards, speed regulation.

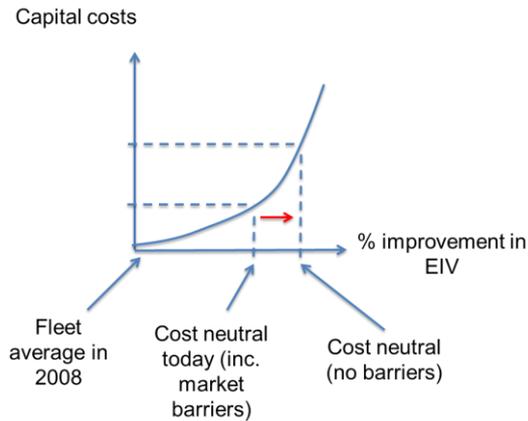
The introduction of these policies has different effects on the model and its input assumptions. The technical efficiency policies, such as existing fleet improvement programme (EFIP), EEDI for existing ships, and strengthening the EEDI for new ships, would improve the EIV and lead to an increase in capital costs (as shown in Figure 14).

Figure 14 - Effects on the model of technical efficiency policies



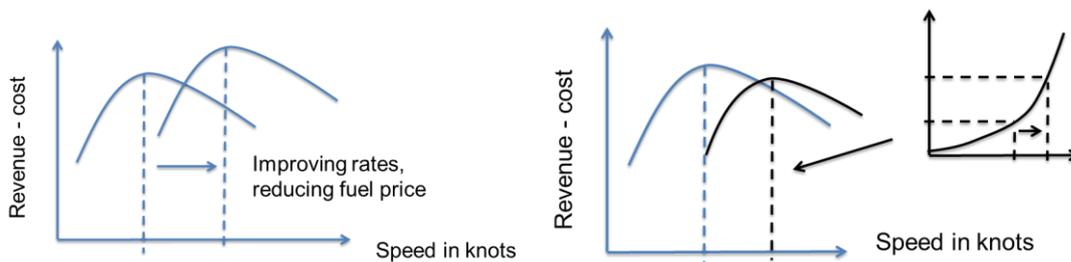
On the other hand, policies removing market barriers, such as further improvement of the SEEMP (goal setting and periodic efficiency assessment) and national action plans, would allow for greater investment reaching higher level of EIV improvement with associated higher investment costs (as shown in Figure 15).

Figure 15 - Effects on the model of policies that address market barriers



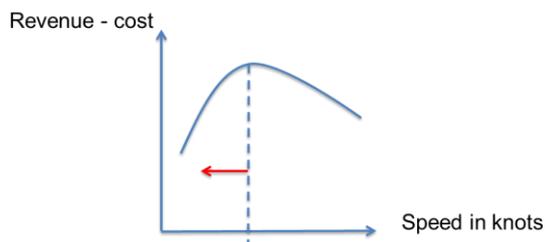
The model captures the response in speed under different market conditions (freight rates and fuel prices) which create different optimal speeds for each ship (as shown in Figure 16, on the left), and for the fleet average speed. For example, in the BAU scenario, we expect that freight rates will improve out to 2030, relative to 2012, and therefore that fleet average speeds will increase. The model also captures the effect of technologies on the shape of the profit/speed relationship for an individual ship as shown in Figure 16 on the right).

Figure 16 – Relationship between speed and profits



In the case of policies that mandate operational carbon intensity improvements such as speed limits, the model constrains an individual ship to operate at its optimal speed as represented in Figure 17.

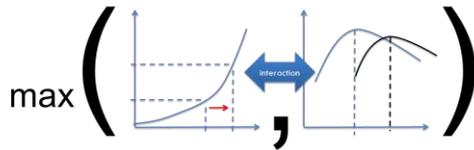
Figure 17 - Effects on the model of speed limits policies



Taking into account the interactions between both speed and technology costs, the model chooses the combinations of technology and speed that maximise a shipowner's profits, under given constraints (e.g. max speeds, max AER, max EEDI, different levels of market barriers, etc).

The objective function of the model is shown in Figure 18 and provided in equation (1).

Figure 18 - Illustrative representation of the objective function



$$\max(NPV = \sum_t^T \frac{365P_{tc\_pd} + B_{tc}(R_{vc\_pa} + B_{vc} - C_{I\_delta} - C_{vpa} - 365P_{tc\_pd}) - C_{s\_base} + C_{s\_delta}}{(1+d)^t})$$

Where:

- NPV is the net present value;
- T is the time horizon for the investment;
- t is the year of the cash flow;
- d is the discount rate;
- Ptc\_pd is the time charter per day;
- B\_tc is the barrier factor for time charter;
- R\_vc\_pa is the revenue per year of the ship operator;
- B\_vc is the barrier factor for voyage charter;
- CI\_delta is the inventory cost difference (relative to the baseline inventory cost);
- C\_vpa is the voyage cost per year;
- C\_s\_base is the cost base of the shipowner;
- C\_s\_delta is the extra investment costs for the shipowner (relative to the baseline fleet).

### A.3 Input assumptions

#### Fleet

The baseline fleet is aggregated by ship type, size and generation categories as shown in Table 17. Each bin is represented in the model using a representative ship with common technical and operational specifications (such as power installed, design speed, active days per year, time spent in ECA, etc.).

Table 17 - Baseline fleet aggregated by ship type, size and generation categories

Type/size	Generation			
	< 1990	1990-2000	2000-2010	2010-2016
Bulk carrier 0-9999	348	167	211	175
Bulk carrier 10000-34999	947	430	616	765
Bulk carrier 35000-59999	560	457	993	1825
Bulk carrier 60000-99999	348	452	793	1799
Bulk carrier 100000-199999	101	277	387	740
Bulk carrier 200000-+	30	77	84	267
Chemical tanker 0-4999	303	280	342	154
Chemical tanker 5000-9999	153	164	390	219
Chemical tanker 10000-19999	74	117	595	243
Chemical tanker 20000-+	170	173	889	587
Container 0-999	209	415	463	83
Container 1000-1999	167	479	598	227
Container 2000-2999	100	198	411	89
Container 3000-4999	82	231	529	252
Container 5000-7999	0	76	455	138

Type/size	Generation			
	< 1990	1990-2000	2000-2010	2010-2016
Container 8000-11999	0	0	196	305
Container 12000-14500	0	0	3	166
Container 145000+	1	0	0	56
General cargo 0-4999	4152	1509	1265	596
General cargo 5000-9999	1151	651	933	486
General cargo 10000-+	936	314	652	705
Liquefied gas tanker 0-49999	283	314	302	298
Liquefied gas tanker 50000-199999	67	81	279	197
Liquefied gas tanker 200000-+	6	0	40	5
Oil tanker 0-4999	1187	521	311	336
Oil tanker 5000-9999	164	121	217	197
Oil tanker 10000-19999	99	54	59	31
Oil tanker 20000-59999	189	180	373	123
Oil tanker 60000-79999	35	40	287	84
Oil tanker 80000-119999	47	219	532	249
Oil tanker 120000-199999	17	107	246	177
Oil tanker 200000-+	13	116	337	255

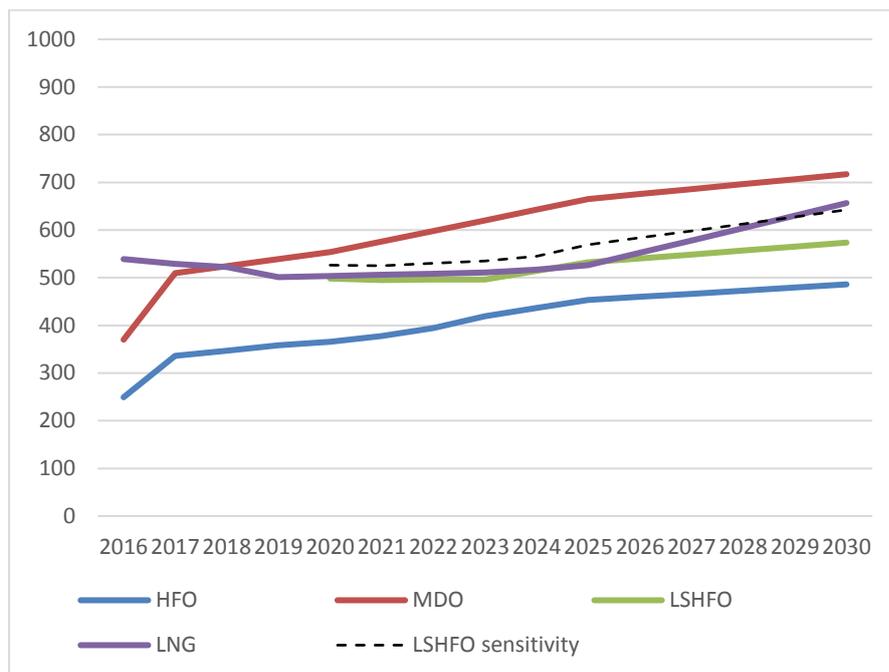
### Fuel prices

The fuel prices assumed in this study are provided in Figure 19. This projection is derived from the Shipping in Climate Changes (SCC)<sup>8</sup> research programme, using the scenario “Middle of the Road 2 degree”.

We have also conducted a fuel price sensitivity scenario, based on feedback from the stakeholder consultation, in which we explore a scenario with a larger price difference between compliant and no-compliant fuels from 2020 (referred to as a ‘spike’ in 2020) due to the incoming IMO sulphur cap. To simulate such a ‘spike’, we narrowed the price difference between MDO and LSHFO by higher fuel prices for LSHFO (as shown in Figure 19). The results of this scenario are provided in Section A.4.

<sup>8</sup> [http://www.lowcarbonshipping.co.uk/index.php?option=com\\_content&view=article&id=38&Itemid=176](http://www.lowcarbonshipping.co.uk/index.php?option=com_content&view=article&id=38&Itemid=176)

Figure 19 – Fuel price projections



### Transport demand

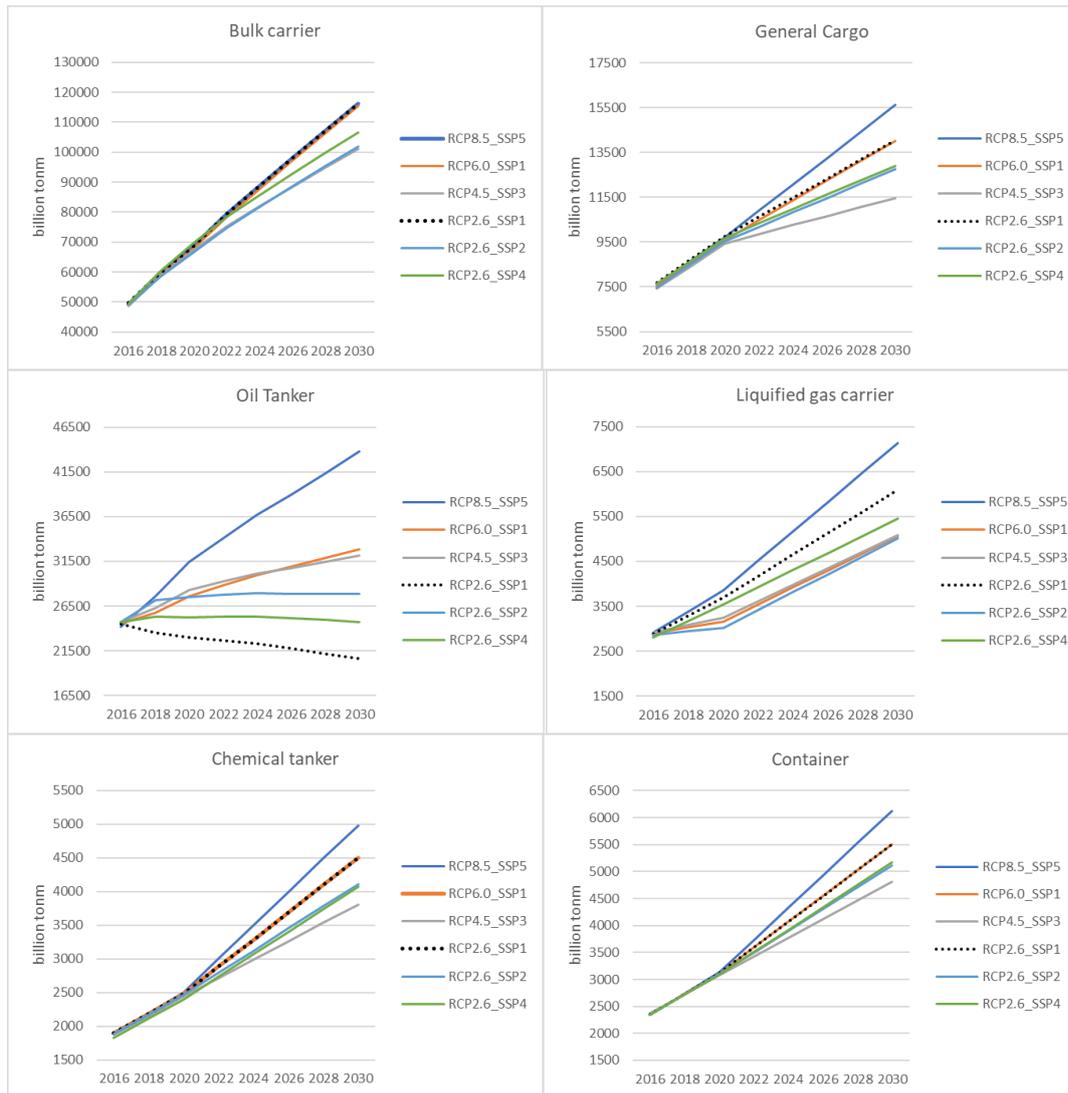
There are six different transport demand scenarios available in the model. These are listed in Table 18 and shown in Figure 20 across different ship types. The transport demand used in the modelling simulations for this study is the 1.6C sustainability demand which reflects the RCP2.6 and SSP1 scenarios.

We have also conducted a sensitivity scenario, based on feedback from the stakeholder consultation, in which we explore a scenario with a different transport demand. We used the scenario “regional rivalry” which reflects the RCP4.5 and SSP3 scenarios. This scenario has a higher level of transport demand for oil tanker and lower levels for the other ship types relative to the 1.6 C sustainability demand scenario. The results of this sensitivity scenario are provided in Section A.4

Table 18 - Transport demand scenarios

Transport demand scenario	RCP scenario	SSP scenario
4°C - Fossil fuelled development	RCP8.5	SSP5
3°C - Sustainability	RCP6.0	SSP1
2.5°C - Regional rivalry	RCP4.5	SSP3
<b>1.6°C - Sustainability</b>	<b>RCP2.6</b>	<b>SSP1</b>
1.6°C - Middle of the road	RCP2.6	SSP2
1.6°C - Inequality	RCP2.6	SSP4

Figure 20 - Transport demand scenarios by ship type



### Technologies and fuels

A number of energy efficiency technologies is made available in the model. Table 19 shows the list of technologies and their assumed efficiency improvement.

None of these technologies is assumed to be implemented in the baseline fleet in 2016 (base year).

Table 19 - Energy efficiency technologies and their assumed efficiency improvement (%)

	Efficiency improvement (%)
Rudder Bulb	2
Preswirl Stator Duct	3
Trim and Draught Optimisation	3
Vane Wheels	3
Contra-rotating Propeller	8
Tip Loaded Propeller	2
Stern Flaps	3
Biocide Hull Coating	1
Foul Release Hull Coating	2
Steam WHR	3.5
Organic Rankine Cycle WHR	3

	Efficiency improvement (%)
Engine Tuning	0.5
Engine Derating	2
Common Rail	0.3
Autopilot Upgrade	1
Air lubrication	8
Wind assistance	5/10

#### Other assumptions

The fleet renewal rate is driven by the transport demand scenario. In each time step, a number of new ships enter the market to meet the transport demand. We assume a perfect balance between supply and demand, so if demand increases, supply increases as well to meet this demand. In the base year and if the demand decreases, the model has the capability to lay up ships that are not required to meet the demand.

For this study, the model assumes that up to 2030, there is no availability of low/zero carbon fuels. The fuel options considered are: HFO, LSHFO, MDO/MGO, LNG.

The market barriers are different for each ship type, therefore we use different market factors as provided in Table 20. The barrier factor represents the proportion of a charterer's fuel cost savings that are returned to the shipowner (0 market barrier = 100% of the fuel saving is passed to the shipowner).

Table 20 - Market barrier assumptions by ship type

Ship type	Market factor
Bulk carrier	0.315
Chemical tanker	0.56
Container	0.635
General cargo	0.4
Liquefied gas tanker	0.675
Oil tanker	0.535

## A.4 Detailed results

This section provides the detailed modelling results over the period 2016 to 2030 at a fleet aggregated level for the following parameters:

- CO<sub>2</sub> emissions;
- number of active ships;
- fleet average operational speed;
- EIV (for technical energy efficiency);
- AER (for operational energy efficiency).

The EIV, AER and operational speed are weighted average with emissions in each cohort.

#### Impact on CO<sub>2</sub> emissions

The impact of each short-term measure on CO<sub>2</sub> emission is presented and discussed under the respective sections in the body of the report. Figure 21 below shows the indexed CO<sub>2</sub> emissions trends for all of the short-term measures policy scenarios and the BAU. As can be seen in Figure 14, policies which focus on increasing technical efficiency (e.g. measures that only apply to new ships (EEDI), and measures that encourage or mandate an improvement of the technical efficiency such as mandatory retrofits, EFIP, EEDI for existing ships) would likely only have a modest impact on CO<sub>2</sub> emissions, at least in the short term. In contrast, policies that mandate carbon intensity improvements (e.g. setting mandatory operational efficiency standards, speed reduction) can lead to

significant cumulative CO<sub>2</sub> reductions (e.g. 31% for operational efficiency standard at - 60% AER) compared to the BAU scenario over the period to 2030 (as shown in Table 21).

Figure 21 - Indexed CO<sub>2</sub> emissions for BAU and the short-term measures

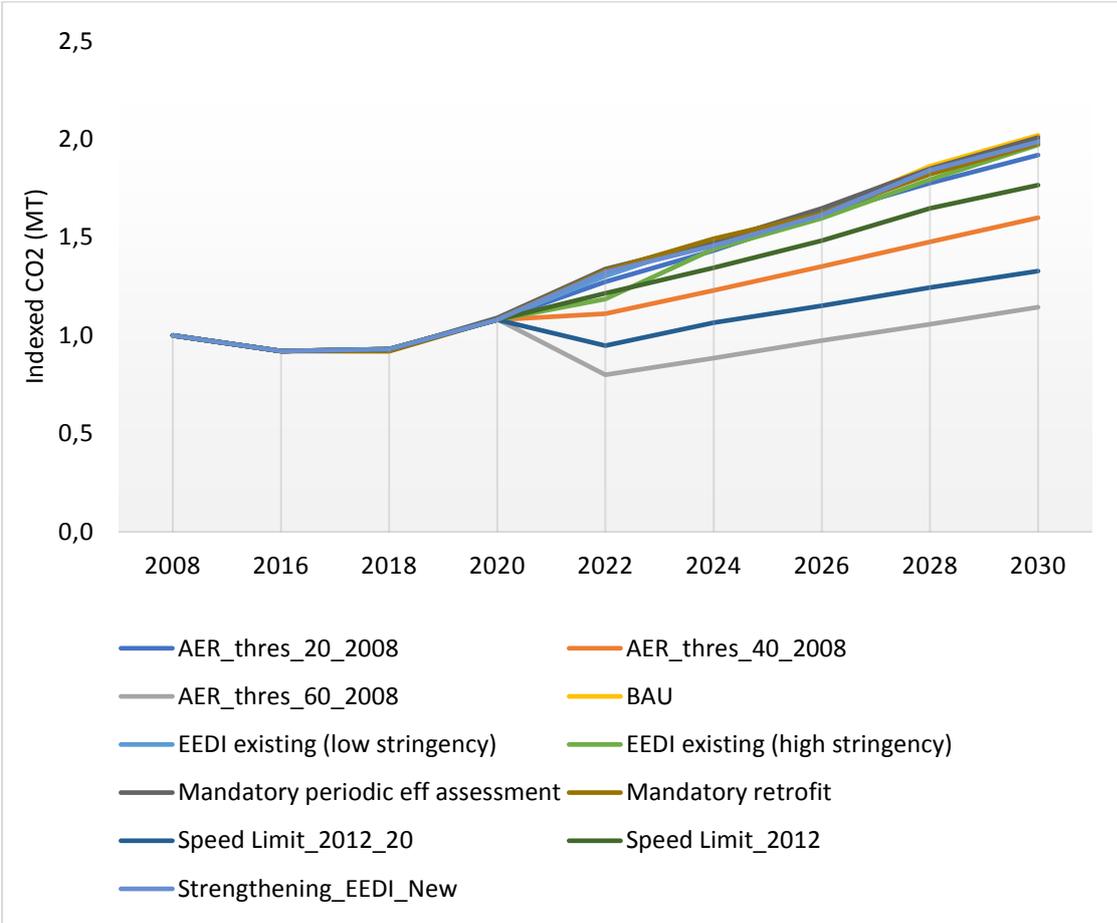


Table 21 - Tabular results of the indexed CO<sub>2</sub> emissions for BAU and the short-term measures

	2008	2016	2018	2020	2022	2024	2026	2028	2030	% CO <sub>2</sub> reduction in 2030	% cum. CO <sub>2</sub> reduction*
BAU	1.0	0.9	0.9	1.1	1.3	1.5	1.6	1.9	2.0	0%	0%
AER_thres_20_2008	1.0	0.9	0.9	1.1	1.3	1.4	1.6	1.8	1.9	-5%	-3%
AER_thres_40_2008	1.0	0.9	0.9	1.1	1.1	1.2	1.4	1.5	1.6	-21%	-14%
AER_thres_60_2008	1.0	0.9	0.9	1.1	0.8	0.9	1.0	1.1	1.1	-43%	-31%
EEDI existing /EFIP (low stringency)	1.0	0.9	0.9	1.1	1.3	1.5	1.6	1.8	2.0	-1%	-1%
EEDI existing/EFIP (high stringency)	1.0	0.9	0.9	1.1	1.2	1.4	1.6	1.8	2.0	-3%	-3%

	2008	2016	2018	2020	2022	2024	2026	2028	2030	% CO <sub>2</sub> reduction in 2030	% cum.CO <sub>2</sub> reduction*
Mandatory goal setting/ periodic eff assessment	1.0	0.9	0.9	1.1	1.3	1.5	1.6	1.8	2.0	-1%	0%
Mandatory retrofit	1.0	0.9	0.9	1.1	1.3	1.5	1.6	1.8	2.0	-2%	-1%
Speed Limit_2012_20	1.0	0.9	0.9	1.1	0.9	1.1	1.2	1.2	1.3	-34%	-23%
Speed Limit_2012	1.0	0.9	0.9	1.1	1.2	1.3	1.5	1.6	1.8	-13%	-8%
Strengthening EEDI	1.0	0.9	0.9	1.1	1.3	1.5	1.6	1.8	2.0	-2%	-1%

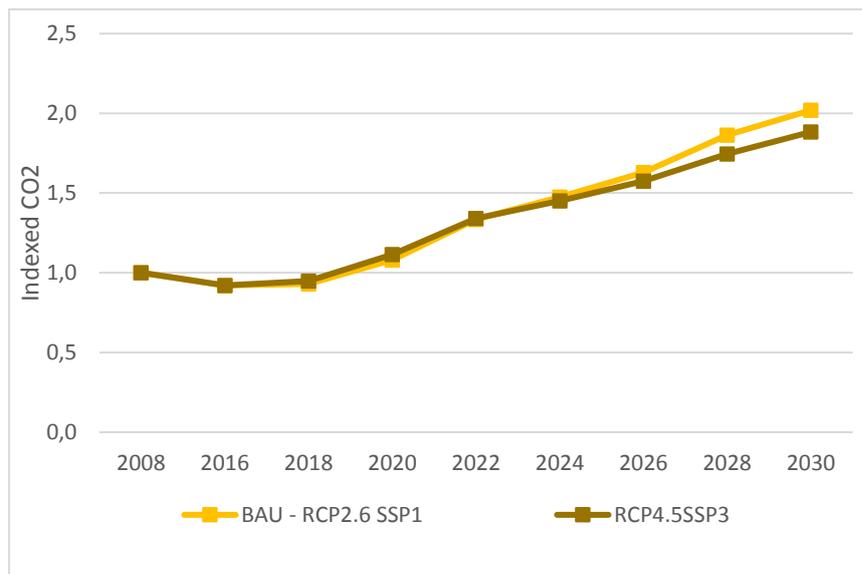
### Sensitivity scenarios

In addition to the scenarios used to explore the sensitivity of the results with and without the rebound effect, we also conducted two other sensitivity scenarios; one in which we changed the assumption on fuel prices and another one with different transport demand assumptions.

The sensitivity scenario with a fuel price 'spike' (input assumptions in Section A.3) would incentivise ships to slow down or switch to other compliant fuels which in turn would impact CO<sub>2</sub> (and other) emissions. We applied this fuel price projection to the policy scenario speeds reduction 20% below the respective 2012 values. We observe that in this scenario, the average operating speed decreases by an average of 12% relative to the scenario without the spike. As a consequence, the level of CO<sub>2</sub> emissions decreases by an additional 2% compared to the scenario without the fuel price spike. In other words, reducing the average operating speed by 20% would result in 25% cumulative emission reductions over the period 2016 to 2030 in the fuel price spike scenario compared to 23% in the scenario without the spike.

For the sensitivity scenario with a different transport demand (input assumptions in Section A.3), we observe that CO<sub>2</sub> emissions would decrease by about 7% in 2030 relative to the BAU. Figure 22 shows the CO<sub>2</sub> trends relative to the value in 2008 for the BAU scenario (using 'sustainability' RCP2.6 and SSP1) and the BAU scenario with a different transport demand (using 'regional rivalry' RCP4.5 and SSP3). The lower level of CO<sub>2</sub> is associated with an overall lower level of transport demand within the sensitivity scenario. Although, the transport demand 'regional rivalry' has higher level of transport demand for oil tanker, it assumes significant lower level of demand for the other ship types (as shown in figure in Section A.3 Transport demand).

Figure 22 - CO<sub>2</sub> emissions in BAU Sustainability scenario and BAU Regional Rivalry scenarios



### Fleet size

Each short-term measure may have an impact on the number of ships operating over time. Figure 23 shows the number of active ships indexed to the value in 2008 for the BAU scenario and the short-term policy scenarios. In the BAU scenario, the number of active ships is projected to increase by about 133% by 2030 relative to the value in 2008. Policies which incentivise or mandate a speed limit (e.g. operational efficiency standards and speed regulation) would require a larger number of active ships to meet the transport demand. For example, setting the AER to 60% below the 2008 level would require the number of active ships to increase by about 235% relative to the 2008 value (as shown in Table 22).

Relative to the BAU, setting the AER to 40% below the 2008 level would result in an increase in fleet size of about 35% in 2030. In contrast, setting the average speed at 20% below the 2012 values would result in the fleet size increasing by 86% in 2030 relative to the BAU.

In those scenarios with technical efficiency policies, the number of active ships would likely decrease because there is an increasing in efficiency. The results suggest that the number of active ships under these policy measure scenarios could decrease by between 1 and 9% relative to the BAU in 2030 (see Figure 23).

Figure 23 - Projected number of ships indexed to the value in 2008 for the BAU and the policy scenarios

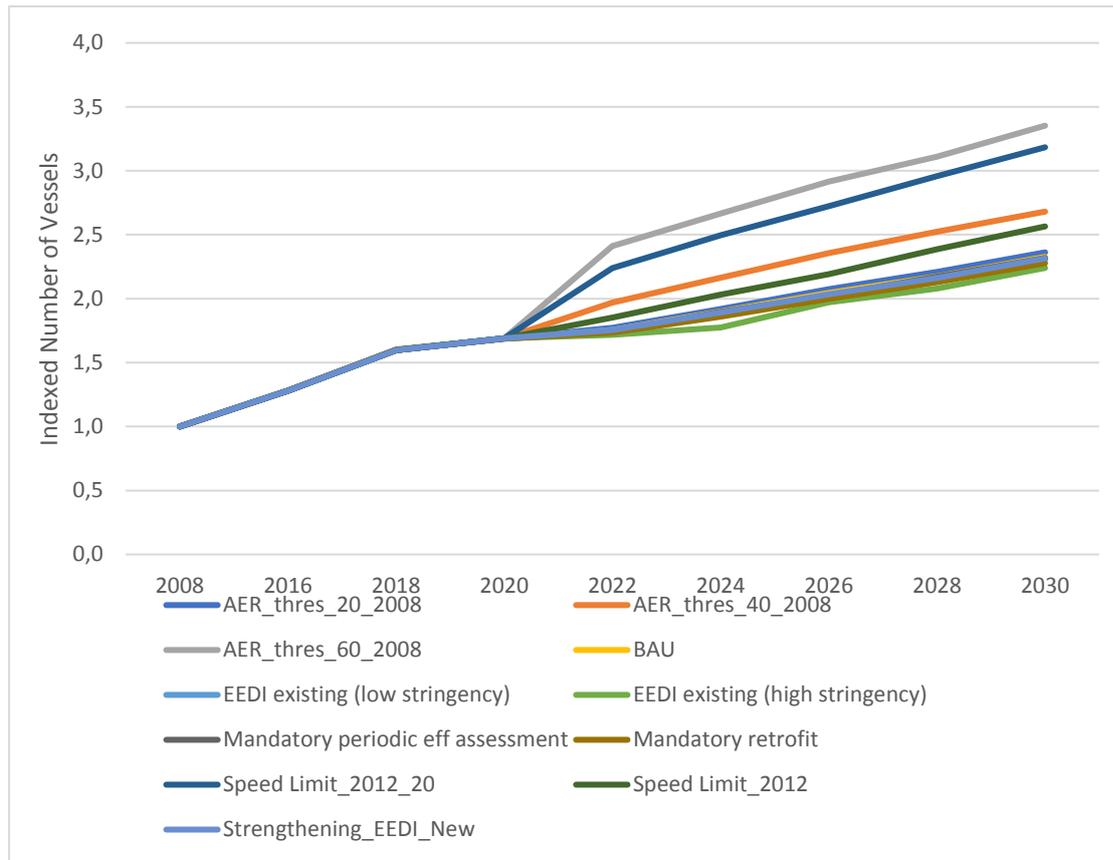


Table 22 - Tabular results of projected number of ships indexed to the value in 2008 for the BAU and the policy scenarios

	2008	2016	2018	2020	2022	2024	2026	2028	2030	% increase in fleet size	diff to the BAU
BAU	1.00	1.28	1.60	1.69	1.75	1.90	2.04	2.17	2.33	133%	
AER_thres_20_2008	1.00	1.28	1.60	1.69	1.77	1.92	2.08	2.21	2.36	136%	4%
AER_thres_40_2008	1.00	1.28	1.60	1.69	1.97	2.16	2.36	2.52	2.68	168%	35%
AER_thres_60_2008	1.00	1.28	1.60	1.69	2.41	2.67	2.92	3.11	3.35	235%	103%
EEDI existing /EFIP(low stringency)	1.00	1.28	1.60	1.69	1.75	1.88	2.03	2.16	2.31	131%	-2%
EEDI existing/EFIP (high stringency)	1.00	1.28	1.60	1.69	1.72	1.77	1.97	2.08	2.24	124%	-9%
Mandatory goal setting/ periodic eff assessment	1.00	1.28	1.60	1.69	1.74	1.90	2.03	2.17	2.32	132%	-1%
Mandatory retrofit	1.00	1.28	1.60	1.69	1.74	1.86	2.00	2.13	2.28	128%	-5%
Speed Limit_2012_20	1.00	1.28	1.60	1.69	2.24	2.50	2.72	2.96	3.18	218%	86%
Speed Limit_2012	1.00	1.28	1.60	1.69	1.85	2.03	2.19	2.39	2.56	156%	24%
Strengthening EEDI	1.00	1.28	1.60	1.69	1.75	1.89	2.03	2.16	2.32	132%	-1%

### Operational speed

Figure 24 shows the trends of the fleet weighted average operational speed indexed to the value in 2008 for the BAU and the policy scenarios. The BAU shows an average operating speed increasing from 2020 onwards and by 2030 reaching almost the 2008 speed level. Speed developments over time are similar in those scenarios in which policies mandate or incentivise technical energy efficiency: they show a general increase

in speed over time. In the scenario imposing a stringent EEDI for existing ships, average operating speed increases the most out of the various scenarios and even surpasses the 2008 average speed level by 1%. As explained in A.1.1 and in Section 2.2.6, this can be explained with the rebound effect (due to the incentive to increase operating speed in response to the improved technical energy efficiency and resulting cost reductions).

The scenarios for speed regulation and operational efficiency standards show a significant speed reduction depending on the level of stringency of the regulation. For example, the operational speed under the operational efficiency standard set at 40% below the AER baseline in 2008 would result in a speed reduction of about 14% relative to the 2008 level, whereas the speed reduction measure set at the average 2012 in-service speed level would reduce speed by about 10% relative to the 2008 level.

Figure 24 - Indexed operational speed for the BAU and the policy scenarios

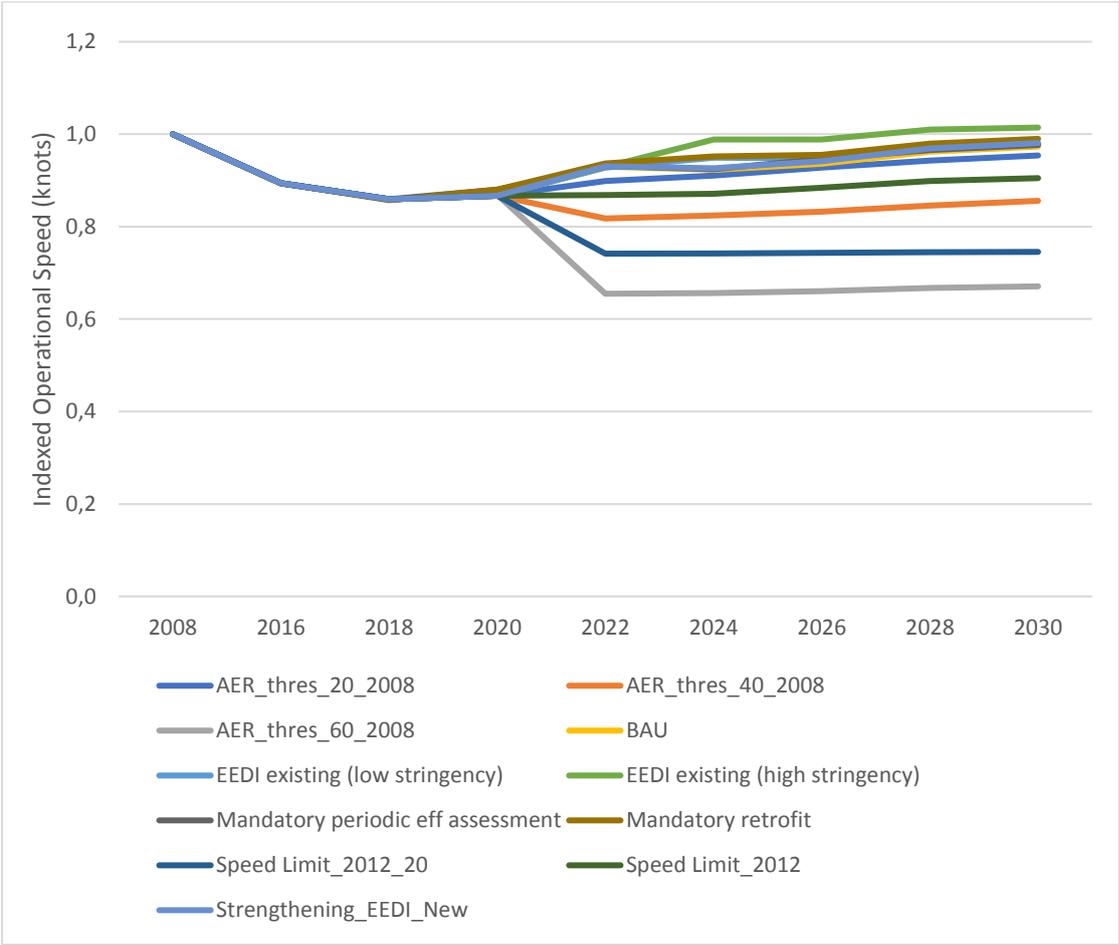


Table 23 - Tabular results of the indexed operational speed for the BAU and the policy scenarios

	2008	2016	2018	2020	2022	2024	2026	2028	2030	% diff. relative to 2008
BAU	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	-3%
AER_thres_20_2008	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.0	-5%
AER_thres_40_2008	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.9	-14%
AER_thres_60_2008	1.0	0.9	0.9	0.9	0.7	0.7	0.7	0.7	0.7	-33%
EEDI existing /EFIP (low stringency)	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	-2%
EEDI existing/EFIP (high stringency)	1.0	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1%
Mandatory goal setting/ periodic eff assessment	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	-2%
Mandatory retrofit	1.0	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	-1%
Speed Limit_2012_20	1.0	0.9	0.9	0.9	0.7	0.7	0.7	0.7	0.7	-25%
Speed Limit_2012	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	-10%
Strengthening EEDI	1.0	0.9	0.9	0.9	0.9	0.9	0.9	1.0	1.0	-2%

### Technical energy efficiency

Figure 25 shows the projected weighted EIV indexed to the value in 2008 for the BAU and the policy scenarios. The BAU scenario shows a considerable improvement of the technical efficiency between 2008 and 2018. For ships that entered the fleet in this period, this improvement is plausible and also reflected in EIVs of these ships. For existing, pre-EEDI ships, this improvement is based on the expectation that shipping companies will retrofit, to some extent, cost-effective technologies like propeller and rudder upgrades, bulbous bow improvements, advanced hull coatings, etc. From 2022, when the policy measures are assumed to enter into force, the EIV trends change relative to the BAU scenario, with the EEDI for existing ships measures (with high level of stringency) reaching the highest level of improvement (approximately 37% relative to the value in 2008).

Figure 25 - EIV trends for the BAU and the policy scenarios

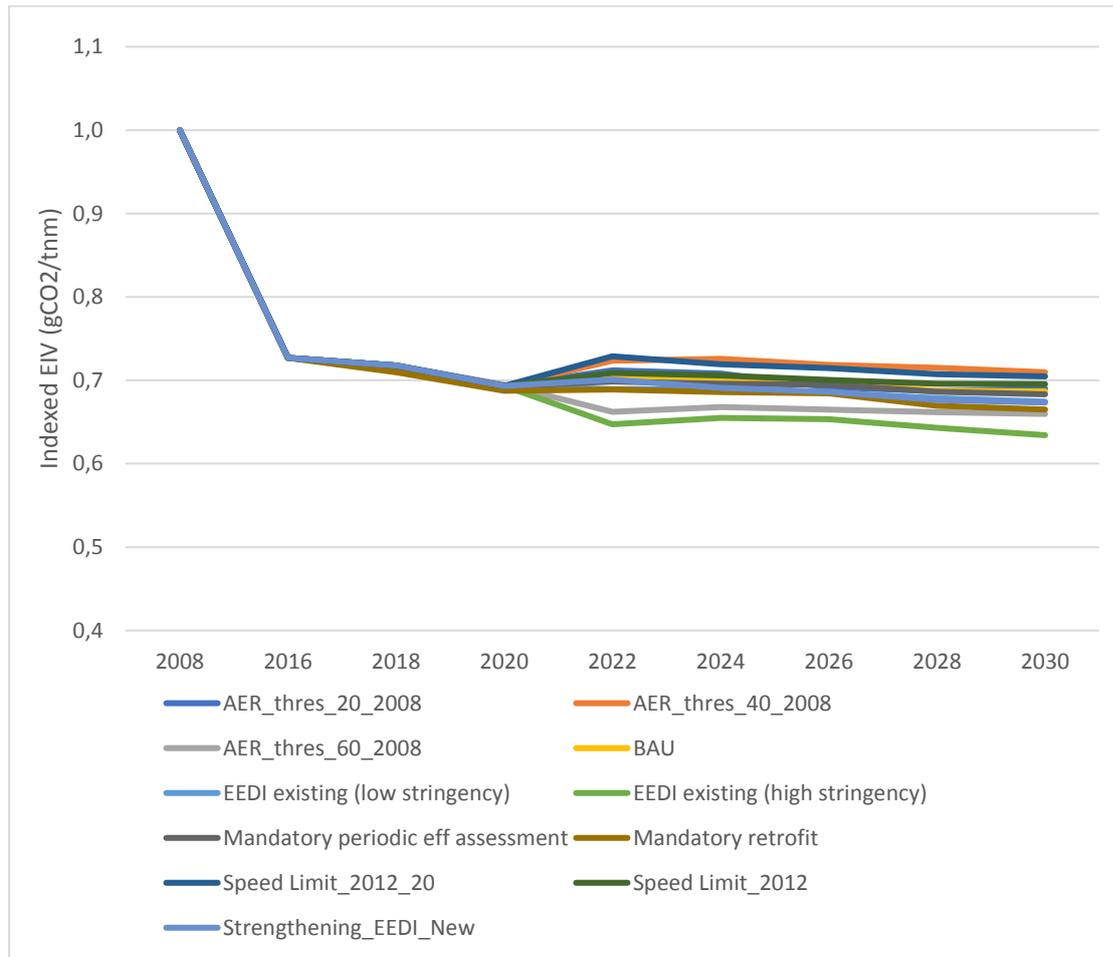


Table 24 - Tabular results for the EIV trends for the BAU and the policy scenarios

	2008	2016	2018	2020	2022	2024	2026	2028	2030	% diff. relative to 2008
BAU	1.00	0.73	0.72	0.69	0.71	0.70	0.70	0.69	0.69	-31%
AER_thres_20_2008	1.00	0.73	0.72	0.69	0.71	0.71	0.69	0.69	0.69	-31%
AER_thres_40_2008	1.00	0.73	0.72	0.69	0.72	0.73	0.72	0.71	0.71	-29%
AER_thres_60_2008	1.00	0.73	0.72	0.69	0.66	0.67	0.66	0.66	0.66	-34%
EEDI existing /EFIP (low stringency)	1.00	0.73	0.72	0.69	0.69	0.69	0.69	0.68	0.67	-33%
EEDI existing/EFIP (high stringency)	1.00	0.73	0.72	0.69	0.65	0.65	0.65	0.64	0.63	-37%
Mandatory goal setting/periodic eff assessment	1.00	0.73	0.71	0.69	0.70	0.70	0.69	0.69	0.68	-32%
Mandatory retrofit	1.00	0.73	0.71	0.69	0.69	0.69	0.68	0.67	0.66	-34%
Speed Limit_2012_20	1.00	0.73	0.72	0.69	0.73	0.72	0.71	0.71	0.70	-30%
Speed Limit_2012	1.00	0.73	0.72	0.69	0.71	0.71	0.70	0.70	0.70	-30%
Strengthening EEDI	1.00	0.73	0.72	0.69	0.70	0.69	0.69	0.68	0.67	-33%

### Operational energy efficiency

Figure 26 shows the projected weighted AER indexed to the value in 2008 for the BAU and the policy scenarios. The BAU scenario shows an improvement in operational energy efficiency of about 25%. Policies that mandate or incentivise technical energy efficiency would result in a marginal operational efficiency improvement of less than 1.5% relative

to the BAU (up to 26% AER improvement relative to the 2008). In contrast, policies that mandate speed reduction and operational efficiency standards would result in a significant operational efficiency improvement relative to the BAU ranging from 3% to 31% relative to the BAU (27% to 56% AER improvement relative to 2008). Such an improvement is mainly driven by speed reduction.

Figure 26 - AER trends for the BAU and the policy scenarios



Table 25 - Tabular results of AER trends for the BAU and the policy scenarios

	2008	2016	2018	2020	2022	2024	2026	2028	2030	% reductin relative to	diff to the BAU
BAU	1.0	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.8	-25%	
AER_thres_20_2008	1.0	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.7	-27%	-3%
AER_thres_40_2008	1.0	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6	-37%	-12%
AER_thres_60_2008	1.0	0.7	0.7	0.6	0.4	0.4	0.4	0.4	0.4	-56%	-31%
EEDI existing /EFIP(low stringency)	1.0	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.7	-25%	-0.5%
EEDI existing/EFIP (high stringency)	1.0	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.7	-26%	-1.3%
Mandatory goal setting/ periodic eff assessment	1.0	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.8	-25%	0.2%
Mandatory retrofit	1.0	0.7	0.6	0.6	0.7	0.7	0.7	0.7	0.7	-26%	-1.4%
Speed Limit_2012_20	1.0	0.7	0.7	0.6	0.5	0.5	0.5	0.5	0.5	-46%	-21%
Speed Limit_2012	1.0	0.7	0.7	0.6	0.6	0.6	0.6	0.7	0.7	-33%	-8.7%
Strengthening EEDI	1.0	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.7	-25%	-0.6%

## B Minimum propulsion power

## C Design efficiency of the existing fleet

### C.1 Introduction

This Annex analyses how the average design efficiency of the fleet changes when relatively inefficient ships are improved to have the average efficiency.

### C.2 Method

CE Delft maintains a database of all bulk carriers, tankers and container ships that have entered the fleet from the 1960s up to and including 2015. For all the ships for which sufficient data is available, the Estimated Index Value (EIV) has been calculated.

The EIV is a simplified form of the EEDI, which has been used, amongst others, to calculate the EEDI reference lines ([CE Delft 2016](#)). The EIV is given by the formula (Resolution MEPC.231(65)):

$$\text{Estimated Index Value} = 3.1144 \cdot \frac{190 \cdot \sum_{i=1}^{NME} P_{MEi} + 215 \cdot P_{AE}}{\text{Capacity} \cdot V_{ref}}$$

In line with resolution MEPC.231(65) the following assumptions have been made in calculating the EIV:

- The carbon emission factor is constant for all engines, i.e.  $CF_{ME} = CF_{AE} = CF = 3.1144 \text{ g CO}_2/\text{g fuel}$ .
- The specific fuel consumption for all ship types is constant for all main engines, i.e.  $SFC_{ME} = 190 \text{ g/kWh}$ .
- $P_{ME(i)}$  is main engines power and is 75% of the total installed main power ( $MCR_{ME}$ ).
- The specific fuel consumption for all ship types is constant for all auxiliary engines, i.e.  $SFC_{AE} = 215 \text{ g/kWh}$ .
- $P_{AE}$  is the auxiliary power and is calculated according to paragraphs 2.5.6.1 and 2.5.6.2 of the annex to MEPC.212(63).
- No correction factors on ice class, voluntary structural enhancement, etc. are used.
- Innovative mechanical energy efficiency technology, shaft motors and other innovative energy efficient technologies are all excluded from the calculation, i.e.  $P_{AEff} = 0$ ,  $P_{PTI} = 0$ ,  $P_{eff} = 0$ .
- Capacity is defined as 70% of dead weight tonnage (dwt) for container ships and 100% of dwt for other ship types.

From this database, the ships were selected that were labelled as being 'in service' in the latest available year, i.e. 2015. Next, the ships have been identified for which the EIV is more than 0%, 10%, 20% and 30% above the EEDI reference for each of the three shiptypes. As can be seen in Figure 27 through Figure 29, the patterns varies across shiptypes: whereas bulkers and tankers have many ships that are somewhat above the reference line, most container ships that are not below the reference line are more than 30% above it.

Figure 27 - Design efficiency of the drybulk fleet in 2015

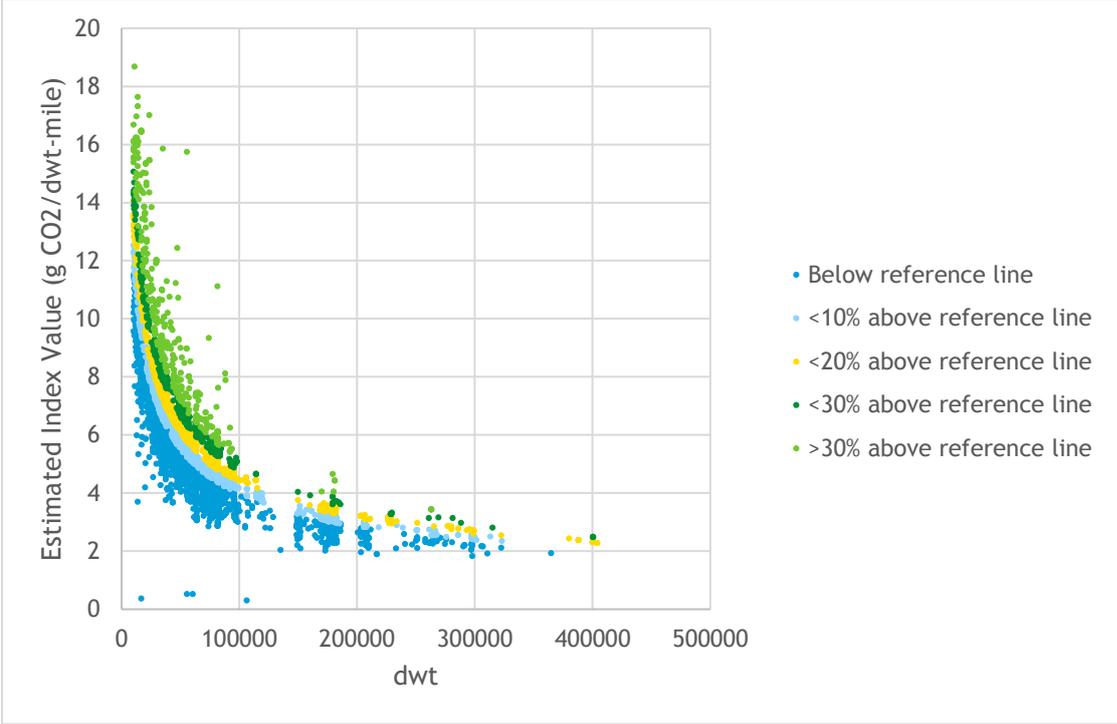


Figure 28 - Design efficiency of the tanker fleet in 2015

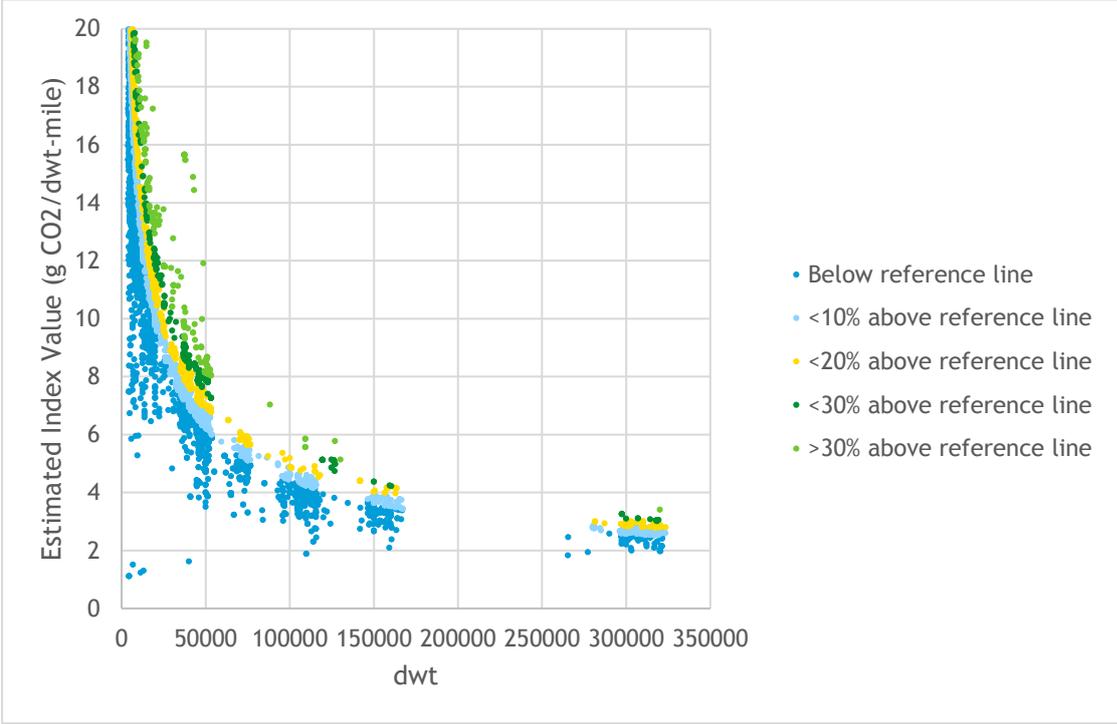


Figure 29 - Design efficiency of the containership fleet in 2015

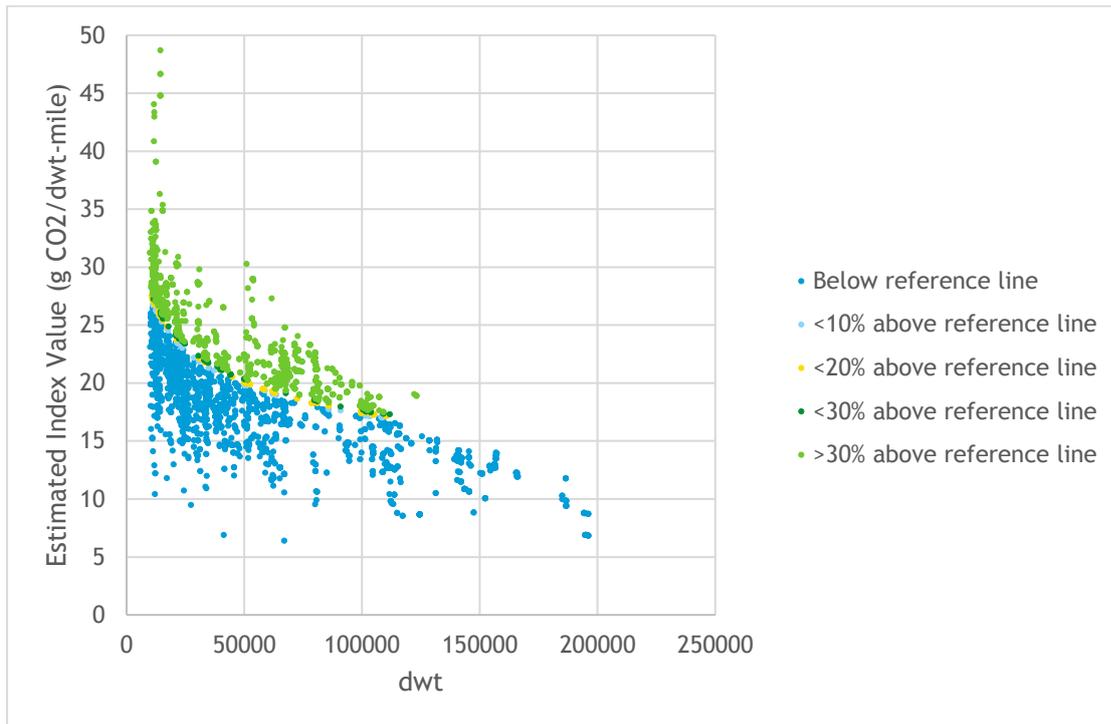


Table 26 through Table 28 show the impact on the fleet of a policy that would require ships that have a design efficiency above a certain target value to improve their efficiency to the average value. As a measure for the impact on emissions, we have used the Pme-weighted average EIV, because fuel use and emissions are probably better correlated with main engine power than with other ship characteristics such as capacity.

Table 26 - Impact on ships and average design efficiency (bulk carriers)

Cut-off value	Pme-weighted EIV	% improvement	% non-compliant ships
0% above the reference line	4,4	-14%	60%
10% above the reference line	4,6	-10%	31%
20% above the reference line	4,8	-6%	10%
30% above the reference line	4,9	-4%	4%
No cut-off	5,1	0%	0

Table 27 - Impact on ships and average design efficiency (tankers)

Cut-off value	Pme-weighted EIV	% improvement	% non-compliant ships
0% above the reference line	5,5	-16%	51%
10% above the reference line	5,8	-11%	21%
20% above the reference line	6,0	-8%	8%
30% above the reference line	6,2	-5%	4%
No cut-off	6,5	0%	0%

Table 28 - Impact on ships and average design efficiency (Containerships)

Cut-off value	Pme-weighted EIV	% improvement	% non-compliant ships
0% above the reference line	16,4	-13%	36%
10% above the reference line	17,5	-8%	14%
20% above the reference line	18,1	-5%	5%
30% above the reference line	18,3	-4%	1%
No cut-off	19,0	0%	0%

Table 26 through Table 28 show that the improvement of the EEDI is fairly consistent across the ship-types analysed. If ships that are 30% (10%) or more above the EEDI reference line are eliminated from the fleet, the Pme-weighted average EIV would improve by about 4% (10%). One could assume that the operational efficiency of the fleet would improve by similar numbers and the emissions would decrease by the same extent.

Two caveats have to be made:

- When efficiently designed ships sail faster than less efficiently designed ships, the Pme-weighting overestimates the contribution of inefficient ships in the total emissions. Hence, the resulting emissions reduction could be *lower*.
- When ships that are taken out of the fleet are replaced by new ships, which have an EEDI that is below the reference line, the static analysis underestimates the impact on the design efficiency. Hence, the resulting emissions reduction could be *higher*.

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