CII and EU maritime decarbonisation

CE Delft

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Delft, CE Delft, June 2023

Publication code: 23.220400.083

Client: EDF Europe

Publications of CE Delft are available from www.cedelft.eu

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Content

Executive Summary

Aim of study

The aim of this study, commissioned by the Environmental Defense Fund Europe, is to investigate whether the Carbon Intensity Indicator (CII) is a meaningful tool which additional measures could use to ensure the timely decarbonisation of the EU maritime shipping sector.

Context

In April 2018, the IMO's Marine Environment Protection Committee (MEPC) adopted the 'Initial IMO Strategy on Reduction of GHG emissions from Ships'. This strategy aims to phase out GHG emissions from international shipping as soon as possible in this century.
In addition, the following specific levels of ambitions are included in the strategy:

- improvement of the carbon intensity of shipping by at least 40% in 2030, relative to 2008 and pursue efforts to improve it by 70% by 2050;
- GHG emissions reduction of shipping by at least 50% by 2050, relative to 2008.

The Initial Strategy, including the levels of ambition, are currently under review with the aim to adopt the revised strategy at the 80th meeting of the MEPC to be held in July 2023.

To achieve the targets as laid down in the Initial Strategy, short-, medium- and long-term policy measures are being developed. The Carbon Intensity Indicator (CII) is a short-term measure which has already been adopted by IMO's MEPC. Regulation 28 of revised MARPOL Annex VI lays down the requirements for the CII certification and came into effect on 1 January 2023.

The CII requires ships of 5,000 GT and above of certain ships types to determine their operational carbon intensity on an annual basis. The operational carbon intensity is thereby measured in terms of grams of CO_2 emitted per cargo carrying capacity per nautical mile. In addition, depending on the CII levels attained, CII labels ranging from A to E are assigned to the ships. To incentivize an improvement of the operational carbon intensity, the CII is designed in such a way that the boundaries of the label categories shift over time, in the line with the increasingly stricter CII reduction factors. This means that ships which do not improve their operational carbon intensity, run the risk of receiving worse CII labels over time. In addition, Regulation 28 requires ships that achieve a D rating for three consecutive years or an E rating in a single year, to develop a corrective action plan to achieve the required annual operational CII and thus a C rating. Regulation 28 also requires these ships to duly undertake the planned corrective actions in accordance with the revised Ship Energy Efficiency Management Plan (SEEMP).

At the EU level, in parallel to the IMO measures, the European Commission has proposed different measures to reduce the GHG emissions of EU maritime shipping as part of the Fit for 55 package. The FuelEU Maritime Regulation aims at reducing the GHG intensity of the energy consumption of ships and the proposed revision of the European Emissions Trading System (EU ETS) would require shipping companies to submit allowances for CO_2 emitted within the scope of the system.

Scope of study

The study focusses on the EU MRV fleet, i.e. the ships which have submitted an emissions report as required by the EU MRV Regulation (2015/757) and for which data is publicly available. These are ships above 5,000 GT and their voyages to/from EEA ports serving the purpose of transporting passengers or cargo for commercial purposes.

For the EU MRV fleet, data for the EU MRV reporting periods 2018 to 2021 are currently available.

In the first instance, we determine and analyse the attained CII and the CII labels of all the ships that have a submitted an emissions report in the first four reporting periods. For the analysis up to 2030 - the time horizon of this study – we focus, however, on the 2019 reporting period, with 2019 being the reference year for the CII measure and the last pre-COVID year.

Please also note that for the analysis up to 2030, we take the 2019 EU MRV fleet as starting point and do not analyse the potential growth of the fleet or a change in the activity of the fleet until 2030. The replacement of old ships by newly built ships is however accounted for. This is relevant in the context of the emission reduction potential of measures that can only be applied to newly built ships. Further, the study assumes that the design efficiency of the ships and their operational carbon intensity remain constant over time.

The study considers the effect of the FuelEU Maritime Regulation, while additional effects of the EU ETS are not accounted for. Until 2030, however, the additional in-sector emission reduction induced by the EU ETS is expected to be relatively low.

Main conclusions

The Carbon Intensity Indicator (CII) with its metric and labelling scheme is, in principle, a very useful tool to incentivize an improvement of ships' operational carbon intensity and CO_2 emissions.

Given a 2030 CII reduction factor of 21.5%, in line with the current IMO 2030 target, an obligation to improve the CII label can be expected to have a relatively large 2030 emission reduction potential: Our analysis of the 2019 EU MRV fleet shows that, considering the impact of the FuelEU, an additional 19 Mt of CO_2 would have to be reduced if all ships had to achieve at least a label C and an additional 43 Mt of CO_2 would have to be reduced if all ships had to achieve label A.

Since the CII is an operational carbon intensity indicator, ships can in principle improve their CII label by means of a wide range of different measures: measures that improve the operational energy efficiency, measures that improve the technical energy efficiency, as well as by using renewable energies, including renewable fuels.

Renewable fuels have a high emission reduction potential and play a pivotal role for the decarbonisation of the sector. Whether the use of renewable fuels is actually incentivized by the CII depends on whether the CII metric will be amended to reward the use of these fuels. It also depends on the availability of these fuels, as well as on the carbon price.

Speed reduction also has a high emission reduction potential, but it can be expected that other emission reduction measures will be applied too. Reducing speed may deteriorate the competitive position of a ship if not implemented by a speed limit. In addition, capacity shortage to keep up the transport work may be a barrier, at least in the short run, and for ships with a relatively high energy consumption of auxiliary engines and boilers the CII improvement potential of sailing slower may be limited.

The use of technical energy efficiency measures and the use of wind power should in general not be disregarded as relevant compliance options for ships with a relatively poor label level: Our analysis of the 2019 EU MRV fleet shows that the average age of the ships in label categories D or E is not necessarily the highest and that the variation of the average age over the label categories can also be rather small.

The CII labelling scheme improves the transparency and there are various measures that could build on the CII labelling system which the EU, EU countries or other actors in the EU could take to stimulate the improvement of the EU fleet's operational carbon intensity. In addition, measures that can facilitate the improvement of the operational carbon intensity of maritime shipping could be taken too. Publication of the CII labels of the individual ships by IMO would be very useful in this context.

The current CII metric that is used to calculate the ships' attained operational carbon intensity has the disadvantage that only Tank-to-Wake CO_2 emissions are captured. Also ships with a relatively high share of emissions at berth/at anchorage can be expected to receive comparably poor labels. On the other hand, a comparison among the ships of the same type might nevertheless lead to a fair assessment and the pressure on ports to improve logistics and/or to embrace concepts like a virtual arrival schemes might as well increase.

Recommendations

1. For the effectiveness of the CII, it is important to ensure that the metric of the CII is amended to reward the use of renewable fuels. For this purpose, the CII metric must, at least, allow for a differentiation between renewable and fossil carbon and hydrogen; this is an integral part of a Well-to-Wake emissions approach.
2. For the review of the CII at the IMO level, scheduled to be completed by 1 January 2026, it should be considered that
   a The CII reduction factors for the period after 2026 have not been determined yet and should be ambitious enough to also stimulate the further and timely development of technical measures to improve the energy and carbon intensity of ships as well as of alternative fuels.
   b Strengthening of the enforcement of the CII measure at the IMO level is important.
   c Publication of individual ship's CII rating can contribute to an even higher transparency in the market.
3. If the enforcement of the CII at the IMO level cannot be strengthened, additional actions/measures that reward ships with a relatively good label and/or penalise ships with a relatively poor label are all the more important.

List of abbreviations

Table 1 - List of abbreviations

Abbreviation	Description
AER	Annual Efficiency Ratio
cgDIST	Capacity gross ton distance
CII	Carbon Intensity Indicator
CO_2-eq.	CO_2-equivalent
DCS	Data Collection System
Dwt	Deadweight tonnage
EC	European Commission
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EEOI	Energy Efficiency Operational Indicator
EEPI	Energy Efficiency Performance Indicator
EEXI	Energy Efficiency Existing Ship Index
EU	European Union
EU ETS	EU Emissions Trading System
EU MRV Regulation	Regulation (EU) 2015/757 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport
FAME	Fatty Acid Methyl Esters
g	gramme
GHG	Greenhouse gas
GT	Gross tonnage
H_2	Hydrogen
HFO	Heavy Fuel Oil
IMO	International Maritime Organization
ISWG-GHG	Intersessional Working Group on Reduction of GHG Emissions from Ships
kt	kilotonne
LFO	Light Fuel Oil
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MARPOL	International Convention for the Prevention of Pollution from Ships (short for ‘marine pollution’)
MEPC	Marine Environmental Protection Committee
MJ	Megajoule
MRV	Monitoring, Reporting, Verification
Mt	Megatonne
NH_3	Ammonia
nm	Nautical mile
ppt	Percentage point
SEEMP	Ship Energy Efficiency Management Plan
SFOC	Specific Fuel Oil Consumption
TEU	Twenty-foot equivalent unit
TtW	Tank-to-Wake
VLSFO	Very Low Sulphur Fuel Oil
WtT	Well-to-Tank
WtW	Well-to-Wake

List of figures

List of tables

1 Introduction

1.1 Political context

Both at the global level (IMO) and at the EU level, instruments to reduce greenhouse gases from maritime shipping are currently being developed.

In April 2018, the IMO's Marine Environment Protection Committee (MEPC) adopted the 'Initial IMO Strategy on Reduction of GHG emissions from Ships' (MEPC 72/17/Add. 1, Annex 11). This strategy aims to phase out GHG emissions from international shipping as soon as possible in this century. In addition, the following specific levels of ambitions are included in the strategy:
- improvement of the carbon intensity of shipping by at least 40% in 2030, relative to 2008 and pursue efforts to improve it by 70% by 2050;
- GHG emissions reduction of shipping by at least 50% by 2050, relative to 2008.

The Initial Strategy, including the levels of ambition, are currently under review with the aim to adopt the revised strategy at the 80th meeting of the MEPC to be held in July 2023.

To achieve the levels of ambition, short-, medium- and long-term policy measures are (being) developed as part of the IMO Strategy. The Carbon Intensity Indicator (CII) is one of the short-term measures which have been adopted by the MEPC. The CII is used to measure the operational carbon intensity of individual ships and according CII efficiency labels will be assigned to the ships.

In July 2021, the European Commission presented the 'Fit for 55'-policy package, aiming to reduce net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. Some of the proposed instruments, as part of the policy package, aim at reducing the GHG emissions of maritime shipping, amongst which:
- Maritime shipping has been proposed to be included into a revised EU Emissions Trading System (EU ETS).
- The FuelEU Maritime Regulation set targets for the improvement of the carbon intensity of the energy used by ships. Aim of the FuelEU Maritime Regulation is to solve the chicken and egg problem regarding the use and the supply of renewable and low-carbon fuels; the use of renewable fuels is key to the decarbonisation of the sector.

However, no specific emission reduction target for the maritime shipping sector has been set at the EU level and the EU ETS is expected to, at least until 2030, mainly lead to out-of-sector CO_2 emission reductions.

1.2 Aim of the study

The aim of this study, commissioned by the Environmental Defense Fund Europe, is to investigate whether the Carbon Intensity Indicator (CII) is a meaningful tool which additional measures could use to ensure the timely decarbonisation of the EU maritime shipping sector.

1.3 Structure of the report

In the following, we will first, in Chapter 2, explain and discuss the Carbon Intensity Indicator (CII) as measure and index and describe the political process at the IMO related to the CII. Subsequently, in Chapter 3, the CII is analysed for the EU MRV fleet, i.e. for the ships that have reported their CO_2 emissions under the EU MRV Regulation, and the different reporting periods. The expected 2025 and 2030 CII levels and labels of the ships of the 2019 EU MRV fleet are presented and discussed in Chapter 4, taking the impact of the FuelEU Maritime Regulation into account. The CO_2 emission reductions required by the ships of the 2019 EU MRV fleet to meet specific targets or to achieve certain CII label levels, as well as technical and operational measures which can contribute to an improvement of the ships' operational carbon intensity, are analysed in Chapter 5. Chapter 6 discusses the potential additional measures and actions that, building upon the CII, the EU, EU countries or other actors in the EU could take to ensure that the EU maritime sector decarbonises in time. Finally, conclusions and recommendations are provided in Chapter 7.

1.4 Scope of the study

The study focusses on the EU MRV fleet, i.e. the ships which have submitted an emissions report as required by the EU MRV Regulation (2015/757) and for which data is publicly available. These are ships above 5,000 GT and their voyages to/from EEA ports serving the purpose of transporting passengers or cargo for commercial purposes. For the EU MRV fleet, data for the EU MRV reporting periods 2018 to 2021 are available.

In the first instance, we determine and analyse the attained CII and the CII labels of all the ships that have a submitted an emissions report in the first four reporting periods. For the analysis up to 2030 - the time horizon of this study – we focus, however, on the 2019 reporting period, with 2019 being the reference year for the CII measure and the last pre-COVID year.

Please also note that for the analysis up to 2030, we take the 2019 EU MRV fleet as starting point and do not analyse the potential growth of the fleet or a change in the activity of the fleet. The replacement of old ships by newly built ships is however accounted for. This is relevant in the context of the emission reduction potential of measures that can only be applied to newly built ships.

The study considers the effect of the FuelEU Maritime Regulation, while additional effects of the EU ETS are not accounted for. Until 2030, however, the additional in-sector emission reduction induced by the EU ETS is expected to be relatively low.

The study also assumes that the design efficiency of the ships and their operational carbon intensity remain constant over time, i.e. the impact of the following policy measures have not explicitly been taken into account: the Energy Efficiency Design Indicator (EEDI), the Energy Efficiency Existing Indicator (EEXI), and the IMO CII requirements for ships with a relatively poor CII label.

2 What is the Carbon Intensity Indicator?

The Carbon Intensity Indicator (CII) is one of the short-term measures which have been developed as part of the 'IMO Strategy on Reduction of GHG Emissions from Ships' and which have been adopted by the IMO's MEPC. This chapter explains the CII.

Section 2.1 starts with an explanation of the different determinants of the carbon dioxide (CO_2) emissions of ships. This is followed by a detailed explanation of the design of the CII in Section 2.2, coving aspects like the scope of the measure, the reference lines, the labels, etc. Section 2.3 discusses the strengths and weaknesses of the CII. Finally, the ongoing political process at the IMO related to the CII is described in Section 2.4.

2.1 The determinants of the CO_2 emissions of ships

The maritime shipping sector emits different greenhouse gases (GHG), with CO_2 dominating. CO_2 is currently the main GHG contributing to the global warming effect.

Figure 1 provides an overview of the determinants that contribute to the CO_2 emissions of a ship.

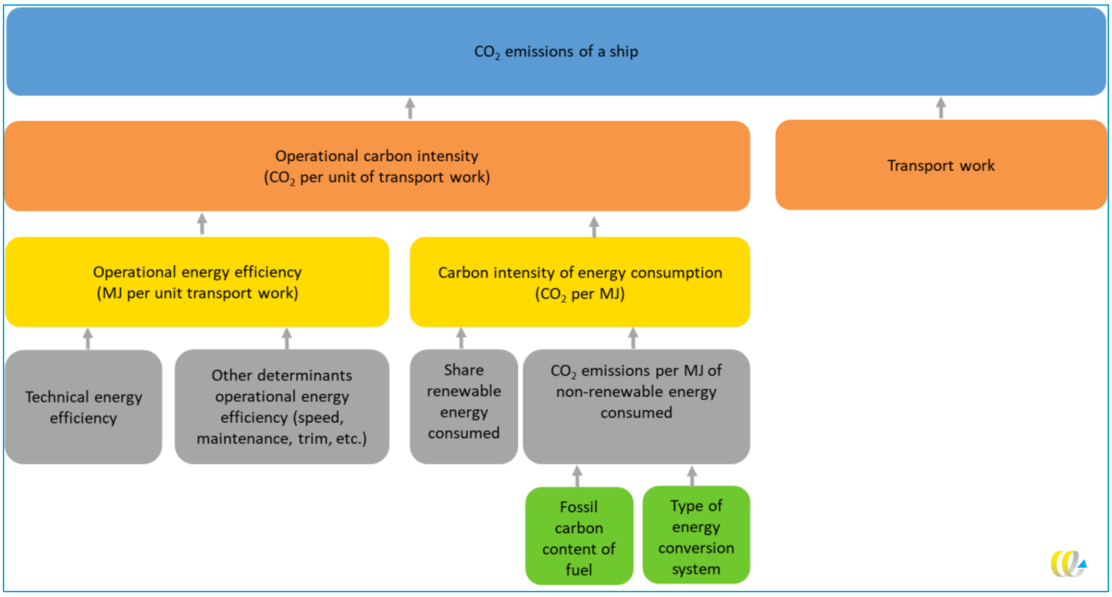
The total annual amount of CO_2 emissions of a ship can be determined based on:
- the operational carbon intensity of the ship (in CO_2 per unit of transport work); and
- the amount of transport work.

The operational carbon intensity (in CO_2 per unit of transport work) in turn can be determined based on:
- the operational energy efficiency (in MJ per unit of transport work); and
- the carbon intensity of the energy consumed to provide the transport work (in CO_2 per MJ).

The operational energy efficiency depends on the technical energy efficiency of the ship (based on the design of the ship) and other, non-technical factors like speed, maintenance, trim, etc.

The carbon intensity of energy consumption depends on the type of fuel used for the transport work (renewable and/or non-renewable), the carbon content of the non-renewable fuel and the type of energy conversion system used.

Figure 1 - Determinants of CO_2 emissions of ships



The CII is a short-term measure that aims at improving the ships' operational carbon intensity. Figure 1 therefore also illustrates the various types of measures that ships have at their disposal if they want to improve their operational carbon intensity. These options will be further discussed in Chapter 5.

2.2 Design of the Carbon Intensity Indicator

Textbox 1 – What is the Carbon Intensity Indicator?

The Carbon Intensity Indicator (CII) is one of the short-term measures which have been developed as part of the *IMO Strategy on Reduction of GHG Emissions from Ships*. The CII applies to bulk carriers, combination carriers, container ships, cruise passenger ships, gas carriers, general cargo ships, LNG carriers, refrigerated cargo carriers, ro-ro cargo ships, vehicle carriers, ro-ro passenger ships and tankers of 5,000 GT and above.

The CII, as a policy measure, uses a specific metric to measure the operational carbon intensity of ships, which is also referred to as CII: grams of CO_2 emitted per cargo carrying capacity per nautical mile.

Ships must determine their attained CII level on an annual basis and depending on the level attained, the ships receive a label, ranging from label A (best) to label E (worst).

The boundaries of the label categories become stricter (=shift downwards) over time. This means that ships which receive a specific label in one year will not automatically receive the same label in subsequent years. In case the operational carbon intensity of the ship is not improved, it can be expected that the ship receives worse CII labels over time.

To give an example for a specific bulk carrier of 10,000 dwt:

	Label A, if attained CII is lower than…	Label B, if attained CII is between…		Label C, if attained CII is between…		Label D, if attained CII is between…		Label E, if attained CII is higher than…
2019	13.5	13.5	14.7	**14.7**	**16.6**	16.6	18.5	18.5
2025	12.2	12.2	13.4	13.4	15.1	**15.1**	**16.8**	16.8
2030*	10.6	10.6	11.6	11.6	13.0	13.0	14.5	**14.5**

* 2030 reduction factor assumed to be 21.5%.

If the bulk carrier has an attained CII level of 15.5 gCO_2/(dwt*nm) in 2019 as well as in 2025 and 2030, then the ship receives a C label in 2019, but a D label in 2025 and an E label in 2030 (see boundaries in bold in the table above).

For ships that achieve a D rating for three consecutive years or an E rating in a single year, a corrective action plan to improve the attained CII has to be developed. And these ships have to duly undertake the planned corrective actions in accordance with the revised SEEMP.

The following subsections explain the CII in detail.

2.2.1 Introduction

MARPOL Annex VI[1] provides regulations for the prevention of air pollution from ships. Regulation 28 of this Annex (see page 53 and 54) sets requirements regarding the operational carbon intensity of ships. This policy measure as well as the underlying operational carbon intensity indicator are referred to as CII.

The CII as short-term *policy measure* applies to bulk carriers, combination carriers, container ships, cruise passenger ships, gas carriers, general cargo ships, LNG carriers, refrigerated cargo carriers, ro-ro cargo ships, vehicle carriers, ro-ro passenger ships and tankers of 5,000 GT and above[2].

The CII as operational carbon intensity *indicator* is defined as grams of CO_2 emitted per cargo-carrying capacity nautical mile. The cargo-carrying capacity of a ship is measured either in deadweight tonnage (dwt) or in gross tonnage (GT), depending on the ship type. And the product of cargo-carrying capacity and nautical miles (the denominator of the indicator) is an approximation of the actual transport wo17%rk carried out by the ships. The formula for the calculation of the indicator is also referred to as the 'metric' with which the operational energy efficiency is measured.

After the end of 2023 and after the end of each following calendar year, each ship which must comply with MARPOL Annex VI Regulation 28 has to calculate and report its attained (= achieved) annual operational CII over a 12-month period from 1 January to 31 December for the preceding calendar year.

And depending on the difference between a ship's attained CII and the required CII, a label ranging from A to E is annually assigned to the ship. For ships that achieve a D rating for three consecutive years or an E rating in a single year, a corrective action plan to achieve the required CII (and thus a label C) needs to be developed and approved as part of the Ship

[1] MARPOL is the IMO's International Convention for the Prevention of Pollution from Ships. It covers the prevention of pollution of the marine environment by ships from operational or accidental causes.

[2] The CII applies to ships which fall into one or more categories in Regulations 2.2.5, 2.2.7, 2.2.9, 2.2.11, 2.2.14 to 2.2.16, 2.2.22, and 2.2.26 to 2.2.29 of MARPOL Annex VI.

Energy Efficiency Management Plan (SEEMP). And these ships have to duly undertake the planned corrective actions in accordance with the revised SEEMP.

Label A and label B mean that the ship has attained a better than required CII, while label D and label E mean that the ship has attained a CII that is worse than the required CII. Label C means that the ship has attained a CII that is equal to the or deviates relatively little form the required CII.

The required CII is thereby determined by means of a reference value and an annual reduction factor.

For each of the different ship types a reference line has been determined. For each ship size (in terms of cargo-carrying capacity), the reference line gives the according reference value.

The reference line represents the median historically, actually attained operational carbon intensity of ships. Given the limited data available for the year 2008 (which is the reference year of the IMO's GHG emission reduction strategy), the operational carbon intensity performance of the ships in 2019 has been used to this end.

The annual reduction factor increases over time, which means that the required CII becomes stricter over time. As a consequence, ships might receive a poorer CII label over time if they do not improve their operational carbon intensity.

The following Sections 2.2.2 to 2.2.4 provide a detailed step-by-step explanation of how the ships' attained and required CII can be calculated and how the associated labels are determined.

2.2.2 Attained annual operational CII

The attained annual operational CII of individual ships is calculated as the ratio of the total mass of CO_2 (M) emitted to the total transport work (W) undertaken in a calendar year. CII Guideline G1 provides guidance on the operational carbon intensity indicators and the calculation methods. This guideline provides the following formula for the attained CII:

$$attained\ CII_{ship} = M/W$$

Mass of CO_2 emissions (M)

The total mass of CO_2 is the sum of CO_2 emissions (in grams from all the fuel oil consumed on board a ship in a given calendar year, as follows:

$$\mathrm{M} = FC_j \text{ x } \mathrm{C}_{Fj}$$

Where:
- j is the fuel oil type.
- FC_j is the total mass (in grams) of the consumed oil type j in the calendar year, as reported under IMO Data Collection System (DCS).
- C_{Fj} represents the fuel oil mass to CO_2 mass conversion factor for fuel oil type. This conversion factor is in line with those specified in 2018 Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships (resolution MEPC.308(73)) and is shown in Table 2.

Table 2 - CO_2 emission factor (fuel oil mass to CO_2 mass)

Type of fuel	C_F (t CO_2/t fuel)
Diesel/Gas Oil	3.206
Light Fuel Oil (LFO)	3.151
Heavy Fuel Oil (HFO)	3.114
Liquefied Petroleum Gas (LPG): Propane	3.000
Liquefied Petroleum Gas (LPG): Butane	3.030
Liquefied Natural Gas (LNG)	2.750
Methanol	1.375
Ethanol	1.913

Source: (MEPC, 2018).

In the event that the type of fuel oil is not covered by these guidelines, the conversion factor must be obtained from the fuel oil supplier and supported by documentary evidence.

In the context of biofuels as alternative fuel, DNV (2023) states that "[a]ny non-standard approach in the determination methodology of tank-to-wake emissions for biofuels is subject to acceptance by the vessel's flag administration as well as the RO handling the IMO DCS and CII verification on behalf of the flag, where an addition to the list of fuel types used and applicable conversion factors needs to be reflected in the SEEMP Part II." This can also be expected to hold for other alternative fuels.

Transport Work (W)

The supply-based transport work (W_s) can be taken as a proxy. The supply-based transport work (W_s) is defined as the product of a ship's capacity and the distance travelled in a given calendar year, as follows:

$$W_s = C \text{ x } D_t$$

Where:
- C is the ship's cargo-carrying capacity:
  - for bulk carriers, tankers, container ships, LNG carriers, gas carriers, general cargo ships, refrigerated cargo carrier and combination carriers, deadweight tonnage (DWT) must be used as capacity;
  - for cruise passenger ships, ro-ro- cargo ships (vehicle carriers), ro-ro passenger ship and ro-ro cargo ships, gross tonnage (GT) must be used as capacity;
  - D_t represents the total distance travelled (in nautical miles (nm)), as reported under the IMO DCS.

Source: (MEPC, 2022a).

2.2.3 Required CII

According to MARPOL Annex VI Regulation 28, the required annual operational CII of individual ships shall be determined as follows:

$$required\ CII_{ship} = \left(1 - \frac{Z}{100}\right) * CII_{ref}$$

Where:
- Z is the annual reduction factor (in %) to ensure continuous improvement (reduction) of the ship's operational carbon intensity within a specific rating level;
- CII_{ref} is the reference value.

Source: (MEPC, 2021b).

CII reference line

Ships which have an CII reporting obligation can be divided into several ship types and ship size categories, each with its own characteristics in terms of operational carbon intensity. It is therefore important to make a distinction between these different ship type-size categories when calculating the required CII. An operational CII reference line is a curve representing the median attained operational carbon intensity performance, as a function of capacity, of a defined group of ships. Given the limited data available for the year 2008 (reference year for the IMO's GHG emissions reduction strategy), the operational carbon intensity performance of ship types in 2019 is taken as reference.

CII Guideline G2 provides guidance on the reference lines for the required CII. This guideline provides the following formula for the reference line, for a defined group of ships:

$$CII_{ref} = a\ Capacity^{-c}$$

Where:
- CII_{ref} is the reference value of year 2019;
- *Capacity* is identical with the one defined in the CII, see Section 2.2.2;
- '*a*' and '*c*' are parameters estimated through median regression fits, taking the attained CII and the *Capacity* of individual ships collected through IMO DCS in year 2019 as the sample.

The parameters in the above formula for determining the ship type specific reference lines are provided in Annex A.1. (MEPC, 2022c).

Annual operational carbon intensity reduction factors

To annually improve the operational carbon intensity in the shipping sector, CII Guideline G3 provides guidance on the operational carbon intensity reduction factors relative to CII reference lines. The reduction factors in this guideline have been set at the levels to ensure that, in combination with other requirements of MARPOL Annex VI, a reduction in CO_2 emissions of transport work by at least 40% by 2030, compared to 2008 (one of the ambitions of the IMO), can be achieved as an average across the international shipping sector (MEPC, 2021a).

The annual operational carbon intensity reduction factor is denoted as 'Z' in Regulation 28 of MARPOL Annex VI. It is a positive percentage value which determines by how much the required CII for a given year must be lower than the reference value. Table 3 provides the reduction factors (Z%) for the CII relative to the 2019 reference line. For example, in 2026, the required CII must be 11% lower than the reference value.

Table 3 - Reduction factor (Z%) for the CII relative to the 2019 reference line

Year	Reduction factor (Z) relative to 2019 reference line
2023	5%
2024	7%
2025	9%
2026	11%
2027	- **
2028	- **
2029	- **
2030	- **

* Z factors of 1%, 2% and 3% are set for the years of 2020-2022.

** Z factors for the years 2027-2030 must be further strengthened and developed taking into account the review of the short-term measure.

Source: (MEPC, 2021a).

The reduction factors for the period after 2026 have not been determined yet. According to the CII Guideline G3, the 2030 IMO target, which is related to 2008, can be translated into an according Z factor related to 2019. The equivalent 2030 reduction factor would be at least 10% measured in aggregated demand-based CII metric and at least 21.5% measured in aggregated supply-based CII metric (MEPC, 2021a).

As explained above, the supply-based CII metric uses the cargo-carrying capacity of ships as a proxy for the actually mass of the cargo carried.

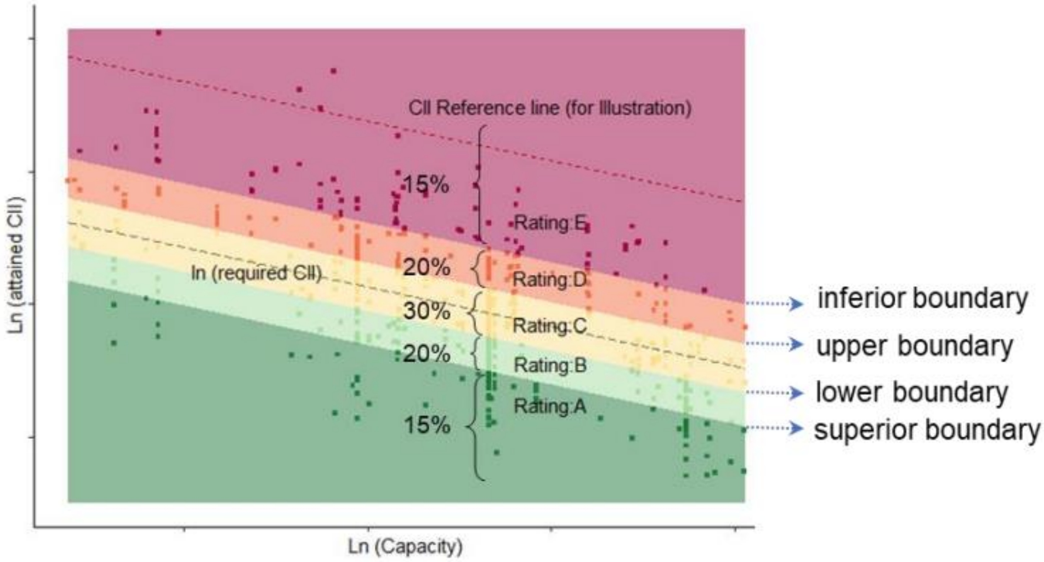
2.2.4 CII rating mechanism

An operational energy efficiency performance rating is yearly assigned to each ship to which Regulation 28 of MARPOL Annex VI applies, based on the deviation of a ship's attained CII from the required CII for a given year.

For the purpose of the performance rating, for each year from 2023 to 2030, four boundaries have been defined for a five-grade rating mechanism, namely the superior, upper, lower and inferior boundary (see Figure 2 for illustration). In this way, a rating from A to E can be assigned by comparing the attained annual operational CII of the individual ship with the boundary levels.

The boundaries have been set based on the distribution of CIIs of individual ships in year 2019 and are expected to generate the following results: 30% of the individual ships across the fleet segment will be assigned to rating C, while the upper 20% and further upper 15% of individual ships will be assigned to rating D and E, and the lower 20% and further lower 15% of the individual ships will be assigned to rating B and A (MEPC, 2022b). This is illustrated in Figure 2. The idea behind this rating mechanism is that 35% of the individual ships per ship type-size segment with the worst operational carbon intensity are forced to improve their operational carbon efficiency.

Figure 2 – Expected breakdown of the fleet segment by rating level (A-E)



Source: (MEPC, 2022b).

CII Guideline G4 provides additional guidance on the operational carbon intensity rating of ships. A detailed explanation on how the four boundaries of the CII-rating mechanisms are calculated is provided in Annex A.2 of this report.

2.3 Strengths and weaknesses of the CII

2.3.1 Introduction

For the discussion of the strengths and weaknesses of the CII it is useful to differentiate between the CII as the short-term policy measure and the CII as indicator/metric which is used for the purpose of the policy measure.

In addition to the CII-metric as presented above, other metrics for the measurement of the operational carbon efficiency of ships are conceivable and have been discussed at the IMO level. The Fourth IMO Greenhouse Gas Study (Faber et al., 2020) presents four metrics for the assessment of ship's operational carbon intensity, namely:

1. Energy Efficiency Operational Indicator (EEOI in g CO_2/t*nm).
2. Annual Efficiency Ratio (AER in g CO_2/dwt*nm).
3. DIST (in kg CO_2/nm).
4. TIME underway (in t CO_2/hr).

With the Energy Efficiency Performance Indicator (EEPI) as a sub-variant of the EEOI, applying laden distances instead of the total distance at sea, and cgDIST as a sub-variant of the AER, applying different capacity units, such as TEU, GT, and cbm instead of only dwt.

The supply-based CII is in line with the AER and cgDIST by using the cargo-carrying capacity of the ships as a proxy for the actually cargo carried. For the purpose of the CII, however, the cargo-carrying capacity is, in contrast to the AER, not measured in dwt for all ship types, but also uses GT for some ship types, which makes the CII partially overlapping with the AER and partially overlapping with the cgDIST metric.

Different carbon intensity metrics can lead to different assessments of the operational efficiency of ships and can differ regarding the incentives they provide.

According to the Fourth IMO Greenhouse Gas Study, ships had already reduced their carbon intensity 32% relative to 2008 as of 2018 under the EEOI metric. This means that only a small annual fleetwide efficiency improvement from 2018 to 2030 is needed to achieve the IMO's 40% reduction target. However, the EEOI is a 'demand-based' efficiency metric which does not take into account the expectation that the demand for shipping is growing faster than the efficiency is improving. The CII, on the other hand, is a 'supply-based' efficiency metric. Under the CII (AER) metric, shipping's carbon intensity in 2018 was only 22% better than 2008. According the Fourth IMO Greenhouse Gas study the shipping's carbon intensity has to fall about 2% annually, starting in 2019, to achieve the minimum 40% reduction from 2008 levels by 2030, which is twice as much as would be required under the EEOI metric. The CII is therefore more reliable and less volatile in order to prevent emissions from increasing this decade by fleet growth (ICCT, 2021).

2.3.2 Assessment of CII

CII as metric

The CII is a 'supply-based' efficiency metric. For the determination of the attained annual operational CII, an approximation of transport work is used by means of the capacity of the ship. In contrast to a 'demand-based' efficiency metric, like the EEOI, the actual cargo load of a ship is thus not considered. This can be considered a disadvantage of the CII. On the other hand, this significantly reduces the monitoring costs – for the EEOI, fuel consumptions and cargo have to be determined on a voyage basis – and an assessment of the ships' operational efficiency by means of a 'supply-based' metric can be expected to be less volatile over the years, though even if a 'supply-based' metric is used, you can expect the ranking of the ships to vary over the years. This is a principal difference between the technical and the operational efficiency of ships.

At anchorage or at berth, ships consume fuel without adding to the 'distance travelled'. This means that waiting time at ports and time at berth contribute to a deterioration of a ship's attained CII and potentially also has an impact on the ship's rating. From a shipowner's perspective this is a weakness of the CII, especially regarding those ship types with a relatively high share of emissions at berth/at anchorage. On the other hand, a comparison among the ships of the same type might nevertheless lead to a fair assessment and, due to this feature of the CII metric, the pressure on ports to improve logistics and/or to embrace concepts like a virtual arrival schemes might increase.

CII as short-term policy measure

The ranking of the ships as part of the CII can be expected to contribute to an increase of the transparency in the market. For ships that achieve a D rating for three consecutive years or an E rating in a single year, a corrective action plan to achieve the required CII needs to be developed and approved as part of the Ship Energy Efficiency Management Plan (SEEMP). And these ships have to duly undertake the planned corrective actions in accordance with the revised SEEMP. These requirements are considered relatively weak by some parties, also because the Regulation does not foresee penalties in case of non-compliance. On the other hand, it can be expected that, next to the requirements, the labelling scheme will also have an indirect impact – if the market prefers ships with relatively good labels then there is a major incentive to improve the label of the ship.

The CII is a measure that aims at the improvement of the carbon intensity of the fleet. It is inherent to efficiency measures that, even if they are effective, total emissions can still increase if the impact of the growth of the fleet and/or the growth of the activity of the fleet on the fleet emissions exceeds the impact of the efficiency improvement.

The CII applies to ships of 5,000 GT and above of certain ship types. Regarding the ship size, the scope of the CII is thereby in line with IMO's DCS, but therefore excludes smaller vessels.

The CII aims at the improvement of the carbon intensity and not at the improvement of the GHG intensity of ships. As a consequence, the sector's GHG emissions could increase if the CII is effective, but if there is a trade-off between the CO_2 and the non-CO_2 GHG emissions. Methane emissions could for example increase, though the CO_2 emissions would decrease if the sector used LNG to a higher extent.[3]

The CII follows a Tank-to-Wake (TtW) CO_2 approach (see Textbox 2 for an explanation) and, at the moment, it is not entirely clear if and how the CII rewards the use of renewable fuels.

Textbox 2 - What is the difference between Well-to-Wake and Tank-to-Wake emissions?

Well-to-Wake (WtW) emissions refer to the emissions which are released during the entire process of fuel production, the transport of the fuel to the ships and the use on board the ships.

WtW emissions consist of Well-to-Tank (WtT) emissions and Tank-to-Wake (TtW) emissions: WtW emissions = WtT emissions + TtW emissions.

WtT emissions are all the emissions that result from the fuel production and the transport of the fuels to the ships. WtT emissions are also known as upstream or indirect emissions.

TtW emissions are all emissions that result from using the fuel, once it is already in the tank of the ship. The missions that result from the production of the fuel and the transportation of the fuels to the tank of the ship are thus not included in a TtW approach.

Applying a TtW CO_2 approach inherently comes with the risk that, although the sector's TtW CO_2 emissions decrease, its WtW GHG emissions increase and, in addition, that the use of renewable fuels might not/might only be partially incentivised.

A TtW CO_2 approach incentivises the use of fuels that lead to no/lower TtW CO_2 emissions on board ships, i.e. the use of:
- Zero-TtW-carbon fuels like hydrogen and ammonia. Hydrogen (H_2) and ammonia (NH_3) lead, if combusted, to zero-TtW-CO_2 emissions since their carbon content is zero.
- Low TtW-carbon fuels like methane or some biofuels.

[3] This has been analysed in more detail in various studies, like for example CE Delft (2022).

A **TtW** CO_2 approach does thereby not allow for a differentiation between fossil fuel and the renewable counterparts: the use of fossil-based hydrogen, ammonia or methane (LNG) are rewarded in the same way as the use of renewable hydrogen, ammonia or methane since their combustion leads to the same TtW CO_2 emissions. And given that the production costs for renewable fuels are higher than for the fossil-based counterparts, the CII cannot be expected to incentivise the use of renewable hydrogen, ammonia or methane.

In general, a **TtW CO_2** approach does not (fully) incentivise the use of renewable fuels (biofuels and e-fuels) as long as they cannot be zero/lower rated, i.e. accounted for as leading to zero/lower TtW CO_2 emissions. In contrast, a **WtW CO_2** emissions approach would inherently incentivise the use of renewable fuels, accounting for the fact that CO_2 is recycled as part of the production of the fuels.

A **TtW CO_2** approach can also lead to an unwanted increase of (other) GHG emissions, like methane or nitrous oxide, if there is a trade-off between TtW CO_2 and other TtW GHG emissions or between TtW CO_2 emissions and WtT GHG emissions. The use of LNG/ renewable methane can, for example, lead to an increase of TtW methane emissions though leading to a decrease of TtW CO_2 emissions. A **WtW GHG** emissions approach would inherently prevent an unwanted increase of other GHG emissions as a consequence of an decrease of TtW CO_2 emissions.

At the IMO level, guidelines on life-cycle GHG intensity of marine fuels are being developed, which should be finalised at MEPC 80 to be held in July 2023. In this context, a formula for the calculation of the TtW GHG emissions of the sector is being discussed in which a factor/factors could be applied to allow for a correction of the CO_2 emission factor, depending on the carbon source (fossil/biogenic/captured carbon) of the according fuel (see submission MEPC 80/7/4 of the Correspondence Group on Marine Fuel Life Cycle GHG Analysis.

2.4 Implementation of the CII and CII related political process at the IMO

Regulation 28 of revised MARPOL Annex VI lays down the requirements for the CII certification which came into effect on 1 January 2023.

For the ships that have to comply with the CII, the Ship Energy Efficiency Management Plan (SEEMP) has to include the following information on or before 1 January 2023 (see Regulation 26 of revised MARPOL Annex VI):
- a description of the methodology that will be used to calculate the ship's attained CII and the processes of how it will be reported to the ship's administration;
- the value of the ship's required CII for the next three years;
- an implementation plan of how these CII values will be achieved;
- a procedure for self-evaluation and improvement.

By 31st of March of each year, ships must report their attained CII to the entity that is responsible for the ship's DCS verification (flag administration or any organisation duly authorised by it). This entity is also responsible for the assignment of the CII label.

The attained CII and the CII rating will be noted on the ship's DCS Statement of Compliance (see Annex X of revised MARPOL Annex VI) which has to be issued no later than 31st of May and has to be kept on board the ship. The Statement of Compliance is valid until June of the subsequent calendar year.

The CII labels that the individual ships achieve will not be published by the IMO.
For ships that achieve a D rating for three consecutive years or an E rating in a single year, a corrective action plan to achieve the required CII (and thus a C label) needs to be developed and approved as part of the Ship Energy Efficiency Management Plan (SEEMP). And these ships have to duly undertake the planned corrective actions in accordance with the revised SEEMP.

Regulation 28 of revised MARPOL Annex VI also encourages flag state administrations, port authorities and other stakeholders to provide incentives to ships rated as A and B.

The following CII-related guidelines have been adopted/are under development:
1. Guideline G1: 2022 Guidelines on the operational carbon intensity indicators and the calculation methods.
2. Guideline G2: 2022 Guidelines on the reference lines for use with operational carbon intensity indicators.
3. Guideline G3: 2021 Guidelines on the operational carbon intensity reduction factors relative to reference lines.
4. Guideline G4: 2021 Guidelines on the operational carbon intensity rating of ships.
5. Interim Guideline G5: 2022 Interim guidelines on correction factors and voyage adjustments for CII calculations.

CII Interim Guideline G5 still needs to be finalised.

According to Regulation 28, IMO's MEPC must complete a review of the Regulation by 1 January 2026, assessing the effectiveness of the CII and the need for an enhancement of the CII enforcement mechanism and/or of the DCS, as well as revising the CII reduction factors and reference values.

As already mentioned in Section 2.2.3, for the period after 2026, Guidance G3 does not specify CII reduction factors yet. The 2030 carbon intensity target as stipulated in the IMO Strategy on Reduction of GHG Emissions from Ships plays an important role in this context. The Initial IMO Strategy, including the targets, is currently under review with the aim to adopt the Revised Strategy at MEPC 80 to be held in July 2023.

3 Current CII of EU MRV fleet

In this chapter, we determine and analyse the CII for the EU MRV fleet[4] for the period 2018 to 2021. Section 3.1 provides method and assumptions applied while in Section 3.2 the outcomes are presented and discussed. Finally, the key findings of this chapter are summarised in Section 3.3.

3.1 Method and assumptions

In a first step, the attained CII is calculated for the individual ships which have submitted an emissions report under the EU MRV Regulation. These calculations are based on:
- the CII metric (see formula in Section 2.2.2);
- CO_2 emissions as published by the European Commission in the context of the EU MRV Regulation (EMSA, ongoing);
- distance sailed derived from data as published by the Commission in the context of the EU MRV Regulation (to be derived from 'total fuel consumption (Mt)'and 'Annual average fuel consumption per distance (kg/nautical mile)') (EMSA, ongoing);
- cargo-carrying capacity data (dwt and GT) for the individual ships, based on Clarksons World Fleet Register database (Clarksons Research Portal, ongoing).

Some ships have been discarded from the analysis: for some ships no cargo-carrying capacity data is available or the data is not plausible, some ships have submitted an emissions report, but have reported zero emissions and other ships have reported an implausibly low distance sailed.

Subsequently, the CII labels of the individual ships are determined by:
- Determining the required CII based on the formula in Section 2.2.3. We hereby assume, as in line with CII Guideline G3 (see also Table 3 above), a reduction factor of:
  - 0% for the years 2018 and 2019;
  - 1% for 2020;
  - 2 % for 2021.
- Applying the rating boundaries that have been specified per ship type to determine the ship's CII labels, see Section 2.2.4 and Annex A.2 of this report.

The ship type categories at the IMO and the EU MRV differ slightly. The ship types which are indicated in green in the right column of Table 4 are included in the analysis. Combination carriers are not included in the analysis, since the number of ships that report under this category at the EU MRV is very small. And 'container/ro-ro cargo ships' and 'other ship types' have been discarded, since these ship types fall outside the scope of the CII.

Table 4 - Ship categories differentiated: CII versus EU MRV

IMO CII ship categories	EU MRV ship category
Bulk carrier	Bulk carrier
Gas carrier	Gas carrier
Tanker	Oil tanker, chemical tanker
Container ship	Container ship
General cargo ship	General cargo ship

4 With 'EU MRV fleet' we mean the ships which have an EU MRV reporting obligation.

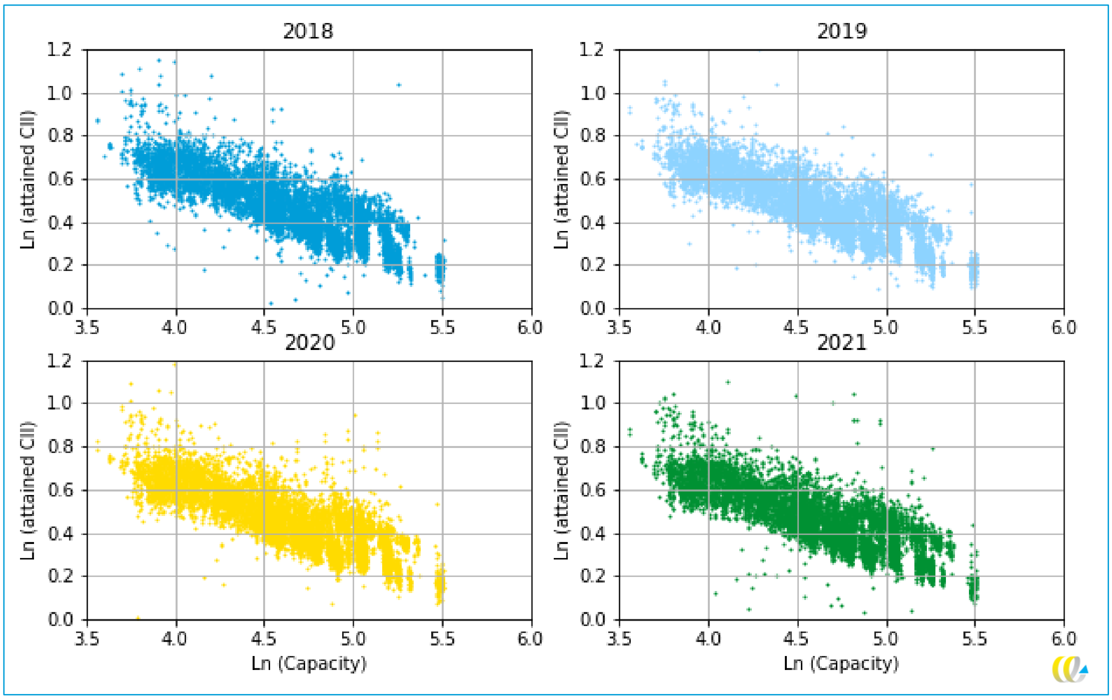
IMO CII ship categories	EU MRV ship category
Refrigerated cargo carrier	Refrigerated cargo carrier
Combination carrier	Combination carrier
LNG carrier	LNG carrier
Vehicle carrier	Vehicle carrier
Ro-ro cargo ship	Ro-ro ship
Ro-ro passenger ship	Ro-pax ship
Cruise passenger ship	Passenger ship
–	Container/ro-ro cargo ship
–	Other ship type

Source: (MEPC, 2022b),(EMSA, ongoing).

The ships' attained CII is calculated based on the EU MRV data and not on the data as collected at IMO level (Data Collection System), which are not publicly available for individual ships. This means that the attained CII values as determined in this study might deviate from the CII values as reported to the IMO. If reported correctly, the deviation should however not be significant.

To check the plausibility or the outcomes, we have plotted the attained CII values for the EU MRV fleet against the ships' capacity. This is shown in four scatterplots in Figure 3.

Figure 3 - Attained CII of all ships which have to comply with the EU MRV Regulation against their ship's capacity



Section 2.2.4 of this report explains the principle of the CII rating mechanism. Figure 2 in that section provides the expected breakdown of the IMO global fleet segment (in 2019) by the rating levels (A-E). The four scatterplots in Figure 3 of the EU MRV fleet in the years 2018 until 2021 show strong similarities with Figure 2.

3.2 CII analysis for the EU MRV fleet for the period 2018 to 2021

3.2.1 EU MRV fleet composition over the years

Table 5 shows the number of vessels which have submitted an EU MRV emissions report for the reporting periods 2018 to 2021, as well as the number of vessels that have been excluded from the analysis due to their ship type category (red-marked ship types in Table 4) and due to the outliers discussed in Section 3.1.

Table 5 - Number of ships which have submitted an EU MRV emissions report and which have been discarded

Year	Total # of ships which have submitted an EU MRV emissions report*	# of ships discarded from the analysis
2018	12,256	1,097
2019	12,395	762
2020	12,045	729
2021	12,208	625

* Since some ships report late, the total number presented here might deviate from the latest total number as published by EMSA.

Please note that the EU MRV scope is a regional scope, which means that the annual fleet composition can be expected to vary to a higher degree compared to the global fleet. As Table 6 shows, this is indeed the case.

Table 6 - Number of ships, depending on number of periods for which ships have submitted EU MRV emissions report

Reporting period 2018 to 2021	Number of ships
Reported all 4 years	5,805
Reported 3 years	3,649
Reported 2 years	3,661
Reported only 1 year	4,191

Just 5,805 ships have submitted an emissions report for all four reporting periods, while 4,191 ships have reported just once. This means that the results in the following sections do not necessarily reflect a development of ships over the years, but changes can also occur due to the change in the composition of the fleet visiting the EU.

3.2.2 Development of average attained CII

As shown in Table 6, 5,805 ships submitted an EU MRV emissions report for all four reporting periods. The average attained CII of these 5,805 ships is shown in Table 7 for these four years. This shows that the average attained CII of the ships which reported all four years has slightly improved.

Table 7 - Fleet average attained CII of the ships which reported all four years to EU MRV (2018-2021)

EU MRV reporting year	Average attained CII of the ships which reported all four years (2018-2021) to the EU MRV
2018	15.92
2019	15.45
2020	14.82
2021	13.42

3.2.3 CII labels of the EU MRV fleet versus the IMO global fleet

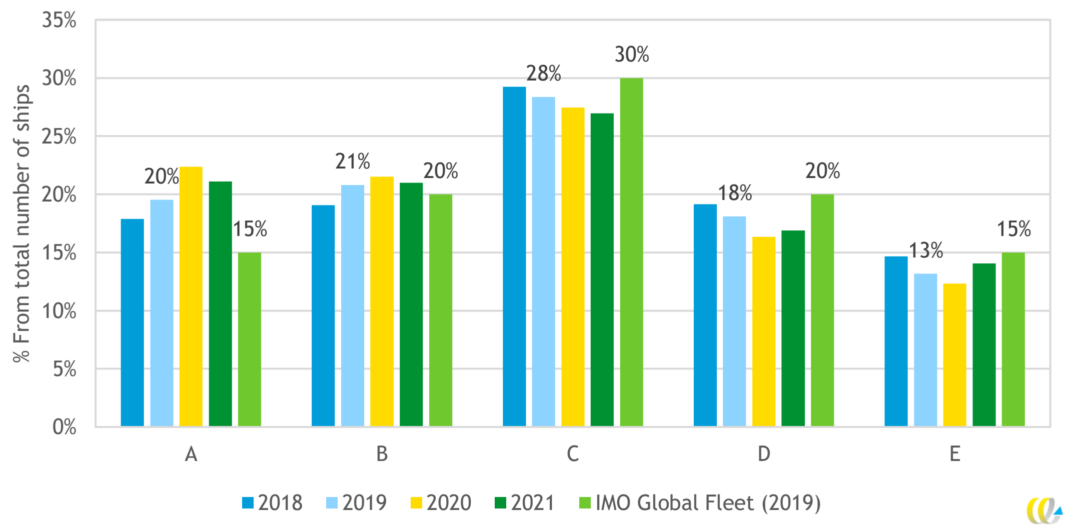
After the calculation of the attained CII for the entire EU MRV fleet, we have also determined the ships' CII labels. Figure 4 provides for each of the EU MRV reporting periods (2018-2021) the share of ships which falls in each CII label category (A-E).

Clearly, label C ships have the highest share (25-30%) and label E ships the lowest share (10-15%). The share of ships with label A, B and D is in between (15-20% respectively) and quite similar.

By way of comparison, Figure 4 also provides the breakdown of the IMO global fleet in 2019 (as is also shown in Figure 2). It can be concluded that the 2019 EU MRV fleet distribution over the labels (percentage shares shown above the light blue bars) is in line with the distribution of the IMO global fleet in 2019 (percentage shares shown above the light green bars). The 2019 EU MRV fleet shows a slightly lower share of ships in the label categories C, D, and E (-2 ppt respectively), while in label categories B and A there is a (slightly) higher share of ships (+1 ppt and +5 ppt respectively).

As Figure 4 also shows, the share of the EU MRV fleet with label A is higher in 2020 and 2021 compared to 2018 and 2019, however this does not necessarily mean that the operational carbon efficiency of the individual ships has improved over the years. As already explained in Section 3.2.1, this could be the result of a change in the composition of the EU MRV fleet.

Figure 4 - Distribution of EU MRV fleet over the CII label categories for the reporting period 2018-2021



3.2.4 CII labels of the EU MRV fleet subdivided by ship type

Figure 5 shows the distribution of the ships of the EU MRV fleet over the CII label categories for the 2019 reporting period subdivided by ship type.

It is noticeable that, if you take label A and B together, the share of container ships and vehicle carriers is significantly lower (share below 30%) compared to the other ship types. Also the share of ro-pax ships in these two categories is comparably low (share below 40%) in 2019. These three ship types also have a relatively high share of ships with labels D and E (share above 40%) in 2019. In addition, gas carriers and passenger ships also feature a relatively high share of ships in labels D and E (share above 30%) in 2019.

Figure 5 - Distribution of ships of the EU MRV fleet over the CII labels in 2019, subdivided by ship type, sorted by share of A+B-labelled ships

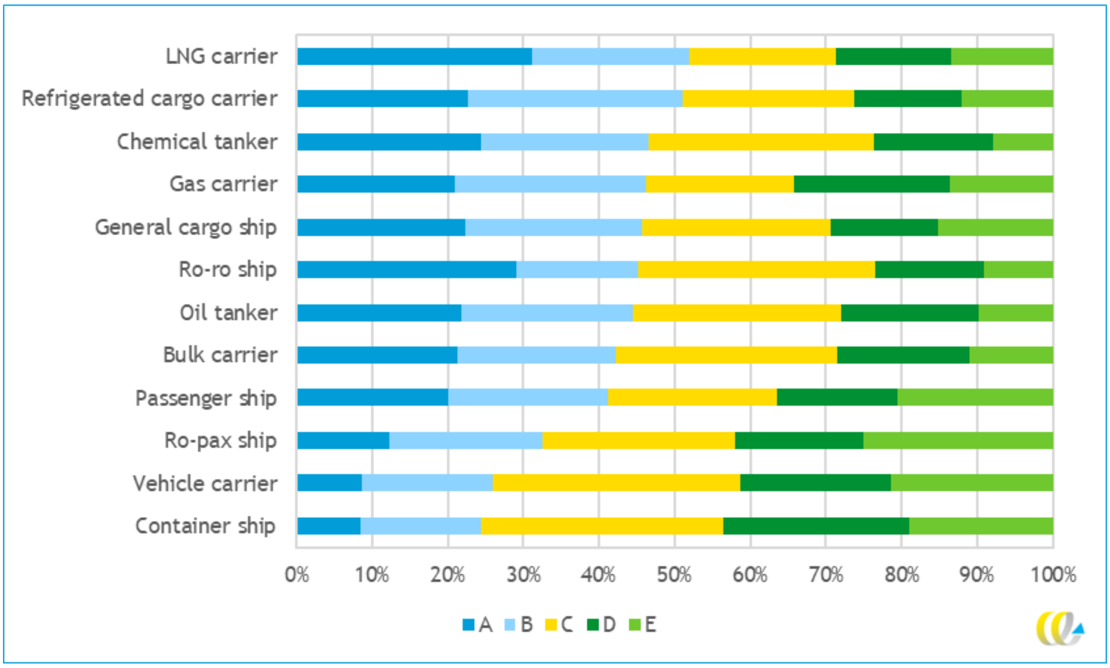


Figure 6 provides the same information as in Figure 5, but for the year 2020. The share of passenger ships with a CII D and E label was significantly higher in 2020. This was also the case for the year 2021. This can be explained by the fact that cruise ships made almost no commercial voyages in 2020 and 2021 due to COVID-19 and were mainly idle. For the distribution in 2018 and 2021, please see Annex A.

Figure 6 - Distribution of ships of the EU MRV fleet over the CII labels in 2020, subdivided by ship type, sorted by share of A+B labelled ships

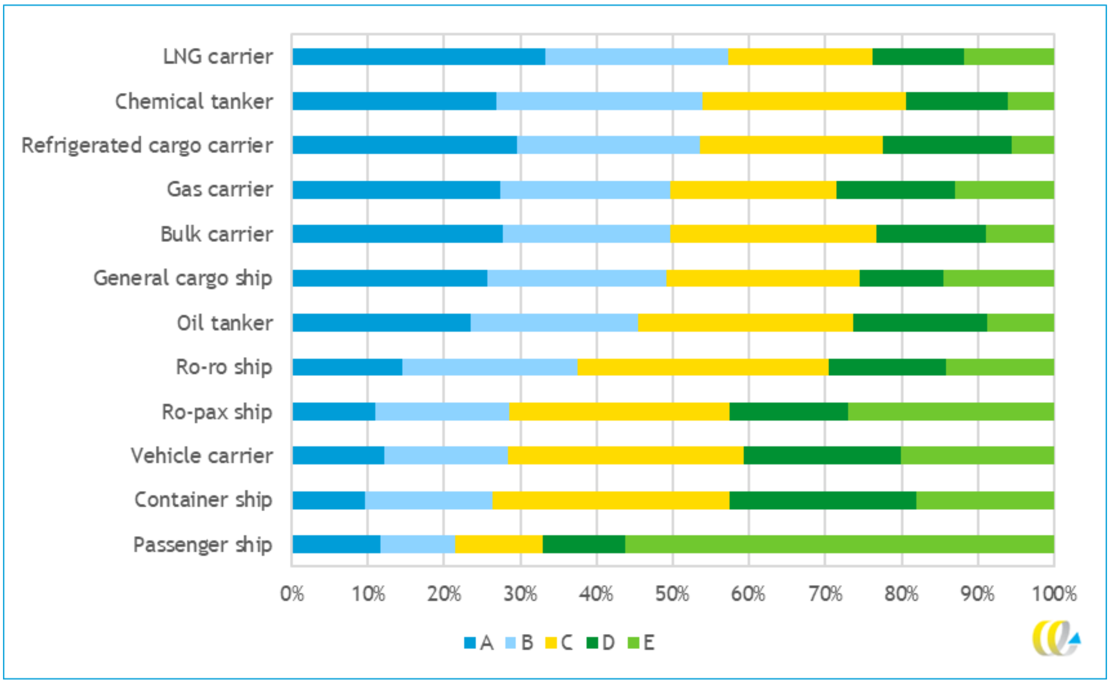
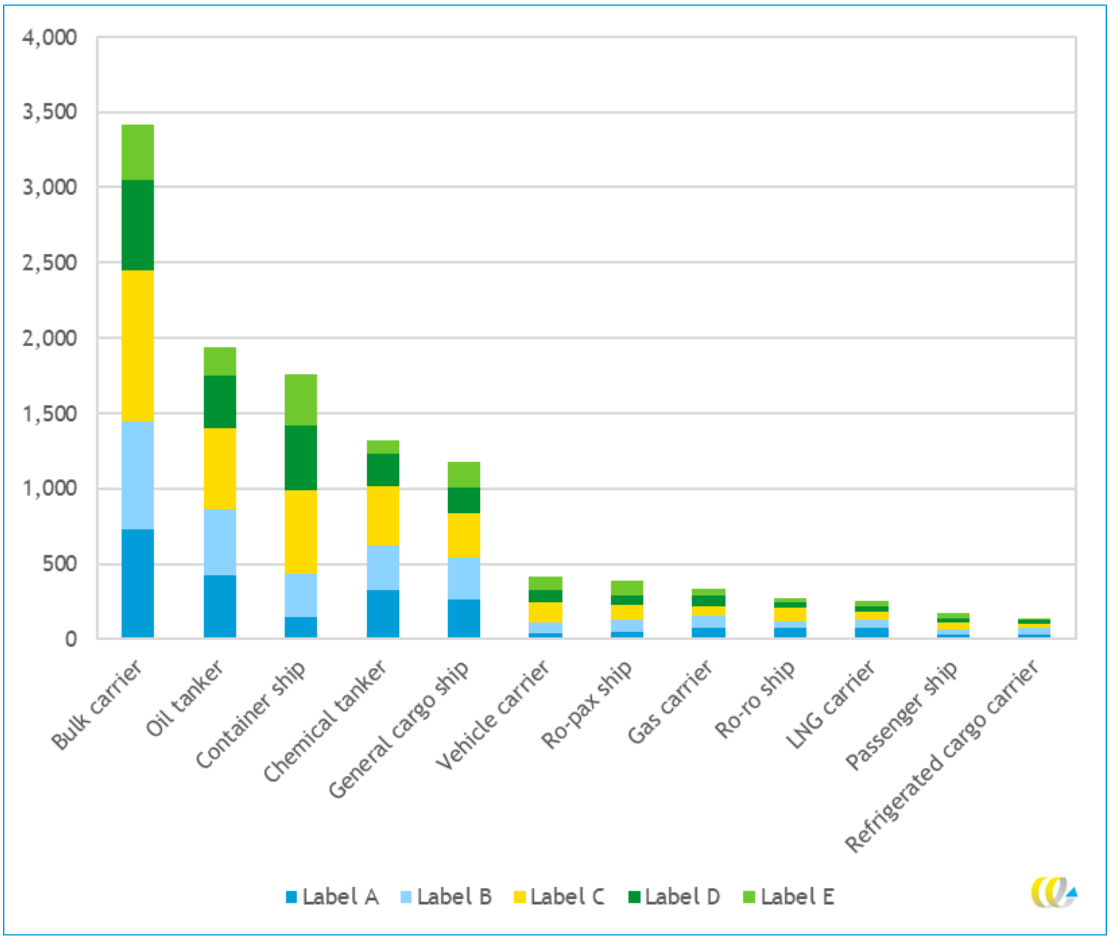


Figure 7 shows the total number of ships in the EU MRV fleet in 2019 per ship type category subdivided per CII label. Bulk carriers, oil tankers, container ships, chemical tankers, and general cargo ships are the ship types with the highest number of ships.

Figure 7 - Number of ships per ship type in the EU MRV fleet in 2019 and CII label shares



Annex A provides more illustrations of the 2018 to 2021 distribution of the ships of the EU MRV fleet over the CII label categories.

3.2.5 Average age of the EU MRV fleet per ship type category and per CII label

Table 8 provides the average age of the 2019 EU MRV fleet per ship type category and per CII label.

From Table 8 it can be concluded that:

- There is a large difference in average age between the different ship types (see second column in the table). The average age of the LNG carriers in the 2019 EU MRV fleet is for example 11.2 years, while the average age of refrigerated cargo carriers is 25.2 years.
- Once we zoom further in on the CII labels per ship type category, it can be concluded that:
  - For three ship types (bulk carriers, oil tankers and passenger ships) a clear pattern can be identified where the average age of the ships increases with the label category. Together these ship types account for around 30% of the emissions of the 2019 EU MRV fleet.

- With the exception of Ro-ro, ro-pax ships, and refrigerated cargo carriers, the average age of the ships is highest in either the label D or in the label E category (indicated in grey).
- For some ship types (LNG carrier, ro-pax ships), however, the average age of the ships in the label E category is lowest (indicated in white).
- And for several ship types it holds that the variation of the average age over the label categories is rather small. For general cargo ships, container ships, vehicle carrier and LNG carrier the variation is even less than 3 years.

Table 8 - Average age of the EU MRV fleet in 2019 per ship type category and per CII label (lowest average age per ship type is given in a cell with a white background and highest average age in a cell with a grey background)

Ship type	Average age in 2019 of					
	All ships	Label A ships	Label B ships	Label C ships	Label D ships	Label E ships
LNG carrier	11.2	11.6	10.5	11.8	12.2	9.4
Gas carrier	11.5	9.9	9.7	11.6	13.0	14.5
Bulk carrier	12.0	9.8	11.2	12.4	13.6	14.0
Oil tanker	12.8	8.5	11.5	14.2	15.4	15.7
Chemical tanker	12.8	9.0	11.9	13.9	16.0	15.7
Vehicle carrier	14.9	15.8	14.1	14.5	14.5	16.3
Container ship	15.0	14.8	14.2	14.2	15.4	16.3
General cargo ship	15.7	15.0	15.0	15.8	16.7	16.5
Passenger ship	18.4	12.0	15.5	19.0	20.8	24.9
Ro-ro ship	19.0	16.8	22.4	18.2	19.8	22.0
Ro-pax ship	24.9	22.4	27.4	26.2	26.1	22.1
Refrigerated cargo carrier	25.2	26.6	28.1	23.7	22.5	22.2

The age of a ship is thus not necessarily a good predictor of a ship's CII label category and thus also not for a ship's operational carbon intensity. The use of technical energy efficiency measures and the use of wind power should, in general, thus not be disregarded as relevant compliance options for ships with relatively poor label levels.

3.3 Key findings

The key findings of this chapter are as follows:
- The composition of the EU MRV fleet varies over the years: only around 5,800 ships submitted an emissions report in each of the four EU MRV reporting periods (2018-2021), while around 4,190 ships submitted an emissions report in only one of the four reporting periods.
- The average attained CII of the ships that reported in all four years has slightly improved over time.
- Notwithstanding these variations, the distribution of the ships of the EU MRV fleet over the CII label categories is comparable for the years 2018 to 2021: label C ships have the highest share (25-30%) and label E ships the lowest share (10-15%). The share of ships with label A, B and D is in between (15-20% respectively) and quite similar.
- The distribution of the ships of the 2019 EU MRV fleet over the CII label categories is in line with distribution of the 2019 IMO global fleet, though the share of label A ships is slightly higher (+5 ppt) in the EU MRV fleet.

- The total share of container ships and vehicle carriers with CII label A and B are noticeably lower compared to the other types of ships within the EU MRV fleet. Also the share of ro-pax ships in these two categories is comparably low in 2019. These three ship types also have a relatively high share of ships with labels D and E in 2019.
  In addition, gas carriers and passenger ships also feature a relatively high share of ships in labels D and E (>30%) in 2019.
- The number of passenger ships with a CII label A and B was significantly lower in 2020 and 2021 if compared to 2018 and 2019. This is due to COVID-19.
- There is a large difference in average age between the different ship type categories, ranging from 11 years for LNG carriers to 26 years for refrigerated cargo carriers.
- The age of a ship is not necessarily a good predictor of a ship's CII label category and thus also not for a ship's operational carbon intensity. The use of technical energy efficiency measures and the use of wind power should, in general, thus not be disregarded as relevant compliance options for ships with relatively poor label levels.

4 Expected CII in 2025 and 2030

On the 14th of July 2021, the European Commission presented the so-called ‘Fit for 55’ package. This package consists of a number of legislative proposals with the aim of implementing European climate targets: at least 55% net-GHG emission reduction in 2030 compared to 1990 and climate neutrality in 2050).

The FuelEU Maritime Regulation, which is part of the Fit for 55 package, sets limits to the GHG intensity of ships’ energy consumption. In the following, we will analyse the impact of FuelEU Maritime on the CII rating of the EU MRV fleet in 2025 and 2030.

Next to FuelEU Maritime, maritime shipping can also be expected to fall under the EU Emissions Trading System (EU ETS). CO_2 emission reductions incentivised by EU ETS can also have an impact on the CII rating of the ships. Modelling this effect, considering the individual ships, is, however, almost impossible, since we do not know the emission reduction measures that the ships already have applied and therefore out of scope of the study. From the impact assessment of the European Commission (COM(2021) 551 final), we know however that until 2030, it is expected that the EU maritime shipping sector is expected to mainly rely on out-of-sector CO_2 emission reductions. For 2030, the in-sector emissions reduction is estimated to amount to 11 Mt CO_2.[5] The reader should therefore bear in mind that the distribution of the ships over the CII labels as presented here might be slightly pessimistic and that the remaining reduction potential might be overestimated. But since we also abstract from the growth of the fleet, this overestimation is certainly lower than 11 Mt CO_2.

In the following, we start with a brief introduction to the FuelEU Maritime Regulation in Section 4.1. After that, Section 4.2 analyses the impact of stricter CII reduction factors on the 2025 and 2030 CII labels of 2019 EU MRV fleet. Subsequently, Section 4.3 goes into the impact of the FuelEU Regulation on the 2025 and 2030 CO_2 emissions and CII labels of the 2019 EU MRV fleet. Finally, the key findings of this chapter are summarised in Section 4.4.

4.1 FuelEU Maritime Regulation

4.1.1 Introduction

The FuelEU Maritime Regulation applies to the same ships and voyages to which the EU MRV Regulation applies, the geographical scope however differs: FuelEU Maritime also applies to 100% of the intra-EEA voyages, but only to 50% of the extra-EEA voyages.

The FuelEU Maritime Regulation limits the annual average WtW GHG emissions per unit of energy used on board ships. The limits are determined by applying the reduction factors provided in Table 9 to the fleet reference GHG intensity (see Table 10). As Table 9 shows, the reduction factors increase over time which also means that the intensity limit becomes increasingly stringent over time.

[5] See METXRA50-MAR1 Scenario in Table 13 of the Impact Assessment of the European Commission.

Table 9 - GHG intensity reduction factors

Date	Percentages to be applied to reference value
From 1 January 2025	-2%
From 1 January 2030	-6%
From 1 January 2035	-14.5%
From 1 January 2040	-31%
From 1 January 2045	-62%
from 1 January 2050	-80%

Source: (Council of the European Union, 2023).

The reference value corresponds to the 2020 fleet average GHG intensity of the energy used on board ships, determined on the basis of the data monitored and reported under the framework of Regulation (EU) 2015/757 and using the methodology and default values laid down in Annex I to that Regulation. The reference value is given in Table 10.

Table 10 - FuelEU Maritime reference value

	2020 WtW GHG intensity (g CO_2-eq./MJ)
Reference value	91.16

Source: (Council of the European Union, 2023).

Applying the percentages as given in Table 9 to the reference value in Table 10, the GHG intensity limits for the year 2025 and 2030 can be determined (see Table 11).

Table 11 - GHG intensity limits (in g CO_2-eq./MJ)

Date	WtW GHG intensity limit (g CO_2-eq./MJ)
From 1 January 2025	89.34
From 1 January 2030	85.69

These GHG intensity limits can be met by the use of different fuels/fuel mixes. Annex C.1 presents the Well-to-Tank, Tank-to-Wake and Well-to-Wake emission factors for selected fossil and renewable fuels. The emission factors of these fuels differ from each other, resulting in different fuels/fuel mixes that allow compliance with the FuelEU Maritime GHG intensity limits.

Since there is no obligation to use e-fuels and since e-fuels are expected to be relatively expensive, availability and demand of e-fuels can be expected to be relatively low until 2030. And since the GHG intensity must be reduced by only a few percent in 2025 and 2030 compared to reference year 2020 (-2% and -6% respectively) we expect that this will mainly be achieved by blending with biofuels. In this study, we therefore assume that a mix of fossil fuels and biofuels will be used to comply with the FuelEU Maritime GHG intensity limit until 2030.

For the assessment of the impact of FuelEU Maritime on the CO_2 emissions and CII ratings of the EU MRV fleet, we have applied a simplified fuel forecast model, in which:
- Very low sulphur fuel oil (VLSFO) and LNG are assumed to be the fossil fuels that are used in the baseline. These fuels are currently widely used in the maritime sector and have relatively low WtW GHG emissions compared to other types of fossil fuel such as fossil methanol (see Table 19 in Annex C).
- FAME is assumed to be the biofuel that ships will use to blend VLSFO with.
- Biomethane from wet manure is assumed to be the biofuel that ships will use to blend LNG with.
- FAME and biomethane (from wet manure) have been selected as biofuels based on their WtW GHG emission factors and because no major changes to the propulsion system are necessary when these fuels are applied.

The fuel mixes assumed to be used to comply with FuelEU Maritime in 2025 and 2030 are provided in Table 12.

Table 12 - Fuel mixes assumed to be used for compliance with FuelEU Maritime in 2025 and 2030

	Regular ships		LNG ships	
Date	Share VLSFO	Share FAME	Share LNG	Share biomethane
From 1 January 2025	95.7%	4.3%	95.8%	4.2%
From 1 January 2030	91.0%	9.0%	90.8%	9.2%

4.1.2 Impact of FuelEU Maritime on ships' CO_2 emissions, attained CII and CII labels

Where FuelEU maritime sets a limit on all WtW GHG emissions, the CII only considers TtW CO_2 emissions. Other greenhouse gases such as N_20 and CH_4 are not included in the CII, while they are included in the FuelEU Maritime GHG intensity limit.

FuelEU Maritime Proposal, Annex II, Table 1 provides default factors for all greenhouse gas emissions and shows that the CO_2 emission factors are different for each type of fuel. An overview of the TtW CO_2 emission factors of the fossil and biofuels used in this study are given in Table 13. We thereby assume that the TtW CO_2 emissions of biofuels cannot be zero-rated under the CII Regulation.

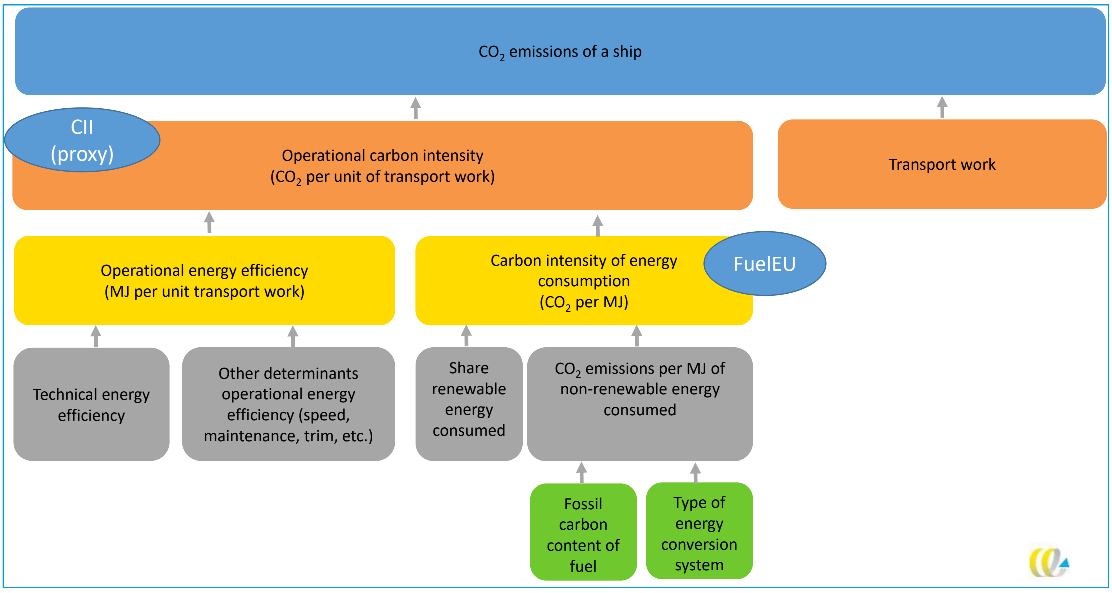
Table 13 – TtW CO_2 emission factors of fossil and biofuels

Fuel type	TtW CO_2 emission factor (g CO_2/g fuel)
VLSFO	3,206
FAME	2,790
LNG	2,755
Biomethane	2,755

Source: (EC, 2021, ABS et al., 2022).

When the ships used the above mentioned fuel mixes (Table 12) to comply with FuelEU Maritime, the CO_2 emissions of the ships and potentially also their CII rating could change. This is visualised in Figure 8. How large the impact actually is, will be discussed in the following sections of this chapter.

Figure 8 - Schematic illustration to show how FuelEU Maritime can impact the CII of a ship



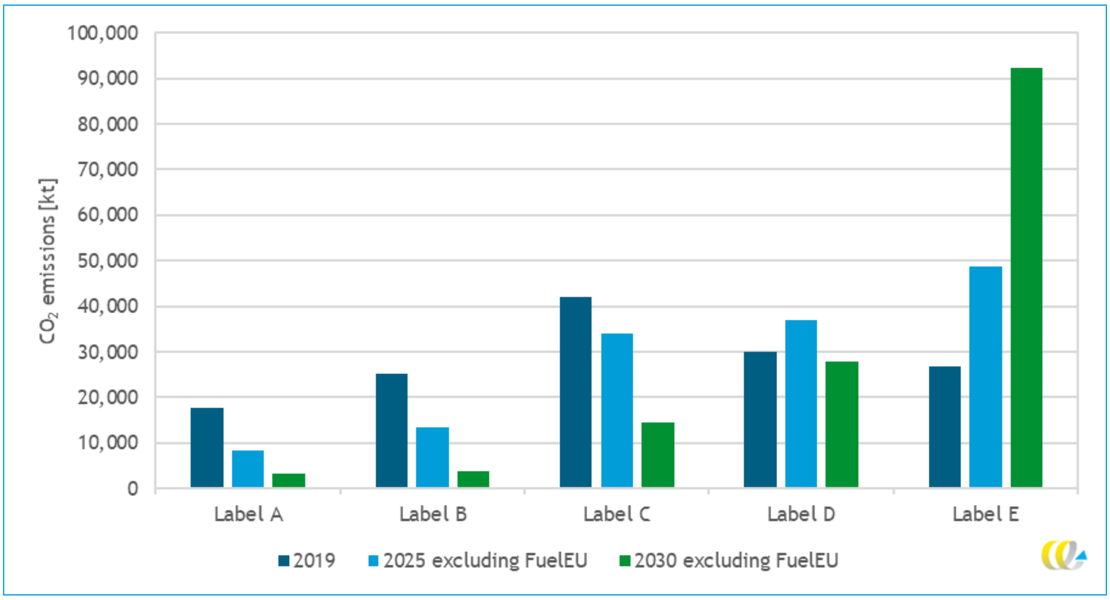
4.2 2025 and 2030 CII labels of 2019 EU MRV fleet - impact of stricter CII reduction factors

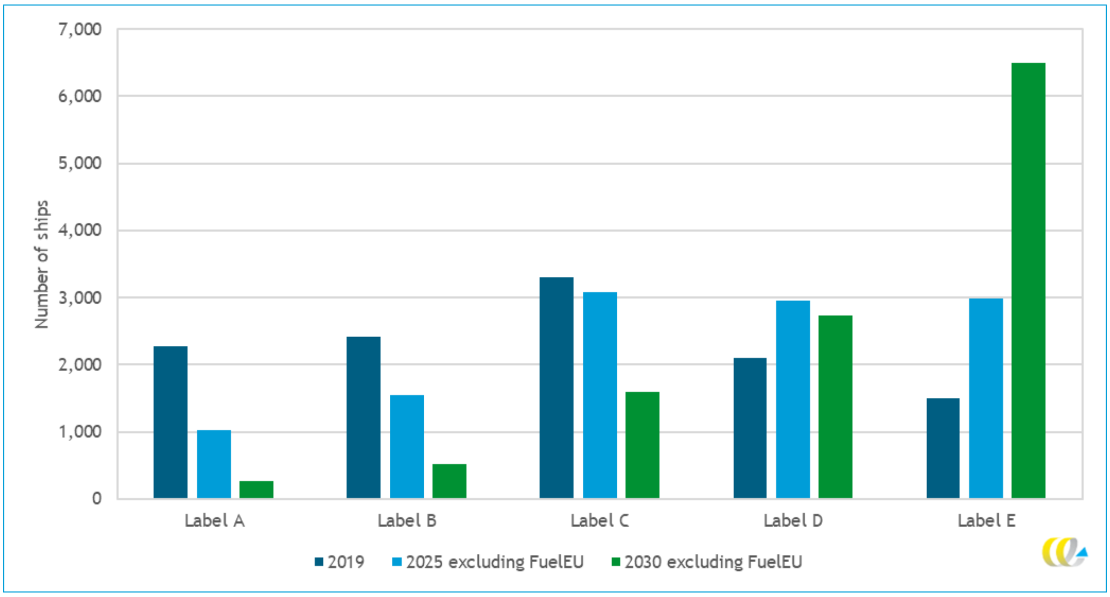
To annually improve the operational carbon intensity in the shipping sector, the CII sets increasingly stringent reduction factors relative to the 2019 reference line.

The reduction factor for 2025 is 9%. The reduction factor for 2030 has not been established yet, but for the purpose of this study we assume it to be 21.5%. As explained above (see Section 2.2.3), the IMO 2030 GHG intensity target of a at least 40% reduction compared to 2008 can be translated into a 2030 reduction factor for a supply-based CII metric of at least 21.5% compared to 2019 (MEPC, 2021a).

The increased stringency of the CII leads to increasingly lower values of the required CII. As a consequence, the labels of the ships deteriorate if the ships do not take additional measures to improve their carbon intensity. This effect is illustrated by Figure 9 where you can see that the reduction factors in 2025 and 2030 have a major influence on the CII labels of the ships: the number of ships with label A, B and C declines while the number of ships with a label E increases in 2025 and 2030. The distribution of the CO_2 emissions of the ships over the different label categories follows the same pattern.

Figure 9 - Distribution of CO_2 emissions number of ships over CII label categories in 2019, 2025 and 2030, only considering the impact of stricter requirements and not the impact of FuelEU Maritime





4.3 CO_2 emissions and CII labels of 2019 EU MRV fleet - impact of FuelEU Maritime

4.3.1 Impact of FuelEU Maritime if the TtW emissions of biofuels are not rated as zero

When the EU MRV fleet will use a mix of fossil fuels and biofuels to comply with FuelEU Maritime (as presented in Section 4.1), this will have an impact on the CO_2 emissions and attained CIIs of the ships and potentially also on their CII ranking. Table 14 shows the impact of FuelEU Maritime on the number of ships per CII label in 2025 and 2030 and Table 15 the impact of FuelEU Maritime on ship's CO_2 emissions in 2025 and 2030. The impact of the reduction factors as presented in Section 4.2 has already been taken into account here.

From both tables it can be concluded that, in contrast to the impact of the stricter CII reduction factors, the impact of FuelEU Maritime is negligible on the CII ranking and the TtW CO_2 emissions in 2025 and 2030. Please note that this is also due to the fact that we have assumed that the CII Regulation does not allow the TtW CO_2 emissions of biofuels to be zero rated, but rather that the emission factors as specified in Table 13 in Section 4.1 apply.

Table 14 - Impact of FuelEU Maritime on the *number of ships* from the EU MRV Fleet per CII label in 2025 and 2030 if biofuels are not zero-rated

CII label	2025			2030		
	2019 EU MRV fleet baseline	2019 EU MRV fleet including Fuel EU	Difference	2019 EU MRV fleet baseline	2019 EU MRV fleet including Fuel EU	Difference
Label A	1,029	1,039	10	258	261	3
Label B	1,547	1,555	8	522	530	8
Label C	3,074	3,085	11	1,593	1,612	19
Label D	2,957	2,943	-14	2,725	2,760	35
Label E	2,991	2,976	-15	6,500	6,435	-65
Total	**11,598**	**11,598**	**0**	**11,598**	**11,598**	**0**

Table 15 - Impact of FuelEU Maritime on ships' *TtW CO_2 emissions* in 2025 and 2030 if biofuels are not zero-rated

CII label	2025			2030		
	2019 EU MRV fleet baseline (Mt)	2019 EU MRV fleet including Fuel EU (Mt)	Reduction from Fuel EU (kt)	2019 EU MRV fleet baseline (Mt)	2019 EU MRV fleet including Fuel EU (Mt)	Reduction from Fuel EU (kt)
Label A	8.34	8.38	42	3,30	3.32	25
Label B	13.53	13.60	64	3,70	3.74	39
Label C	33.99	34.21	228	14,37	14.51	144
Label D	36.14	36.63	-286	27,83	28.28	453
Label E	48.75	48.53	-215	92,33	91.32	-1,014
Total	**141.52***	**141.36**	**167****	**141,52***	**141,01**	**353****

* Fleet composition and baseline emissions are assumed to be as in 2019.

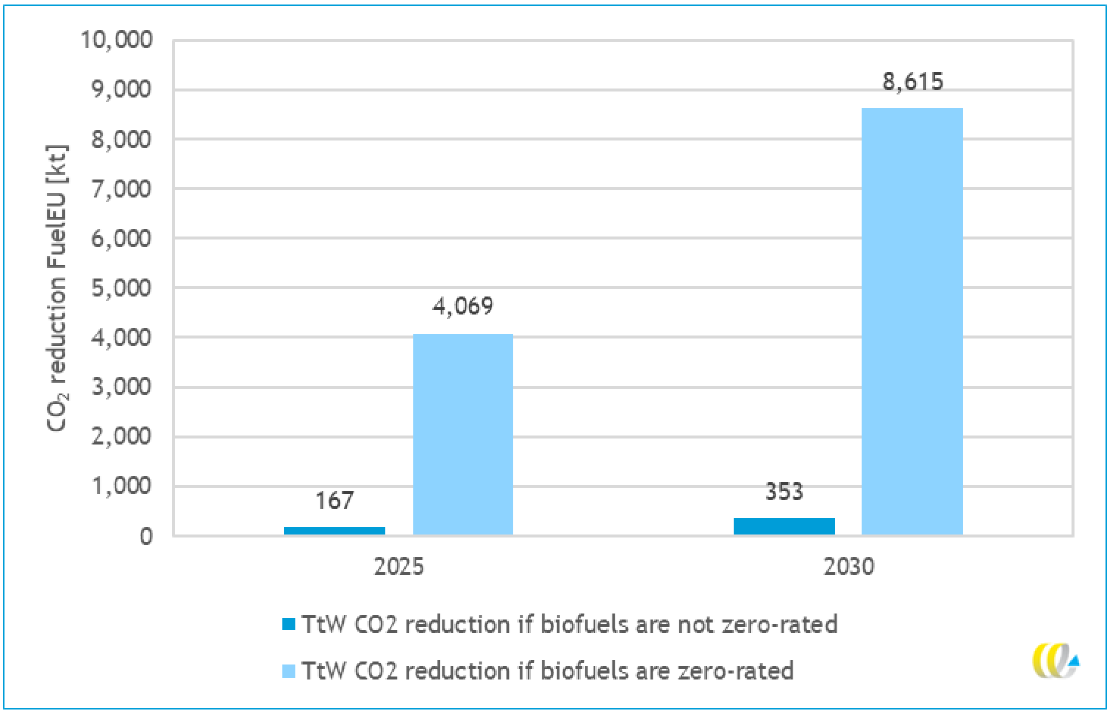
** Please be aware that the emissions in these two columns are, in contrast to the other columns, in kilotonne.

4.3.2 Impact of FuelEU Maritime if TtW emissions of biofuels are zero-rated

If it is allowed to account the TtW CO_2 emissions of biofuels as zero, the impact of FuelEU Maritime on the TtW CO_2 emissions and the CII ranking of the ships in 2025 and 2030 will differ significantly compared to the case in which the biofuels cannot be zero-rated (as presented in Table 14 and Table 15 in Section 4.3.1).

Figure 10 compares the impact of FuelEU Maritime on the CO_2 emission reduction when the TtW CO_2 emissions from biofuels are and are not rated as zero. In 2025, 4,069 kt TtW CO_2 emissions are reduced if the TtW CO_2 emissions of biofuels are rated as zero, while only 167 kt TtW CO_2 emissions are reduced if the TtW CO_2 emissions of biofuels are not rated as zero. In 2030, this is respectively 8,615 kt TtW CO_2 emissions versus 353 kt TtW CO_2 emissions.

Figure 10 - Impact of FuelEU Maritime with and without zero-rating of the TtW CO_2 emissions of biofuels



This means that the 2030 CO_2 emissions of the 2019 EU MRV fleet can be expected to amount to approximately 133 Mt (instead of 141 Mt) if the TtW CO_2 of biofuels can be accounted for as zero.

Please note in this context that the European Commission (COM(2021) 551 final)[6] has assessed the impact of EU ETS on the maritime shipping emissions and has estimated that in 2030, the in-sector CO_2 reduction would amount to 11 Mt CO_2 (for the EU MRV fleet after Brexit and considering fleet growth). This actually means that, on top of the CO_2 reduction as induced by FuelEU Maritime, relatively little extra in-sector emission reduction can be expected.

Whether the TtW CO_2 emissions of biofuels are and are not rated as zero does not only have a significant impact on the TtW CO_2 emission reduction, but also on the number of ships per CII label. Figure 11 provides an overview of the number of ships per CII label in 2030 when:
- the 2019 EU MRV fleet does not have to comply with FuelEU Maritime;
- the 2019 EU MRV fleet complies with FuelEU Maritime and TtW CO_2 emissions of biofuels are not rated as zero (see Section 4.3.1);

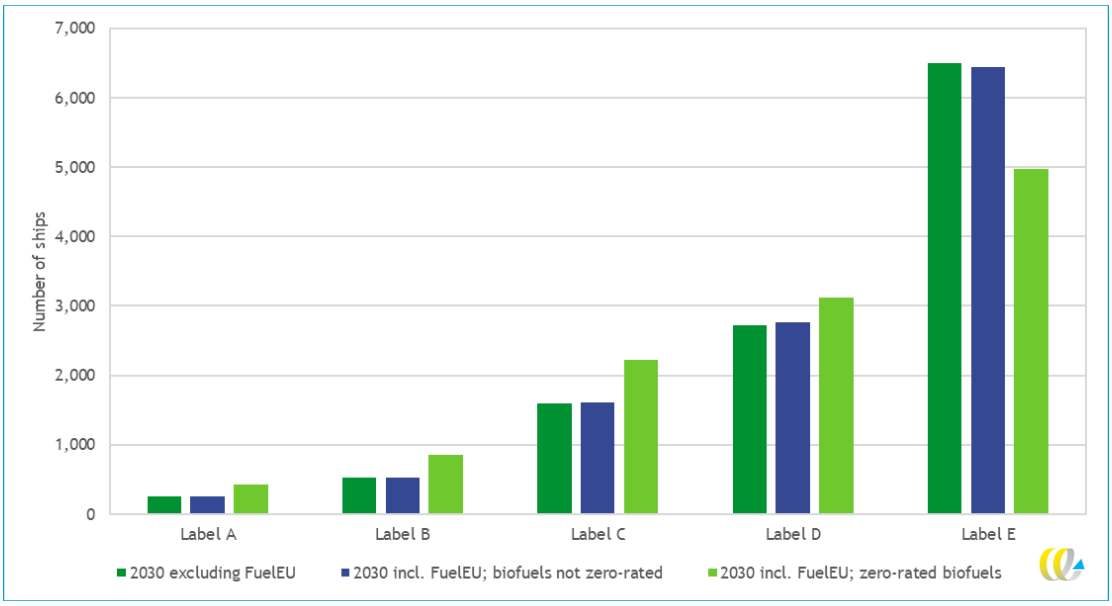
[6] See Table 13 in the impact assessment.

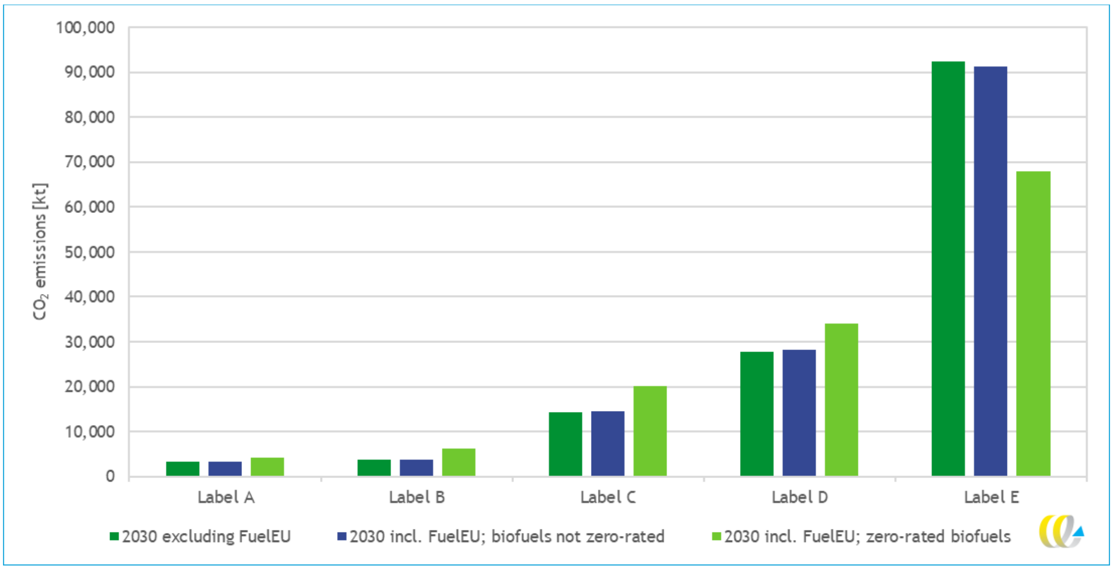
— the 2019 EU MRV fleet complies with FuelEU Maritime and the TtW CO_2 emission factors are rated as zero.

The impact of the increasingly stricter reduction factors as presented in Section 4.2 has hereby been taken into account.

In case the TtW-CO_2 emissions from biofuels can be rated as zero, the number of ships with a CII label E and the CO_2 emissions falling into the label E category decrease significantly, while the number of ships and the CO_2 emissions in the other CII labels actually increases.

Figure 11 - 2030 distribution of the 2019 EU MRV fleet over the CII labels if TtW CO_2 emissions of biofuels are not/are zero-rated





4.4 Key findings

The key findings of this chapter are as follows:

- The increasingly stricter CII reduction factors have a significant impact on the 2025 and 2030 CII labels of the ships of the EU MRV fleet. There is a shift in the distribution of the number of ships over the labels. Without additional measures to reduce the carbon intensity, significantly more ships will have a CII label E both in 2025 and 2030, while the number of ships with a CII label A, B and C will decrease.
- In contrast to the impact of the increasingly stricter CII reduction factors, the impact of FuelEU Maritime on the 2025 and 2030 CII ranking is negligible, at least if biofuels cannot be zero-rated under the CII Regulation.
- If the TtW CO_2 emissions of biofuels can be accounted for as zero, the impact of FuelEU Maritime on the TtW CO_2 emissions (133 Mt versus 141 Mt remaining CO_2 emissions) and the CII labels of the ships will differ significantly compared to the case in which the biofuels cannot be zero-rated.

5 Additional CO_2 reductions

The expected 2025 and 2030 operational carbon efficiency of the 2019 EU MRV fleet has been analysed in Chapter 4, taking into account the impact of the FuelEU Maritime Regulation. It shows that, until 2030, FuelEU Maritime can be expected to have a limited impact on the CII ranking of the fleet. For that reason, additional measures to further improve the fleet's carbon intensity building on the CII could be considered.

Figure 1 illustrates, the operational carbon intensity of the fleet can be improved by both an improvement of the carbon intensity of the energy consumption of ships, but also by an improvement of the operational and technical energy efficiency of the ships. This chapter explores the additional emission reduction potential of both: measures that improve the carbon intensity of the energy consumption of ships as well as measures that improve the energy efficiency of ships. This also with the aim to explore the potential effectiveness and proportionality of additional measures that build on the CII.

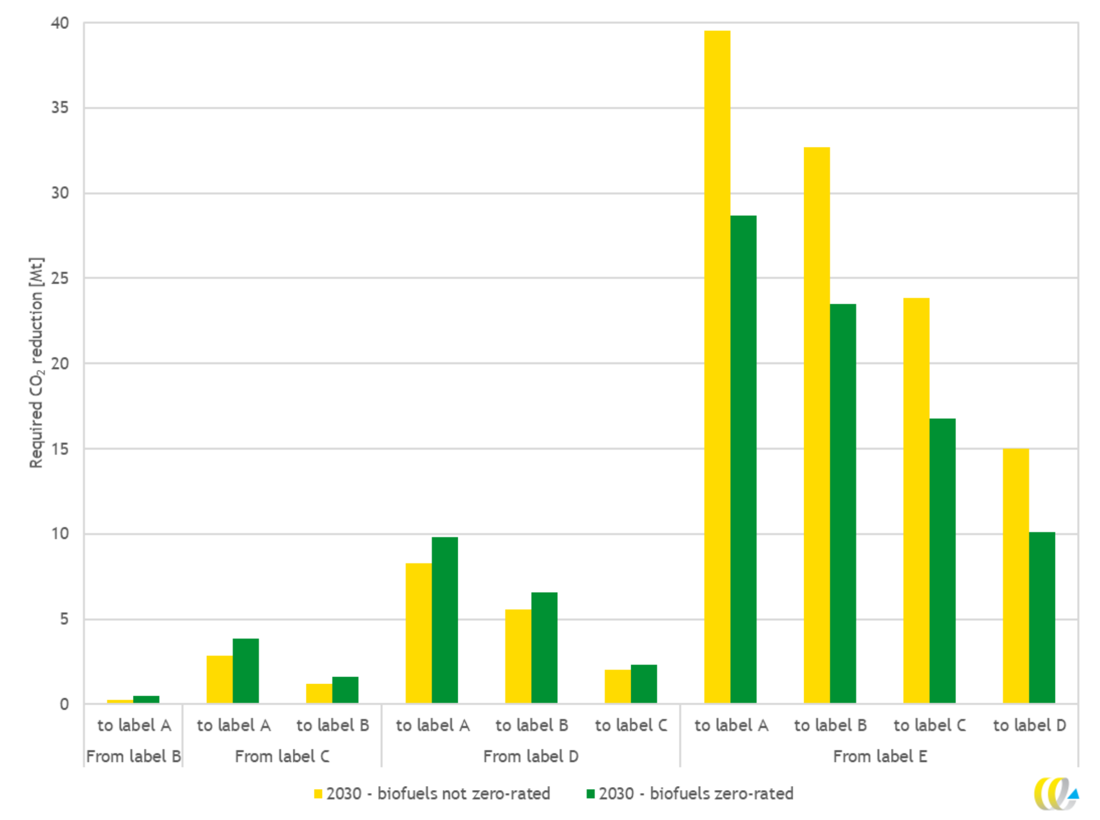
Section 5.1 presents the CO_2 emission reduction which would be required if ships were required to further improve their CII labels. Thereafter, options to improve ships' operational carbon intensity are presented in Section 5.3 and the maximum abatement potential of certain reduction measures for the 2019 EU MRV fleet are analyse in Section 5.4. The focus in this section is on alternative fuels, speed reduction, wind-assisted propulsion and air lubrication. Section 5.5 analyses the costs of these measures on a high level. Finally, the key findings of this chapter are summarised in Section 5.6.

5.1 Required CO_2 emission reduction to achieve an improved CII label

To improve their CII rating, ships have to lower their attained CII level to the point where the level equals at least the upper boundary of the label to be achieved. If the ships' transport work does not change, the attained CII will have to be lowered by a reduction of the TtW CO_2 emissions.

Figure 12 provides a graphical overview of the amount of CO_2 emissions that ships of the 2019 EU MRV fleet would have to reduce in 2030 to achieve certain CII labels, depending on their initial label level.

Figure 12 - 2030 CO_2 reduction required by the 2019 EU MRV fleet to achieve a certain improved CII label, depending on the actual label level and on whether biofuels are zero-rated under FuelEU Maritime



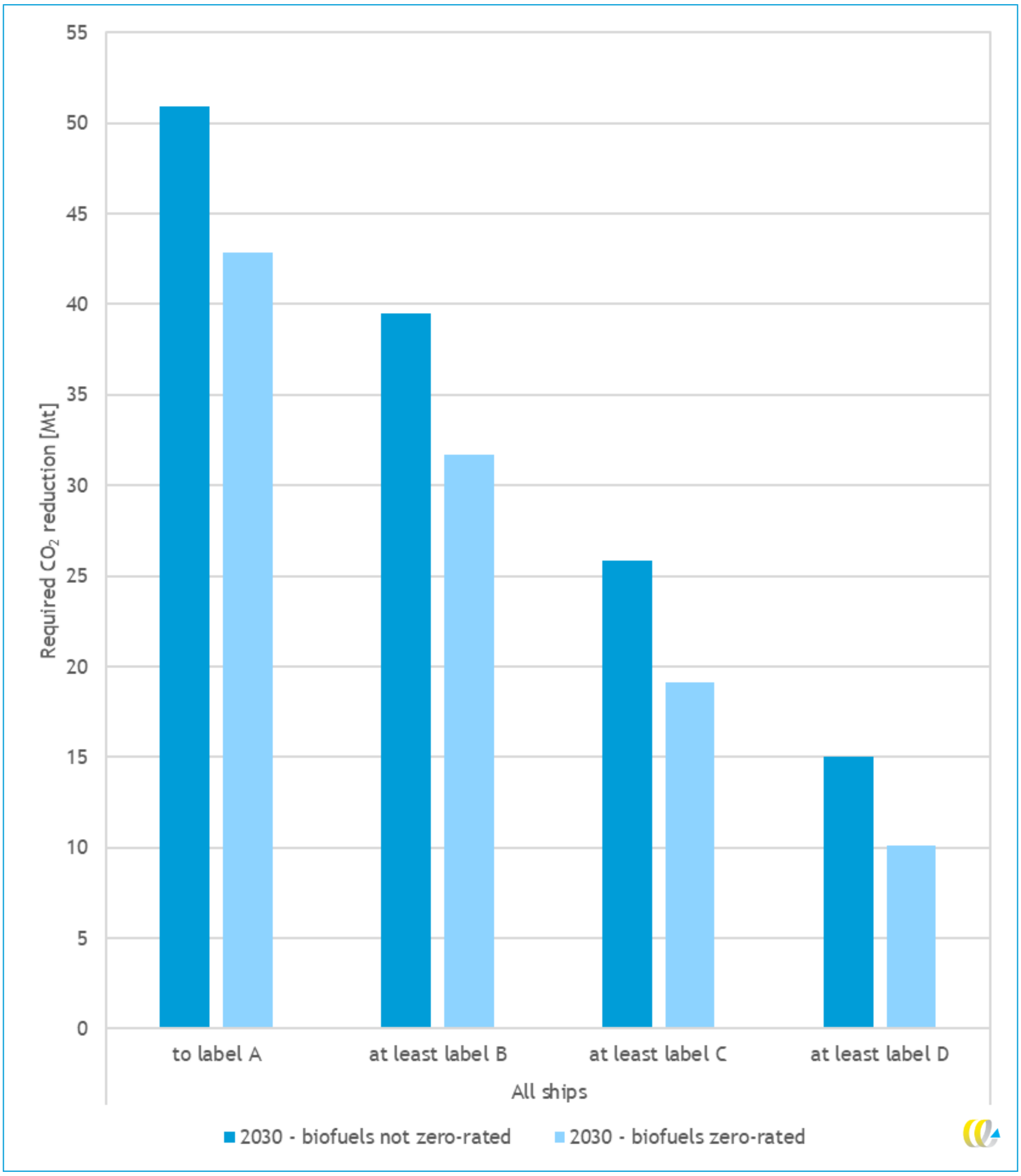
For example:

— If biofuels were zero-rated (green bars) and
  - if all ships with label E (see green bar to the very right of Figure 12) would have to improve their attained CII to achieve label D, they would have to reduce their CO_2 emissions by 10 Mt in 2030;
  - if all ships with label E would have to improve their attained CII to achieve label A, they would have to reduce their CO_2 emissions by approx. 29 Mt in 2030.

— If biofuels were not zero-rated (yellow bars) and
  - if all ships with label E (see yellow bar to the very right of Figure 12) would have to improve their attained CII to achieve label D, they would have to reduce their CO_2 emissions by 15 Mt in 2030;
  - if all ships with label E would have to improve their attained CII to achieve label A, they would have to reduce their CO_2 emissions by approx. 40 Mt in 2030.

Figure 13 summarises the results as given in Figure 12. Here the CO_2 emission reduction that is required for all ships to achieve at least a certain label level is given, not differentiated by the ships' initial CII label level.

Figure 13 - 2030 CO_2 reduction required by all ships of the 2019 EU MRV fleet to achieve (at least) a certain CII label



For example:

- If biofuels were zero-rated (light blue bars) and
  - if all ships had to achieve label A, then the ships labelled B, C, D and E taken together would have to reduce approx. 43 Mt CO_2 in 2030 (see the light blue bar to the very left);
  - if all ships had to achieve at least label C, then all ships with label D, and E would have to reduce approx. 19 Mt CO_2 in 2030.

- If biofuels were not zero-rated (dark blue bars) and:
  - if all ships had to achieve label A, then the ships labelled B, C, D and E taken together would have to reduce approx. 51 Mt CO_2 in 2030 (see the dark blue bar to the very left);
  - if all ships had to achieve at least label C, then all ships with label D, and E would have to reduce approx. 26 Mt CO_2 in 2030.

To put this into perspective, the total 2030 CO_2 emissions of the 2019 EU MRV fleet as considered here are expected to amount to:
- approximately 133 Mt (see Section 4.3.2), including the effect of FuelEU (biofuel zero-rated);
- approximately 141 Mt (see Section 4.3.1), including the effect of FuelEU (biofuel not zero-rated).

But excluding the effect of EU ETS and the effect of the EEXI and CII at IMO level.

5.2 Required CO_2 emission reduction to meet 2030 IMO target

5.2.1 Current IMO 2030 target

The current IMO 2030 target requires an improvement of the carbon intensity of shipping by at least 40% in 2030, relative to 2008. As discussed in Section 2.2.3, this target can be translated into a CII target related to 2019 (the reference year for the CII), which is a 2030 CII reduction factor of at least 21.5% measured in aggregated supply-based CII metric (MEPC, 2021a).This is why we applied a reduction factor (Z% = 21.5%) relative to the 2019 reference line for the calculations of the 2030 CII labels.

The question that then arises is by how much the 2030 CO_2 emissions would have to be reduced in order to meet this CII 2030 target. Assuming that the ships of the 2019 EU MRV fleet would not change their transport work, this 2030 CII target could be met if the fleet CO_2 emissions were reduced by 21.5%. For the 2019 EU MRV fleet as considered here, this would mean that 30.4 Mt of CO_2 emissions would have to be reduced in 2030 compared to 2019.

This could be achieved if all ships reduced their 2019 emissions by 21.5% or, expressed in CII labels, if in 2030, all ships had the same CII label as in 2019, despite the stricter reduction factor. But since the ships that would achieve A, B or C label anyway in 2030 already attain a CII that is better, equal or slightly worse than the required CII, it might be preferable to meet this 2030 target by a CII improvement of ships that would have received a label D or E in 2030.

If the TtW CO_2 emissions of biofuels could be zero-rated, then the fleet emissions would be reduced by 8.6 Mt in 2030 due to FuelEU Maritime (see Section 4.3.2) which means that D- and E-labelled ships would have to reduce their emissions by an extra 21.8 Mt for the 2019 EU MRV fleet to meet the IMO 2030 target.

If both, D- and E-labelled ships
- would achieve a C label, then this would lead to an extra reduction of approx. 19 Mt (see Figure 13), leaving another 2.8 Mt of CO_2 emissions to be further reduced for the 2019 EU MRV fleet to meet the IMO 2030 target, at least if the potential additional effect of EU ETS, EEDI and EEXI are not accounted for;

— would achieve the required CII value (and not just the C label boundary), then this would lead to an extra reduction of approx. 25 Mt and mean that the 2019 EU MRV fleet would meet the IMO 2030 target.

It is thus important to differentiate between the required CII value as such (which inherently falls within label C) and label C.

5.2.2 Potentially stricter IMO 2030 target

The current IMO 2030 target is part of the Initial IMO GHG Strategy on the reduction of GHG emissions from shipping. This initial strategy is currently under revision and in this context the levels of ambition, including the 2030 target, are under discussion.

Different alternative 2030 targets have been proposed. Here two examples for targets that have been proposed to ensure that the sector is in line with 1.5°C goal:

— Canada, the United Kingdom and the USA for example (ISWG-GHG 14/2/9) have proposed to increase the level of ambition to ensure that the sector target is sufficient to ensure that the maritime shipping sector becomes aligned with the 1.5°C goal. They propose a 2030 GHG intensity target of at least minus 65% compared to 2008. It is however unclear whether this target is related to a supply- or a demand-based measurement of the GHG intensity.

— UMAS et al., (2023) have developed a tool for companies in the maritime transport sector to allow them to set in-house emission reduction targets which are in line with the 1.5°C temperature goal. For 2030, UMAS et al., (2023) specify WtW-GHG intensity targets, which differ, depending on how the remaining carbon budget is distributed over a trajectory until 2050. The intensity targets are related to a demand-based measurement of the operational GHG intensity and thus cannot directly be applied to the CII, which is a supply-based measurement of the operational carbon intensity. Table 2 in UMAS et al., (2023) suggests that the 2030 intensity targets in line the 1.5 °C temperature goal, range from 51 to 61% reduction compared to 2020.

An analysis of the feasibility of a target that is stricter than the current 2030 IMO target is beyond the scope of this study.

5.3 Options to improve ships' operational carbon intensity

Figure 1 above not only illustrates the different determinants of the CO_2 emissions, but also the different determinants of the operational carbon intensity of a ship that transports cargo and/or passengers.

An improvement of the operational carbon intensity of a ship can be achieved by means of an improvement of the operational energy efficiency of a ship (energy consumed per unit of transport work) and/or an improvement of the carbon intensity of the energy consumption of the ship (CO_2 per unit of energy consumed).

Measures to improve the operational energy efficiency – technical measures

There are various technical measures that can improve the energy efficiency of a ship, some of which can only be applied to newbuild ships while others can also be retrofitted/applied to existing ships.

A new ship can be designed to feature improved hydrodynamics and aerodynamics and can be equipped with efficient devices (engines, propellers, etc.), ideally designed/selected as part of an overall optimization to also minimize efficiency losses in the interaction of the different design elements.

Existing ships can also be retrofitted to improve their hydrodynamics (e.g. by means of air lubrication devices) and can be equipped with improved propellers or propulsion improving devices (like pre and post devices). While the replacement of main engines can be expected to be very costly, main engine improvements (like tuning or an improved engine control) and engine power limitations are options for existing ships too. The use of waste heat recovery systems and the use of fuel cells instead of auxiliary combustion engines are options to more efficiently produce electricity on board of new and existing ships.
An improvement of the energy efficiency of electricity consumers (pumps, lightning, air conditioning, etc.) plays an important role in this context too.

Larger ships are in general more energy efficient than smaller ships, but since the required CII is also stricter for larger ships – it is thus not necessarily easier to achieve an A label with a larger ship.

Measures to improve the operational energy efficiency – operational measures

There are various operational measures that can improve the energy efficiency of a ship. The reduction of the speed of the ship is for example a very effective measure to reduce a ship's main engine energy consumption and energy losses can be reduced/minimized by reducing hull friction (hull coating, hull cleaning) or by improving the efficiency of propellers (cleaning and polishing).

In contrast to measures that improve the technical energy efficiency of ships, all operational measures can be applied to existing ships.

The operational carbon intensity of a ship, as measured by the CII-metric, can also be improved by reducing the time that a ship emits CO_2 emissions while not covering any distance, like the reduction of the time at anchorage or at berth. The use of onshore power can be useful in this context too.

Measures to improve the carbon intensity of the energy consumption

The carbon intensity of the energy consumption of ships can be improved by the use of renewable energy and/or by the use of non-renewable fuels which lead to lower CO_2 emission per unit of energy, also referred to as low carbon fuels.

Wind propulsion systems allow for the use of wind energy to (partially) reduce ships' main engine power and renewable fuels (biofuels or e-fuels) have the potential to fully eliminate the ships' CO_2 emissions stemming from main engines, auxiliary engines and boilers. Depending on the fuel engine/fuel system changes might however be required which is why the use of some types of renewable fuels is an option for newbuilds only. The availability of some renewable fuels and related systems is also still limited. Wind propulsion systems can be retrofitted and their availability is currently increasing.

Wind turbines and solar cells can be used to produce some of the electricity required on board ships.

Combination and interaction

Many of the measures described above can be applied in combination, but the cost-effectiveness of a measure can be expected to be impacted once another measure has already been applied. This is because some of the reduction potential has already been reaped.

In addition, the effectiveness of some measures varies with the speed of the vessel (e.g. wind propulsion systems and waste heat recovery) which has to be taken into account if engine power limitation or slow steaming is applied.

An improvement of the energy efficiency can contribute to lower fuel expenditures if the relatively expensive renewable fuels are used.

5.4 Maximum abatement potential of specific reduction measures

The EU MRV data as published by the European Commission allows to assess the ships' emissions and efficiency per year, however, the reported data and information do not give insights into the measures that ships have already implemented to reduce their emissions and/or improve their efficiency. This makes an analysis of the scope for further technical and operational improvements difficult. We therefore decided to focus on the following measures which are not widely adopted yet: renewable fuels, wind-assisted propulsion, air lubrication and speed reduction. Renewable fuels and wind-assisted propulsion systems can contribute to the improvement of the carbon intensity of the energy consumption of ships while air lubrication and speed reduction to the improvement of the operational energy efficiency of the ship (see Figure 1). In the following, we will briefly introduce these measures and subsequently go into the CO_2 reduction which could maximally be achieved when these measures where adopted by the 2019 EU MRV fleet.

Renewable fuels

There are different types of renewable fuels that can contribute to an improvement of the carbon intensity of the energy consumption of ships. Regarding the production pathway, two main categories can be differentiated in this context: biofuels and e-fuels. Renewable e-fuels are fuels based on hydrogen that stems from water electrolysis. Hydrogen as such is considered as bunker fuel. For the other types of e-fuel it holds that additional synthesis is required with either nitrogen (for the production of ammonia) or with carbon (for the production of methanol or methane). For the latter, different carbon sources are under consideration: biogenic sources, carbon captured from the air or from a point source, which can either stem from the combustion of fossil or renewable fuel. Methane and methanol can also be produced as biofuel and, depending on the feedstock and the production pathway, different types of biodiesel and biocrudes are options for maritime shipping too (for an overview see for example ABS et al., (2022)).

Speed reduction

The reduction of the speed of ships is a very effective way of reducing the main engine fuel consumption of ships at sea, even if you consider that the ships that slow down, need more time for each voyage and that extra capacity and extra fuel consumption is required to keep the transport work at the former level. Only for ships with a relatively high share of auxiliary and boiler fuel consumption, can a speed reduction lead to a net increase of the ship's fuel consumption. For the analysis of the reduction potential we consider a 10% speed reduction for all of those ships for which the share of auxiliary and boiler fuel consumption is low enough to allow for a net CO_2 emission reduction. In addition, we analyse the average speed reduction that would be required by the 2019 EU MRV fleet on top of FuelEU Maritime to meet the current 2030 EU MRV target.

Wind propulsion systems

Wind propulsion systems convert wind power into thrust allowing ships to use wind power for propulsion purposes. If a ship sails at constant speed, then the use of wind propulsion systems allows for a reduction of the main engine load, leading to lower fuel consumption and GHG emissions.[7] Wind propulsion systems can however also be used to sail at a higher speed without reducing the fuel consumption/GHG emissions. This actually holds for all measures that improve the operational energy efficiency of ships, with the exception of a speed reduction, and thus also for air lubrication systems.

Currently, there are different types of wind propulsion systems available/under development: rotors, suction wings, hard sails, modern soft sails and kites. The different systems cannot be applied to all ship types/sizes, but for most ship types, an applicable system can be expected to become available in the short- to medium-run. The dimensions of the available systems might however not be suitable for very small ships.

The fuel consumption and emission reduction potential of wind propulsion systems depend on several factors (EMSA, 2023):
1. The baseline fuel consumption of the ship.
2. The type of wind propulsion system applied.
3. The number and position of the installed systems and the dimensions of the systems. (The according thrust should ideally be determined also considering the interaction of the devices and the resistance added, considering both aero- and the hydrodynamics of the ships.)
4. The conditions under which systems are applied, like environmental conditions (wind speed, wind angle, wave height), which can vary highly per route and season, and depending on how a ship is operated (speed of ship, its loading condition, its route, also considering potential rerouting due to the application of route optimisation, etc.).
5. The Specific Fuel Oil Consumption (SFOC; g fuel/kWh) of the ship's engine, depending on the engine load, which should be lowest when sailing at the design speed of the vessel (not considering the wind propulsion system) and which thus might be higher if the engine load is reduced when utilising wind propulsion.
6. The energy consumption of the wind propulsion system as such.

[7] Wind propulsion systems can also be used to sail at a higher speed without reducing the fuel consumption/GHG emissions. This actually holds for all measures that improve the operational energy efficiency of ships, with the exception of a speed reduction, and thus also for air lubrication systems.

This makes it very difficult to estimate the 2030 emissions reduction potential of the 2019 EU MRV fleet. For the purpose of this study, we applied the following simplifying approach:
- we differentiate two different reduction percentages which are applied to the main engine fuel consumption: 5 and 10%;
- 5% is applied to the main engine fuel consumption on intra-EEA voyages, assuming that the wind speed is lower on intra-EEA voyages compared to extra-EEA voyages;
- 10% reduction is applied to the main engine fuel consumption on the incoming and outgoing extra-EEA voyages of those ships that sail at a relatively low speed – in most cases, the absolute and relative emission reduction potential is higher for ships with a lower speed;
- for the other ship types that sail at a relatively high speed, the 5% percentage reduction is applied to the main engine fuel consumption on the incoming and outgoing extra-EEA voyages;
- the estimation of the allocation of the fuel consumption of the main engine and the auxiliary engine & boilers is, just as for speed reduction, based on the 4th IMO GHG Study;
- we do not have to exclude very small ships from the analysis, since the very small ships fall outside the scope of EU MRV.

Air lubrication systems

Air lubrication systems work as follows: "By covering hull surface in contact with water with air bubbles, frictional resistance can be reduced. In practice, air bubbles are injected from the bottom part of a ship to reduce the frictional resistance of the ship. Reduction of frictional resistance can result in a CO_2 reduction effect." (Faber et al., 2020) For the CO_2 reduction to materialise, the ship should not speed up once the frictional resistance is improved.

Air lubrication systems can only be installed on ships with a (at least partially) flat bottom. We assume, in line with the information as published by a technology provider, that the system can only be applied to the following ship types and sizes:
- cruise ships;
- ro-ro ships;
- container ships (> 9,000 TEU);
- large gas carriers;
- large tankers and bulk carriers (> 100,000 dwt).

Regarding the reduction potential we assume an average 6% net-reduction, accounting for the energy consumption of the air lubrication system, which is in line with the lower range of an estimation given by a technology provider.

We have analysed the CO_2 emissions reduction potential of the four measures as described above for the 2019 EU MRV fleet under the following assumptions:
- Potential additional measures enter into force into 2026 which means that reduction measures that can only be applied to newbuild ships are assumed to be applied to newbuilds that enter the fleet in the period 2026 to 2030.
- We do not consider the growth of the fleet, but only consider the 2019 EU MRV fleet. Newbuilds are thereby assumed to enter the fleet in order to replace ships aged 25.
- If ships are assumed to be replaced, we assume that they are replaced by the same ship. This is a simplifying assumption, given that new ships might be more efficient. In the 4th IMO GHG Study, it is estimated that the fleet average efficiency will improve by about 25% between 2018 and 2050 as a result of changes in fleet composition

(e.g. the replacement of smaller ships by larger, higher demand growth for containers than for dry bulk and tankers), regulatory efficiency improvements (e.g. the replacement of pre-EEDI ships with EEDI Phase 1, 2 and 3 ships) and market-driven efficiency improvements.
- Ships can, in principle, be retrofitted with wind propulsion systems, however, the production capacity still needs to be ramped up to allow for large-scale retrofitting. We therefore assumed that wind propulsion systems will also only be applied by newbuilds that enter the fleet in the period 2026 to 2030.
- Ships can, in principle, be retrofitted with an air lubrication system. The installation, however, needs to be carried out in a dry dock (ships can expected to be dry-docked every five years) and relatively old ships will probably not be retrofitted, but rather apply operational measures to improve their carbon intensity. We therefore, conservatively, also assumed that only the newbuilds that enter the fleet in the period 2026 to 2030 will apply air lubrication.
- Alternative fuels, other than biodiesel and biomethane, cannot be used on conventional ships. Ships that can be propelled by these fuels need to be build and, for fuels like ammonia, still require further technological developments. In addition, these fuels are, at least in the short-run, not available on a large scale. We therefore assumed that only the newbuilds that enter the fleet in the period 2028 to 2030 could make use of these alternative fuels.
- If alternative fuels are used, we assume that their TtW CO_2 emissions can be zero-rated.

In the following, we will first present the CO_2 emission reduction potential of the measures, if each of the measures was separately applied. In a second step, we discuss the interactions of these measures and estimate their combined reduction potential which is lower than the sum of the reduction potential of the separate measures.

Table 16 - Emission reduction potential if specific measures were applied separately to the 2019 EU MRV fleet in addition to FuelEU Maritime

	Total CO_2 reduction potential	CO_2 reduction potential per 2030 label				
		Label A ships	Label B ships	Label C ships	Label D ships	Label E ships
Air lubrication	0.40 Mt	0.01 Mt	0.01 Mt	0.04 Mt	0.012 Mt	0.023 Mt
Wind propulsion	0.93 Mt	0.006 Mt	0.02 Mt	0.1 Mt	0.20 Mt	0.61 Mt
10% speed reduction	14.17 Mt	0.4 Mt	0.57 Mt	1.96 Mt	3.52 Mt	7.7 Mt
Renewable fuels*	14.51 Mt	0.12 Mt	0.31 Mt	1.6 Mt	3.5 Mt	9.1 Mt

* Zero-rated renewable fuels.

Analysing the reduction potential of the specific measures separately, you can conclude that speed reduction and renewable fuels have the highest reduction potential. Speed reduction is an effective measure and can be applied to all, new and existing ships. Since renewable fuels can potentially eliminate the entire TtW CO_2 emissions of ships, their reduction potential is also relatively high, even if only applied to new ships that are expected to enter the fleet from 2028 on to replace the ships aged 25. Wind propulsion and air lubrication have a comparably lower reduction potential, at least in the short-run - air lubrication cannot be applied to all ships and has to be installed to new ships or during dry docking and the supply of wind propulsion systems still requires upscaling; both only have an impact on the main engine fuel consumption of a ship.

What can also be concluded is that if all ships rated as D and E reduced their speed by approximately 22% or if all ships reduced their speed by approximately 17%, then the current IMO 2030 carbon intensity target can in principle be met by the 2019 EU MRV fleet.[8] However, these ships might not all be able or might not all want to slow down: a shortage of capacity to accommodate the speed reduction might be a barrier to the reduction of the speed and if competitors do not slow down as well, ships might want to avoid a competitive disadvantage by slowing down. Technical measures to improve the energy and carbon intensity of the fleet and renewable fuels then allow to nevertheless meet the target. Therefore, it is necessary to ensure that the CII rewards the use of renewable fuels, also given that renewable fuels have a high reduction potential and play a crucial role in the decarbonisation of the sector.

In addition, unless implemented as a requirement or used as a way to comply with the Energy Efficiency Existing Ship Index (EEXI), ships might not structurally sail at the lower speed. If they sped-up again, the fleet's operational carbon intensity might be worse, also given that the extra capacity needs most probably require the use of additional new ships. This is why the uptake of technical energy efficiency measures like air lubrication and wind propulsion play an important role in this context too.

5.5 Emission reduction costs

Regarding the costs of the emission reduction measures, three types of measures have to be differentiated:
1. Measures that improve the energy efficiency of ships.
2. Devices that allow ships to use wind power.
3. Renewable fuels.

Measures that improve the energy efficiency of the ships lead, by definition, to a reduction of the fuel consumption and thus also to a reduction of the fuel expenditures. The payback time/cost effectiveness of these measures differ, depending on the capital and operational expenditures associated with these measures as well as the price of the fuel of which the consumption is reduced. Even without a carbon price, these measures can be profitable.

Speed reduction is considered a very effective measure to improve the energy efficiency of the ships. It can be cost effective too, at least for those ships that have a relatively low auxiliary and boiler energy consumption. As mentioned above, we estimated that, if all ships reduced their speed by approximately 17%, the current IMO 2030 target could be achieved by the 2019 EU MRV fleet. On a fleet level, this would also lead to net savings, even if the costs for the additionally required capacity is accounted for, however, not for each of the segments of the fleet.

Two types of renewable fuels can be differentiated: biofuels and renewable e-fuels. Renewable fuels are more expensive than the conventional fossil fuels currently used by the sector. In the short- and medium-run, biofuels can be expected to be significantly cheaper than e-fuels, but long-run availability of biofuels is limited by the limited availability of sustainable biomass. The availability of renewable e-fuels highly depends on the upscaling of renewable electricity and electrolyser capacity. For both fuels, but especially for biofuels, demand from other sectors can be expected to significantly rise in the future too. For both types of fuels it also holds that, without a carbon price to close the price gap

[8] In the sense that the fleet would actually reduce their emissions by 21.5% in order to improve the CII by 21.5% as required by the assumed 2030 CII target.

between fossil and renewable fuel, the use of the renewable fuels will never pay off on its own. Especially if the use of the renewable fuels requires different and more expensive onboard propulsion and fuel systems, like for ammonia or hydrogen. Energy efficiency measures can be applied to reduce the additional costs for the renewable fuels.

Devices that allow ships to use wind power can be used to also reduce a ships' fuel consumption, however, the energy consumption of the ships does not have to be reduced, rather parts of the energy demand is covered by wind power instead of main engine power. The use of wind propulsion devices can thus also lead to a reduction of the fuel expenditures and can be profitable even without a carbon price.

An assessment of the cost effectiveness of the different measures should ideally be based on the emission reduction and fuel reduction potential not only within the scope of the EU MRV system, but based on the total annual emission reduction. Otherwise, at least for those ships that also sail on routes outside the scope of the EU MRV Regulation, this would lead to an overestimation of the net costs per unit of CO_2 reduced. According to the Fourth IMO GHG Study (CE Delft et al., 2020), the four specific emission reduction measures analysed can be ranked as follows in terms of fleet average reduction cost per tonne CO_2: speed reduction (lowest), wind propulsion, air lubrication, renewable fuels.

5.6 Key findings

The key findings of this chapter are summarised below:

- Given a 2030 CII reduction factor of 21.5%, in line with the current IMO 2030 target, an obligation to improve the CII label can be expected to have a relatively large 2030 emission reduction potential:
  - if all ships of the 2019 EU MRV had to achieve at least the required CII level, then 25 Mt of CO_2 would have to be reduced on top of FuelEU Maritime; this would actually be sufficient for the 2019 EU MRV fleet to meet the current 2030 IMO target;
  - if all ships of the 2019 EU MRV had to achieve label A, then 43 Mt of CO_2 would have to be reduced on top of FuelEU Maritime.
- Since the CII is an operational carbon intensity indicator, ships can, in principle, improve their CII label by means of a wide range of different measures: measures that improve the operational energy efficiency, measures that improve the technical energy efficiency as well as by using renewable energies, including renewable fuels.
- Renewable fuels have a high emission reduction potential and play a pivotal role for the decarbonisation of the sector. Whether the use of renewable fuels is actually incentivized by the CII, depends on whether the CII metric will be amended to reward the use of these fuels. It also depends on the availability of these fuels, as well as on the carbon price.
- Speed reduction also has a high emission reduction potential, but it can be expected that other emission reduction measures will be applied too. Reducing speed may deteriorate the competitive position of a ship if not implemented by a speed limit. In addition, capacity shortage to keep up the transport work may be a barrier, at least in the short run, and for ships with a relatively high energy consumption of auxiliary engines and boilers the CII improvement potential of sailing slower may be limited.
- Our analysis of the 2019 EU MRV fleet shows that, considering FuelEU Maritime, if all ships rated as D and E reduced their speed by approximately 22% or if all ships reduced their speed by approximately 17%, then the current IMO 2030 carbon intensity target could in principle be met by the 2019 EU MRV fleet.

6 Additional EU measures

The expected 2025 and 2030 operational carbon efficiency of the 2019 EU MRV fleet has been analysed in Chapter 4, taking into account the impact of the proposed FuelEU Maritime Regulation. It shows that, in order to meet the 2030 IMO target, the CO_2 emissions of the 2019 EU MRV fleet must be reduced by 18 Mt on top of FuelEU and EU ETS and that this can almost be achieved if the ships that rated D and E (if biofuels were not zero-rated) would improve their CII label to C. Since the actions that need to be taken under the CII Regulation[9] might not be effective enough to ensure that the 2030 target can be met by the EU MRV fleet, this chapter discusses potential additional policy measures/actions that the EU, EU countries or other actors in the EU could take to ensure that the maritime sector decarbonises in time. The focus lies on measures which build on the CII and a distinction is made between rewarding systems, penalty systems, requirements and facilitating measures. The CII labels of the individual ships will not be published by the IMO. Independent of the type of measure, a centralized publication of the CII labels of the ships would, however, increase transparency and facilitate the implementation of additional measures that build upon the CII.

6.1 Rewarding systems

An improvement of the operational carbon intensity of ships could be incentivised by rewarding ships with a relatively good intensity, like ships with a relatively good CII label or by rewarding ships that intent to improve their intensity. Discounts, time benefits, interest rate advantages and subsidies are all options in this context.

Discounts

- Ports could offer a discount on harbour dues.
- Infrastructure providers could offer a discount on infrastructure fees.
- Flag state providers could offer a discount on flag state fees.

Many ports already provide benefits for ships depending on the ship's sustainability compared to the regulatory requirements (e.g. Environmental Ship Index, Green Marine, etc.). It is thus conceivable that, for example, CII A-labelled ships are rewarded in this context too.

Time benefits

- Infrastructure providers (e.g. canal, locks, etc.) could provide ships with a relatively good operational carbon intensity with a time advantage by shortening their waiting time.

[9] For ships that achieve a D rating for three consecutive years or an E rating in a single year, a corrective action plan to achieve the required CII needs to be developed and approved as part of the Ship Energy Efficiency Management Plan (SEEMP). And these ships have to duly undertake the planned corrective actions in accordance with the revised SEEMP.

Interest rate advantages

- Entities on various levels could provide a low interest rate loan to ships which want to improve their operational carbon intensity by means of technical measures.

Funding

- Entities on various levels could provide fundings to ships which want to improve their operational carbon intensity by means of technical measures.

The effectiveness of measures based on rewarding systems depends on the extent to which the rewarding systems are applied. If only one port would provide a discount on harbour dues, the financial incentive for a shipowner to improve the ship's carbon intensity is limited. Once national administrations, the EU, several flag states, ports and infrastructure providers all provide incentives, it will become more attractive for ship owners to improve the carbon intensity of their ship.

With a rewarding system, ships with a relatively good operational carbon intensity are rewarded, while ships with a worse intensity are not disadvantaged. This prevents ships with these labels from not willing to operate under a certain flag state or avoiding certain ports. Flag states and ports could otherwise lose customers. On the other hand, schemes that work with monetary rewards come at the expense of the incentive provider, at least if not combined with a penalty system (e.g., a bonus/malus system).

As part of the CII Regulation, the IMO encourages administrations, port authorities and other stakeholders to provide incentives to ships rated A and B.

6.2 Penalty systems

An improvement of the operational carbon intensity of ships could alternatively be incentivised by penalising ships with a relatively poor intensity, like ships with a relatively poor CII label (D or E).

In line with the discounts as described above, infrastructure providers (ports, canals, locks, etc.) could penalise ships with a relatively poor operational carbon intensity by means of higher infrastructure fees.

However, for commercial entities (e.g. ports and flag states) it is more difficult to implement a penalty system due to competition – customers (in this case ships) may decide to call at other ports or change the flag, at least if the system is not implemented in a coordinated way.

In addition, ships with a relatively poor intensity could also be penalised by means of business disadvantage:
- National administrations could, as part of public procurement, and companies could commit to only charter/make use of the services of ships that meet a certain CII label.
- National administrations could commit to only buy ships for the national fleet and/or to only licence ships to operate on certain routes that meet certain CII labels.

6.3 Requirements

Next to systems that reward/penalise ships with a relatively good/poor operational carbon intensity, also requirements to the operational carbon intensity of ships could be implemented:

- The EU could require the EU MRV fleet to, on average, meet a specific required CII level, by implementing a so-called baseline and credit scheme. Ships with a below-average intensity would have to buy credits which ships with an above average intensity would generate. This measure can potentially be very effective, however, given that the EU is busy implementing the FuelEU Maritime Regulation and integrating shipping into the EU ETS, the probability that an extra EU measure is being implemented on the short-run is rather slim.
- The EU/Member States could require ships that call at an EAA port/at a port in the Member States to meet a specific required CII level and to ban non-compliant ships. This would give a very strong incentive for ships to improve their operational carbon intensity. Disadvantage of such a ban is that it is a rather drastic measure and that, at least in the short-/medium-run, a potential shortage of transport capacity associated with higher transportation costs could occur. In addition, should the CII label levels for individual ships turn out to fluctuate over the years, such a ban would introduce an uncertainty to the market, at least if ships cannot fully control their CO_2 emissions (e.g. due to an economic downturn and related long periods of anchorage) and thus the label that the ships will receive in the subsequent period.
- As part of the EU Corporate Sustainability Reporting Directive, companies could be required to specifically report the operational carbon intensity of the ships that have been used in their value chain.

Further, requirements could be set regarding reduction options that contribute to the improvement of ships' operational carbon efficiency:

- As discussed above, reducing speed can result in significant reductions of the ships' fuel consumption and GHGs. Ships could therefore be required to stick to **speed limits** specific areas. Speed limits could also be useful in the sense that ships that reduce their speed would, in contrast to a voluntary reduction of their speed, not suffer a competitive disadvantage. However, reducing speed may result in a longer travel time, which means that a ship can make fewer voyages annually and could lose revenues if there is no spare capacity available. A regional (and not global) speed limit also comes with the risk that ships increase their speed outside the speed limit area to make up for lost time. This would lead to a higher fuel consumption and GHG emissions and reduce the environmental effectiveness of a speed limit.

6.4 Facilitating actions

Finally, also actions that facilitate the ships' improvement of their operational carbon efficiency could be taken:

- The maritime shipping sector is characterised by, on the one hand, a relatively small number very large shipping companies and, on the other hand, by a high number of very small companies. Especially for the latter, it could be very useful to get support for the improvement of the efficiency of their fleet. Flag states or classification societies could for example arrange onboard ship-specific energy audits and/or facilitate the exchange of information/experiences between ship owners.
- Public funding of pilots for which results are made publicly available can also contribute to a quicker development and uptake of reduction measures.

Here are two examples of facilitating measures that have already been realised:
- BIMCO has developed a wide range of contracts and clauses covering every aspect of shipping activities, including **charter parties**, bills of lading and finance (BIMCO, 2023). One of BIMCO's most recent developed **clauses** is the CII Operations clause for time charter parties 2022. This clause sets out a way forward for the shipowners and the charterers to contribute towards reducing the ship's carbon intensity, which is required by the MARPOL CII Regulations. Commercial elements are included in this clause to assist the charterer and the shipowner to cooperate and collaborate in a balanced way. Sharing information and transparency on ship data, focussing on energy efficiency and flexibility in ship operation and employment are fundamental principles underlying this clause. This clause is designed to make it work in practice.
- According to the **Just In Time Principal**, a ship's sailing speed and route are adjusted in such a way that its arrival time coincides with the port's handling operations, so that the waiting time of the ship is minimised. Reducing ships' speed to arrive just in time, results in fuel savings, reduced GHGs and an improved CII. The IMO published the Just In Time Arrival Guide to provide information and proposals to ports and shipping sectors as well as port and maritime administrations on how to facilitate JIT Arrival of ships, with a view to reduce greenhouse gas emissions by optimising the port call business process and providing sustainable solutions to customers in the end-to-end supply chain (IMO, 2020).

6.5 Key findings

- Various additional measures which build upon the CII and which different actors in the EU could implement are conceivable.
- An improvement of the operational carbon intensity of ships could be incentivised by rewarding ships with a relatively good carbon intensity or by penalising ships with a relatively poor carbon intensity.
- Ships calling at EAA ports could also be required to attain certain CII levels/labels or EU companies could be required to report the operational carbon intensity of the ships that have been used in their value chains.
- Measures that facilitate ships' improvement of their operational carbon efficiency could be implemented.
- The CII labels of the individual ships will not be published by the IMO. A centralized publication of the CII labels of the ships would, however, increase transparency and facilitate the implementation of additional measures that build upon the CII.

7 Conclusions & recommendations

Conclusions

The Carbon Intensity Indicator (CII) with its metric and labelling scheme is, in principle, a very useful tool to incentivize an improvement of ships' operational carbon intensity and CO_2 emissions.

> Our analysis of the 2019 EU MRV fleet shows that, considering the impact of the FuelEU Regulation and applying a 2030 CII reduction factor of 21.5%, a relatively large share of ships can be expected to obtain a D- and E-CII label in 2030:
> - D label: 27% of the ships, accounting for 34 Mt CO_2 (26% of fleet CO_2 emission);
> - E label: 43% of the ships, accounting for 68 Mt CO_2 (51% of fleet CO_2 emissions).

Given a 2030 CII reduction factor of 21.5%, in line with the current IMO 2030 target, an obligation to improve the CII label can be expected to have a relatively large 2030 emission reduction potential.

> Our analysis of the 2019 EU MRV fleet shows that, considering the impact of the FuelEU Regulation and applying a 2030 CII reduction factor of 21.5%, an obligation to improve the CII label would be associated with the following 2030 emission reduction potentials:
> - if, for example, all ships had to achieve at least a label C: 19 Mt of CO_2;
> - if, for example, all ships had to achieve at least the required CII level: 25 Mt of CO_2 (this would be sufficient for the 2019 EU MRV fleet to meet the current 2030 IMO target);
> - if, for example, all ships had to achieve label A: 43 Mt of CO_2.

Since the CII is an operational carbon intensity indicator, ships can, in principle, improve their CII label by means of a wide range of different measures: measures that improve the operational energy efficiency, measures that improve the technical energy efficiency as well as by using renewable energies, including renewable fuels.

Renewable fuels have a high emission reduction potential and play a pivotal role for the decarbonisation of the sector. Whether the use of renewable fuels (on top of the fuels used due to the FuelEU Maritime Regulation) is actually incentivized by the CII, depends on whether the CII metric will be amended to reward the use of these fuels. It also depends on the availability of these fuels, as well as on the carbon price.

> Our analysis of the 2019 EU MRV fleet shows that, should all ships be replaced at the age of 25 and would be replaced by newly built ships that can be operated by means of 100% renewable fuel, 14.5 Mt CO_2 could be saved in 2030 in total, 12.6 Mt CO_2 of which by ships rated D and E.

Speed reduction also has a high emission reduction potential, but it can be expected that other emission reduction measures will be applied too. Reducing speed may deteriorate the competitive position of a ship if not implemented by a speed limit. In addition, capacity shortage to keep up the transport work may be a barrier, at least in the short run, and for ships with a relatively high energy consumption of auxiliary engines and boilers the CII improvement potential of sailing slower may be limited.

> Our analysis of the 2019 EU MRV fleet shows that, having considered the impact of the FuelEU Maritime Regulation, a 10% speed reduction by ships rated D and E would lead to a CO_2 emission reduction of approx. 11 Mt in 2030. And if all ships rated as D and E reduced their speed by approximately 22% or if all ships reduced their speed by approximately 17%, then the current IMO 2030 carbon intensity target could in principle be met by the 2019 EU MRV fleet.

The use of technical energy efficiency measures and the use of wind power should in general not be disregarded as relevant compliance options for ships with a relatively poor label level.

> Our analysis of the 2019 EU MRV fleet shows that, for most ship types, with the exception of Ro-ro, ro-pax ships and refrigerated cargo carriers, the average age of the ships in label D or label E category is highest. However, for some ship types (LNG carrier, ro-pax ships), the average age of the ships with label E is lowest and for several ship types it holds that the variation of the average age over the label categories is rather small. For, for example, general cargo ships, container ships, vehicle carrier and LNG carrier the variation is even less than 3 years.

The CII labelling scheme improves the transparency and there are various measures that could build on the CII labelling system that the EU, EU countries or other actors in the EU could take to stimulate the improvement of the EU fleet's operational carbon intensity. In addition, measures that can facilitate the improvement of the operational carbon intensity of maritime shipping could be taken too. Publication of the CII labels of the individual ships by IMO would be very useful in this context.

The current CII metric that is used to calculate the ships' attained operational carbon intensity has the disadvantage that it only captures Tank-to-Wake CO_2 emissions. Also ships with a relatively high share of emissions at berth/at anchorage can be expected to receive comparably poor labels. On the other hand, a comparison among the ships of the same type might nevertheless lead to a fair assessment and the pressure on ports to improve logistics and/or to embrace concepts like a virtual arrival schemes might as well increase.

Recommendations

1. For the effectiveness of the CII, it is important to ensure that the metric of the CII is amended to reward the use of renewable fuels. For this purpose, the CII metric must, at least, allow for a differentiation between renewable and fossil carbon and hydrogen; this is an integral part of a Well-to-Wake emissions approach.
2. For the review of the CII at the IMO level, scheduled to be completed by 1 January 2026, it should be considered that
   a The CII reduction factors for the period after 2026 have not been determined yet and should be ambitious enough to also stimulate the further and timely development of technical measures to improve the energy and carbon intensity of ships as well as of alternative fuels.
   b Strengthening of the enforcement of the CII measure at the IMO level is important.
   c Publication of individual ship's CII rating can contribute to an even higher transparency in the market.
3. If the enforcement of the CII at the IMO level cannot be strengthened, additional actions/measures that reward ships with a relatively good label and/or penalise ships with a relatively poor label are all the more important.

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A Design of the CII

A.1 Parameters to determine the reference lines

Table 17 provides the parameters to determine the 2019 ship type-specific reference lines.

Table 17 - Parameters to determine the 2019 ship type specific reference lines

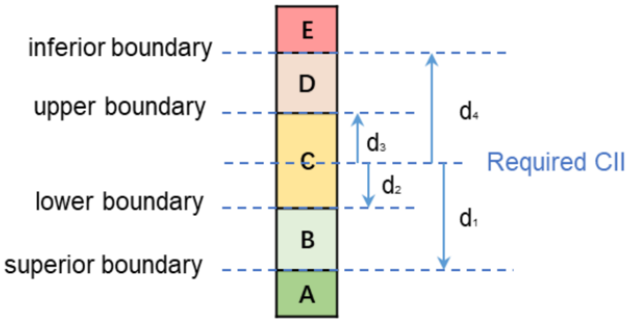
Ship type		Capacity	a	c
Bulk carrier	279,000 DWT and above	279,000	4745	0.622
	less than 279,000 DWT	DWT	4745	0.622
Gas carrier	65,000 and above	DWT	14405E7	2.071
	less than 65,000 DWT	DWT	8104	0.639
Tanker		DWT	5247	0.610
Container ship		DWT	1984	0.489
General cargo ship	20,000 DWT and above	DWT	31948	0.792
	less than 20,000 DWT	DWT	588	0.3885
Refrigerated cargo carrier		DWT	4600	0.557
Combination carrier		DWT	5119	0.622
LNG carrier	100,000 DWT and above	DWT	9.827	0.000
	65,000 DWT and above, but less than 100,000 DWT	DWT	14479E10	2.673
	less than 65,000 DWT	65,000	14779E10	2.673
Ro-ro cargo ship (vehicle carrier)	57,700 GT and above	57,700	3627	0.590
	30,000 GT and above, but less than 57,700 GT	GT	3627	0.590
	Less than 30,000 GT	GT	330	0.329
Ro-ro cargo ship		GT	1967	0.485
Ro-ro passenger ship	Ro-ro passenger ship	GT	2023	0.460
	High-speed craft designed to SOLAS chapter X	GT	4196	0.460
Cruise passenger ship		GT	930	0.383

Source: (MEPC, 2022c).

A.2 Calculation of the rating boundaries of the CII rating mechanism

The four boundaries of the CII rating mechanism are determined by the required annual operational CII in conjunction with vectors (*dd*) which indicate the direction and distance they deviate from the required value. This is shown in Figure 14.

Figure 14 - Vectors and rating bands of CII rating mechanism



Source: (MEPC, 2022b).

Statistically, the *dd* vectors depend on the distribution of the attained annual operational CII of ships of the type concerned. This can be estimated through a quantile regression, using data collected through DCS in year 2019 as a sample.

Through an exponential transformation of each *dd* vector, the four boundaries (see Figure 14) can be derived based on the required CII as follows:

$$\text{superior boundary} = \exp(d1) * required\ CII$$
$$\text{lower boundary} = \exp(d2) * required\ CII$$
$$\text{upper boundary} = \exp(d3) * required\ CII$$
$$\text{inferior boundary} = \exp(d4) * required\ CII$$

Where:

- The estimated *dd* vectors after exponential transformation for determining the rating boundaries of ship types are provided in Table 18.

Table 18 - *dd* vectors for the determination of the rating boundaries of ship types

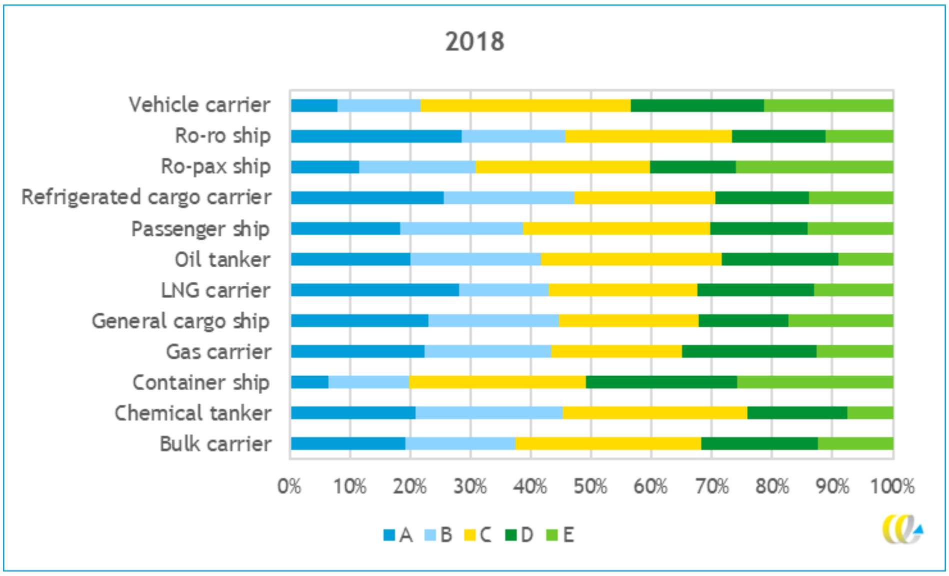
Ship type		Capacity in CII calculation	*dd* vectors (after exponential transformation)			
			exp(d1)	exp(d2)	exp(d3)	exp(d4)
Bulk carrier		DWT	0.86	0.94	1.06	1.18
Gas carrier	65,000 DWT and above	DWT	0.81	0.91	1.12	1.44
	less than 65,000 DWT	DWT	0.85	0.95	1.06	1.25
Tanker		DWT	0.82	0.93	1.08	1.28
Container ship		DWT	0.83	0.94	1.07	1.19
General cargo ship		DWT	0.83	0.94	1.06	1.19
Refrigerated cargo carrier		DWT	0.78	0.91	1.07	1.20
Combination carrier		DWT	0.87	0.96	1.06	1.14
LNG carrier	100,000 DWT and above	DWT	0.89	0.98	1.06	1.13
	less than 100,000 DWT		0.78	0.92	1.10	1.37
Ro-ro cargo ship (vehicle carrier)		GT	0.86	0.94	1.06	1.16
Ro-ro cargo ship		GT	0.76	0.89	1.08	1.27
Ro-ro passenger ship		GT	0.76	0.92	1.14	1.30
Cruise passenger ship		GT	0.87	0.95	1.06	1.16

Source: (MEPC, 2022b).

B CII of the EU MRV fleet 2018-2021

Figure 15 and Figure 16 provide an overview of the CII labels of the EU MRV fleet over the years 2018-2021, each time presented in a different way.

Figure 15 - Distribution of the ships of the EU MRV fleet over the CII labels; 2018 and 2021 subdivided by ship type (in %)



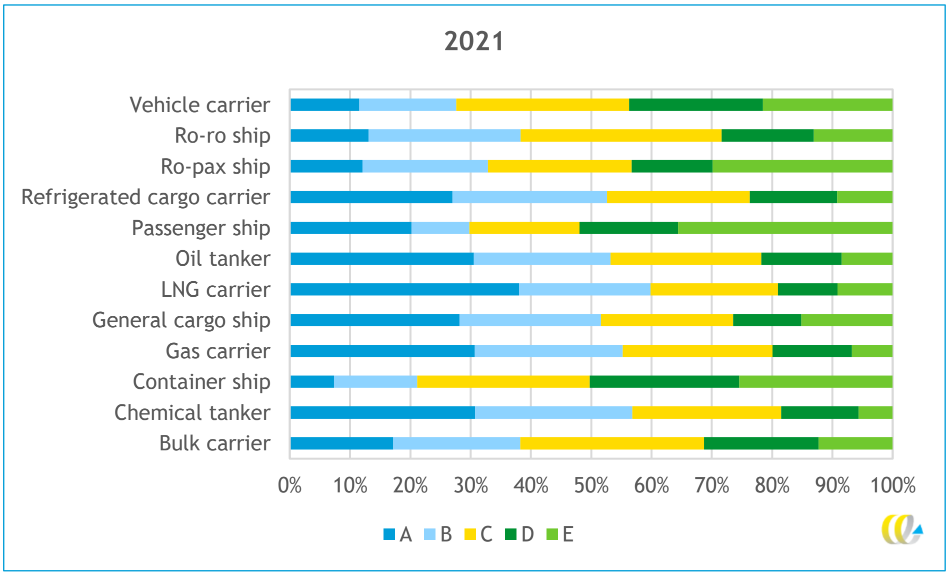
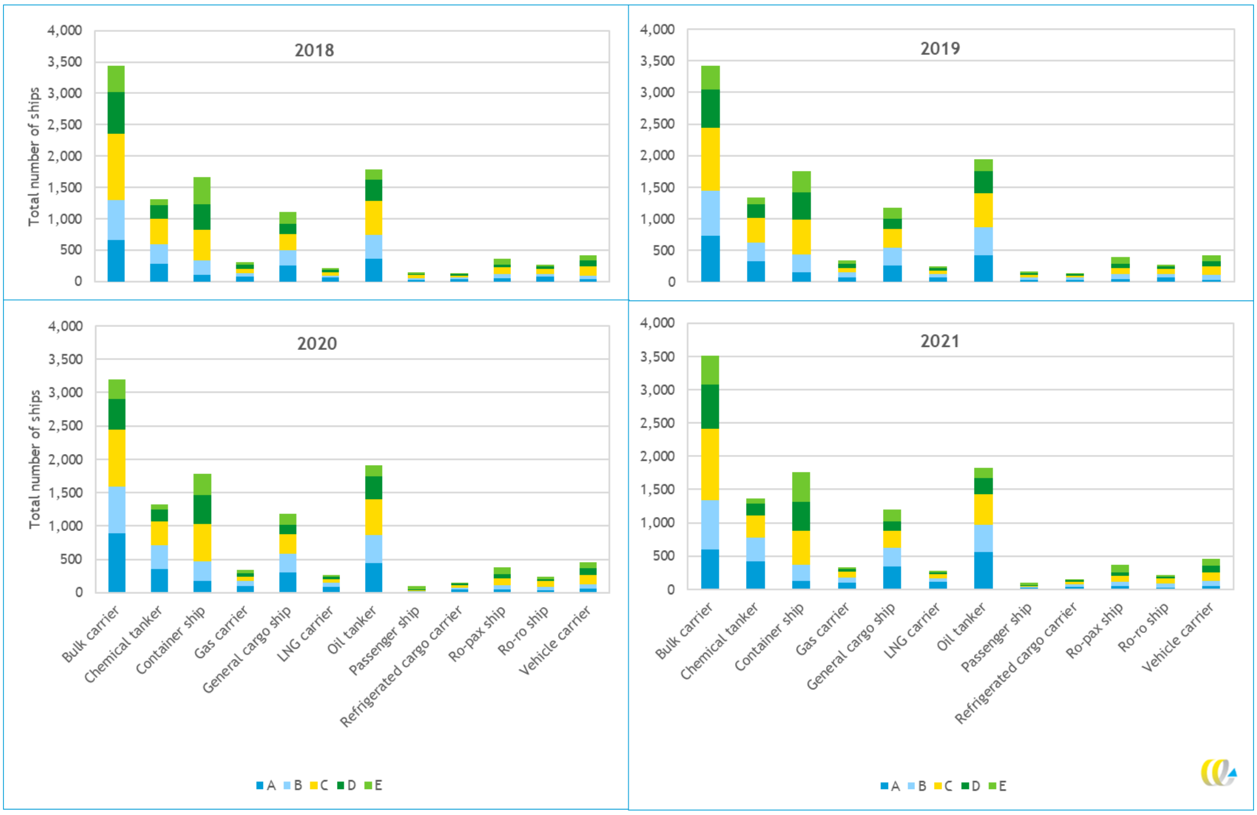


Figure 16 - Total number of ships in the EU MRV fleet in 2018-2021 per ship type category per CII label



C FuelEU Maritime

C.1 GHG emission factors

FuelEU maritime sets targets in terms of Well-to-Propeller GHG emissions. These targets can be met by the use of different fuel mixes.

Table 19 presents the Well-to Tank, Tank-to-Wake and Well-to-Wake (also called Well-to-Propellor for ships) emission factors for selected fossil and renewable fuels.

Table 19 - Well-to-Tank, Tank-to-Wake and Well-to-Wake emission factors for selected fossil and renewable fuels

	Fossil fuel type (LNG engine used)	WTT EF (g CO_2-eq./MJ)	TTW EF (g CO_2-eq./MJ)	WTW EF (g CO_2-eq./MJ)
Fossil	Fossil methanol	31.3	71.57	102.87
	VLSFO	13.2	79.40	92.60
	LNG (Otto dual fuel medium speed)	18.5	73.89	92.39
	LNG (Lean burn spark ignition)	18.5	69.56	88.06
	LNG (Otto dual fuel slow speed)	18.5	66.13	84.63
	LNG (Diesel dual fuel slow speed)	18.5	57.81	76.31
Renewable	Biomethane from biowaste (Close digestate, off-gas combustion) (Otto dual fuel medium speed)	14.0*	18.3***	32.3
	Biomethane from wet manure (Open digestate, off-gas combustion) (Otto dual fuel medium speed)	1.0*	18.3***	19.3
	Biomethanol from farmed wood	16.2*	2.5***	18.7
	E-methane (Renewable electricity from Europe/Africa) (Otto dual fuel medium speed)	0.0**	18.3***	18.3
	FAME from waste cooking oil	14.9*	1.3***	16.2
	Biomethane from biowaste (Close digestate, off-gas combustion) (Diesel dual fuel slow speed)	14.0*	1.7***	15.7
	Biomethanol from black liquor	10.4*	2.5***	12.9
	Biomethane from wet manure (Open digestate, off-gas combustion) (Diesel dual fuel slow speed)	1.0*	1.7***	2.7
	E-methanol	0.0**	2.5***	2.5
	E-methane (Renewable electricity from Europe/Africa) (Diesel dual fuel slow speed)	0.0**	1.7***	1.7

* Based on Renewable Energy Directive.
** Assumed to be zero.
*** For all renewable fuels, TTW CO_2 emissions are assumed to be zero.
Source: (CE Delft, 2022).

The table shows that fossil methanol has the highest and LNG (used in diesel dual fuel slow speed engines) has the lowest WTW GHG emissions per MJ for selected fossil fuels. Regarding the renewable fuels considered, biomethane from biowaste used in an Otto dual fuel medium speed engine has the highest and e-methane used in a diesel dual fuel slow speed engine the lowest WTW GHG emissions per MJ. The emissions of the latter are however still rather uncertain (CE Delft, 2022).

There are different fuel forecast scenarios possible. DNV expects that it will be a mix of fossil fuels, biofuels, e-fuels and electricity from grid (DNV, 2022). The actual fuel mix in 2025-2030 depends on several aspects, such as the fuel availability, the fuel price, available energy conversion technologies and the regulations to comply with.

Table 19 shows that the different types of fossil and renewable fuels each have different Well-to-Wake (Well-to-Propeller) emission factors. This results in different fuel ratios (in % of both fuel types) for different fuel mixes to meet the FuelEU Maritimes GHG intensity targets.