Fleet-level compliance with the CII Regulation

CE Delft

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Summary

The ultimate goal of the Initial IMO Strategy on Reduction of GHG Emissions from Ships is to phase out greenhouse gas emissions from international shipping. It envisages to do so as soon as possible in this century and recognises that this requires a transition from fossil fuels to low- and zero-carbon fuels.

Because ships sailing on low- and zero-carbon fuels have a higher total cost of ownership than ships sailing on conventional fuels, business-as-usual scenarios do not project that the uptake of these fuels will increase. The mandatory goal-based technical and operational measures to reduce carbon intensity of international shipping, which have been agreed at MEPC 75, are not expected to change this situation because, according to their impact assessments, cheaper emission reduction options are available to improve the carbon intensity of ships.

At the same time, many shipping companies are undertaking trials with low- and zero-carbon fuels and have indicated that they would increase their use of these fuels if the costs of doing so would be lower.

One way to improve the business case for using low- and zero-carbon fuels is to allow for fleet-level compliance by shipping companies: instead of requiring that all ships of a company meet the required carbon intensity indicator (CII) individually, companies could opt to comply by demonstrating that their fleet (or a number of their ships) does not emit more than it would if all ships would meet the required CII. This means that the money which would otherwise have been spent on improving the CII of all non-compliant ships can be used to let ships sail on low- and zero-carbon fuels in such a way that the total emissions would not exceed the emissions of a compliant fleet.

This report shows that fleet-level compliance can contribute to the business case of using low- and zero-carbon fuels. In the best cases, over 70% of the additional costs of using low- and zero-carbon fuels can be covered by not investing in the improvements of other ships in the fleet (on average, it is between 25 and 50%, in the worst case, it is about 5%). The total emissions of the fleet will then be the same as when all ships would have had a C label. Fleets of 2 to 3 ships or more can help the business case for ships sailing exclusively on low- and zero-carbon fuels. Taking into account that in some cases fuels can be blended with conventional fuels, fleet-level compliance could be an option for many shipping companies.

Fleet-level compliance can be an attractive option for shipping companies wishing to invest in low- and zero-carbon fuels, especially when they do not have cost-effective options to improve the carbon intensity of their fleet. It can be applied to both large and small fleet and may then encourage the uptake of these fuels. This will have positive impacts on the development of technology, fuel production and bunkering infrastructure.

1 Introduction

The IMO MEPC has approved draft amendments to MARPOL Annex VI concerning mandatory goal-based technical and operational measures to reduce carbon intensity of international shipping at its 75th session in November 2020. Amongst others, the measures require ships to:

- meet or exceed a limit value for the Energy Efficiency Existing Ship Index (EEXI);
- meet or exceed a limit value for the annual operational carbon intensity indicator (CII).

The aim of the measures is to improve the fleet average carbon intensity by at least 40% in 2030, relative to 2008. This aim is linked to one of the Levels of Ambition of the Initial IMO Strategy on Reduction of GHG Emissions from Ships, namely to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008.

In order to fulfil these requirements it is expected that ships will need to invest in retrofits to improve their fuel efficiency, reduce their operational speed, or a combination of both. The Initial Impact Assessments of the measure did not indicate that low- or zero-carbon fuels would be needed to meet the targets. Because these fuels are relatively expensive, the short-term measures are not expected to result in an increase in their uptake.

At the same time, it is clear that in order to meet the ambition of the Initial Strategy beyond 2030, the use of low- or zero-carbon fuels is essential. Also, because of lead-times required to build ships and bunkering infrastructure, recent studies consider it important that the uptake of these fuels starts in the current decade (see, e.g. (Osterkamp, et al., 2021).

This study explores to which extent the short-term measure can be used to incentivise the uptake of low- or zero-carbon fuels by allowing fleets, rather than individual ships to comply. If fleet-level compliance would be allowed, overperformance of the standard becomes valuable because it would reduce the expenses for other ships in the fleet to improve their carbon intensity.

1.1 Aim of the study

The aim of the study is to analyse whether, and if so, how fleet-level compliance can result in an increase in the use of low- and zero-carbon fuels. It does so by analysing the business-case for using low- and zero-carbon fuels, either exclusively or in combination with fossil fuels, for both individual ships and for fleets.

The underlying assumption is that when there is a business case for using low- and zero-carbon fuels, there will be an increase in the uptake because many shipping companies have already signalled that they are ready to use those fuels.

1.2 Outline of the report

Chapter 2 analyses the uptake of low- and zero-carbon fuels in business-as-usual scenarios and in impact assessments of the mandatory goal-based technical and operational measures. Chapter 3 presents the concept of fleet-level compliance, and Chapter 4 analyses quantitatively the costs and benefits of such an approach. Chapter 5 draws conclusions.

2 The outlook for the use of low- and zero-carbon fuels

2.1 Introduction

This chapter analyses projections of fuel use of shipping under a business-as-usual scenario. The two main questions to be answered are:

1. How would the use of low- and zero-carbon fuels evolve in BAU scenarios?
2. How would the use of low- and zero-carbon fuels evolve as a result of the short-term measure?

2.2 Methodology

In order to analyse to which extent the agreed measures will result in decrease of carbon intensive fuel use and increase in the use of low- and zero-carbon fuels we have conducted a literature review on business-as-usual projections of fuel use in the maritime sector and impact assessments of the measures.

2.3 Projections of the uptake of low- and zero-carbon fuels

In the Fourth IMO GHG Study (Faber, et al., 2020), the projection of maritime transport work is projected for the period 2018-2050. These projections are based on global socio-economic scenarios and future energy use scenarios. From this, we can obtain either future scenarios on carbon emissions or fuel use directly. The study states that under a business-as-usual (BAU) scenario the CO_2 emissions will increase from 1 Gt in 2018 to 1.5 Gt in 2050. This is under the assumption no new regulation will be adopted for shipping that has an impact on emissions or energy efficiency of the maritime sector, while considering the assumed future world population and GDP growth projections (from the OECD and IPCC).

The emission projections are based on transport work projections and carbon-intensity projections. The latter are based on an analysis of the cost-effectiveness of various options to improve the carbon intensity, including the use of low- and zero-carbon fuels. The analysis shows that the carbon intensity will improve significantly as a result of existing energy-efficiency regulation, market-driven use of cost-effective options and an increase in the average size of ships. However, the use of low- and zero-carbon fuels is never cost-effective and therefore the fuel mix is considered to be constant over time. The estimated operating energy efficiency of ships is estimated to improve by approximately 25% between 2018 and 2050 as a result of changes in fleet composition, regulatory efficiency improvements and market-driven efficiency improvements[1] (Faber, et al., 2020).

As a result of the future increase in transport work, total emissions of bulkers increase by 10-50% (depending on the method applied for transport work projections), emissions from tankers decrease by 10% or increase by 30% because the transport of chemicals and gas increases, even when crude oil transport work decreases. Emissions from containers are

1 E.g. the replacement of smaller ships by larger ones, higher demand growth for containers than for dry bulk and tankers and the replacement of pre-EEDI ships with EEDI Phase 1, 2 and 3 ships.

projected to increase by almost 20-70%, driven by an increase in transport work of 70-140% and increases in efficiency because of an increase in sizes of ships.

The impact assessment of the goal based energy efficiency improvement measure on existing ships (EEXI) argues that fuel costs for main engines significantly decrease in accordance with the level of efficiency improvement (ISWG-GHG 7/2/8). In other words, the implementation of EEXI results in a decrease of CO_2 reduction per unit of transport work (Greece; Japan; Norway; ICS, 2020). The impact assessment does not project a change in the type of fuels used.

A second paper provides a further quantification (ISWG-GHG 7/2/15). It specifies that the application of EEXI will result in a 7% reduction in carbon intensity measured by the Annual Efficiency Ratio (AER) by 2030, relative to 2019 (Greece; Japan; Norway, 2020). Again, an impact on the type of fuel used is not foreseen.

The detailed impact assessment of the mandatory operational goal-based short-term measure (ISWG-GHG 7/2/20) considers that the uptake of alternative and low carbon fuels is ‘unpredictable’. It does not explicitly address the question of whether the CII will result in an increased use of low-carbon fuels, but suggests that this would only occur at increased levels of ambition, for example if the carbon intensity should be reduced by 70% or more relative to 2008, instead of 40%.

2.4 Main barriers to the uptake of low- and zero-carbon fuels

From the preceding paragraph we understand that in a BAU scenario, under the current directive and requirements, no significant uptake of low- and zero-carbon fuels in the shipping sector will take place. There are barriers regarding the uptake of these alternative fuels impeding shipping firms to switch to these new technologies. The main barriers regarding the adoption of alternative fuels in shipping are the costs of alternative fuels and the capital expenditures (capex) of the associated technology system. Also, availability and readiness of bunkering infrastructure of the alternative fuel in (all) attending harbours may be another barrier for adoption.

As stated in the fourth IMO GHG study, fuel prices for low- and zero-carbon fuels such as bio-FAME, ammonia and methanol are currently several factors higher than the conventional fossil fuels VLSFO and MGO. The prices of these fuels are expected to remain at least 200%-400% higher in 2030 (Faber, et al., 2020). As fuel cost is a major expense part in the total cost of ownership of a vessel, the large difference in fuel prices will remain a major barrier to switch from fossil fuels to the aforementioned low- and zero-carbon fuels. We have calculated additional operational-, capital expenditure, and total cost of ownership for a number of reference ships in Section 4.4, and this clearly demonstrates that low- and zero-carbon fuels are yet unable to cost effectively compete with conventional fuels in shipping.

Table 1 - Future fuel costs as assumed in 2030. Source: (Faber, et al., 2020)

Fuels	$ per GJ in 2030
VLSFO	$ 9
Bio-FAME	$ 20
e-Ammonia	$ 22
e-Methanol	$ 38

2.5 Conclusion

Neither business-as-usual developments nor the agreed goal-based measures will result in a significant uptake of low- and zero-carbon fuels in order to decrease the carbon intensity of the fleet, at least in the period up to 2030. In order to comply to requirements of the CII regulation, ships will improve their energy efficiency by fleet renewal, market driven energy savings technologies, and speed reductions. In this way, the required reductions in carbon intensity can be achieved. The main barrier to the uptake of low- and zero-carbon fuels is their high costs compared to conventional fuels.

3 The concept of fleet-level compliance

The basic concept of fleet-level compliance is that ships can either comply with the regulation individually or collectively. For the CII requirement, this means that ships either have to meet the required CII individually, of that a group of ships can collectively meet the required CII.

The requirement for the fleet would be set at a level where the collective CO_2 emissions will be less than or equal to the collective CO_2 emissions in case all ships had met the required CII. Mathematically, the requirement for a fleet of N ships would be:

$$\sum_{i=1}^{N} CO_{2_i} \leq \sum_{i=1}^{N} CII_i \,.\, DWT_i . D_i$$

Where

CO_{2_i} – the mass of CO_2 emitted by ship i

CII_i – the carbon intensity indicator of ship i

DWT_i – the deadweight tonnage of ship i

D_i – the distance travelled by ship i

By allowing some ships to overperform, and ensuring that overperformance has value, the chances are increased that some ships will use renewable fuels. It is a well known observation in environmental economics that when actors are required to meet a standard, R&D is focussed on lowering the costs of meeting the standard, whereas when actors are rewarding for overperformance, R&D is focussed on improving the cost-effectiveness of pollution abatement (Popp, 2003).

The proposal of the Danish Shipping is that DOC holders may choose to comply on fleet-level or on individual ship level. The DOC holder may decide to base the compliance of the DOC holder's fleet (or part of the fleet) rather than the performance of each individual ship provided they are under the same flag by following the steps below. The SEEMP must be updated to document whether the vessels under this DOC are considered as a fleet in relation to the IMO GHG reduction targets. A supporting document (a balance sheet) must be issued by the DOC holder and verified by RO detailing the fleet, the reduction status of each vessel, rating for each ship and the balance of the total fleet under the DOC.

Each DOC holder is required to calculate the CII for each vessel as well as the fleets total attained reductions in tonnes of CO_2. Records must be available for the annual verification by Flag State/RO. The DOC holder is responsible for obtaining approval from the Flag State in order to make use of the fleet compliance scheme. It is also responsible for achieving the mandatory reductions across the fleet under a given flag.

The flag State verifies compliance annually. The DOC holder and the verifier must keep record and calculations of the audit for a specific period of time. The result of the verification is documented in the SEEMP of which a copy must be present on each ship under the given flag including a copy of the verified balance sheet to be available for audits.

The role of Port State Control in a fleet-based compliance scheme is fully aligned with role under the individual compliance. The only difference is the verified balance sheet annexed to the SEEMP of each vessel.

4 Benefits of fleet-level compliance

4.1 Introduction

In order to analyse whether fleet-level compliance can result in an increased use of low- and zero-carbon fuels, this chapter analyses whether a business case can be made for the use of these fuels in a system of fleet-level compliance. This would be the case when the total cost of ownership of compliance for a fleet are equal to or lower than the total cost of ownership of ship level compliance.

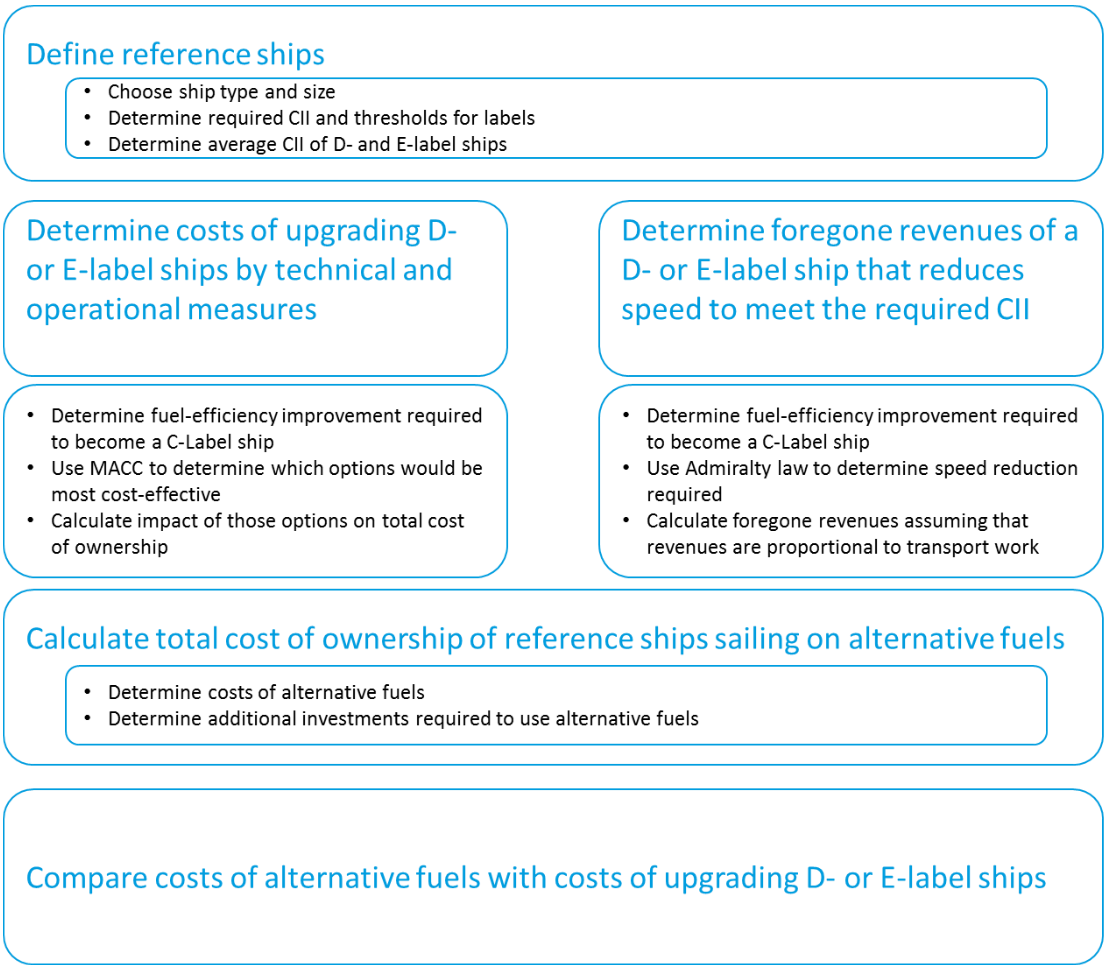
4.2 Methodology

The methodology comprises four steps:

1. In order to improve the transparency of the analysis, six reference ships are defined. For each of these ship types, the required CII is determined as well as the average CII for D and E label ships. This is a measure for the carbon intensity improvement these ships would need in order to comply individually.
2. The costs of complying individually are determined in two ways:
   - The marginal abatement cost curve of the fourth IMO Greenhouse gas study is used to identify technical and operational measures that result in carbon intensity improvements which are sufficient to become a C label ship. And
   - The speed reduction is calculated which is required to become a C label ship. A reduced speed results in less transport work, so the earnings of a ship decrease. This decrease is calculated.
3. The total costs of ownership of a ship sailing on FAME, e-ammonia and e-methanol are calculated.
4. The costs of using alternative fuels are compared with the costs of improving the label of a ship to analyse the composition of a fleet which would be required to make a business case for using alternative fuels.

Figure 1 presents a graphical presentation of the methodology.

Figure 1 - Methodology of determining the business case for the use of low- and zero-carbon fuels



4.2.1 Reference ships

The business case carried out in this study is performed for six different reference ships. We use reference ships from the three ship types which emit the largest amount of emissions: container ships, bulk carriers and tankers. For each of these three ship types we selected two different ship sizes, a relatively small one and a larger one.

The reference ships and their main characteristics are presented in more detail in Table 2. The average size, engine power, days at sea and speed are taken from the Fourth IMO GHG study 2020. (IMO, 2020). We assume throughout this analysis that these characteristics will remain constant over time.

In this report, we choose the AER as the CII.[2] For each ship, the CII reference value and the CII requirements for 2030 have been calculated in line with the draft guidelines as published in MEPC 76/7/5, choosing the option of supply-based measurement of 2030 target combined with flat reduction factors.

[2] The AER is defined as the mass of CO_2 emitted per ship per year per distance sailed per tonne of deadweight of the ship.

The 2019 DCS data have been used to categorise ships in prospective A, B, C, D and E labels for 2030, i.e. using the applicable boundary values for 2030. For each ship, the AER has been identified and compared with the required AER for that ship. For D and E label ships, the average deviation from the required AER has been calculated. For E ships, outliers have been omitted (defined as ships with an AER of two times the reference line or more).

Table 2 - Overview reference ships and their characteristics

Characteristics	Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small oil tanker	Large oil tanker
TEU or DWT	27,303 DWT	169,868 DWT	1,500 TEU (19,051 DWT)	17,250 TEU (179,871 DWT)	43,750 DWT	155,878 DWT
Size category	10,000-34,999 DWT	100,000-199,999 DWT	1,000-1,999 TEU	14,500-19,999 TEU	20,000-59,999 DWT	120,000-199,999 DWT
Avg. main engine power (kW)	5,941	16,741	12,083	60,202	8,975	17,446
Avg. design speed (kn)	13.8	14.5	19.0	20.2	14.6	15.1
Avg. days at sea	177	252	210	250	166	220
Avg. speed over ground at sea	11.0	11.2	13.4	16.5	11.2	11.4
CII reference value	8.32	2.65	16.17	5.42	7.80	3.61
Required AER in 2030	6.49	2.07	12.61	4.23	6.08	2.81
Average AER of D label ships as a % of required AER	112%	113%	113%	116%	118%	118%
Average AER of E label ships as a % of required AER	145%	141%	146%	138%	156%	150%

4.2.2 Carbon intensity of reference ships

We assume that the activity of the reference ships is not dependent on the CII label. This allows us to calculate the emissions of the C , D and E label ships. By dividing the emissions by the average fuel-based emissions factor of the 2018 fuel mix, according to the Fourth IMO Greenhouse gas Study, we arrive at the fuel consumption for each reference ship, as shown in Table 3.

Table 3 - emissions and fuel consumption of reference ships

Characteristics	Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small oil tanker	Large oil tanker
TEU or DWT	27,303 DWT	169,868 DWT	1,500 TEU (19,051 DWT)	17,250 TEU (179,871 DWT)	43,750 DWT	155,878 DWT
Size category	10,000-34,999 DWT	100,000-199,999 DWT	1,000-1,999 TEU	14,500-19,999 TEU	20,000-59,999 DWT	120,000-199,999 DWT
CII reference value	8.32	2.65	16.17	5.42	7.80	3.61
CII required	6.49	2.07	12.61	4.23	6.08	2.81
Category 'C' ship						
AER boundaries	6.10-6.88	1.94-2.19	11.85-13.49	3.97-4.52	5.66-6.57	2.62-3.04
Annual CO_2 emissions (tonnes)	8,275	23,766	16,224	75,239	11,875	26,394
Annual fuel consumption (tonnes)	2,647	7,601	5,189	24,062	3,798	8,441
Category 'D' ship						
AER boundaries	6.88-7.65	2.19-2.44	13.49-15.01	4.52-5.03	6.57-7.73	3.04-3.57
AER deviation with reference to a C ship (%)	112%	113%	113%	116%	118%	118%
Annual CO_2 emissions (tonnes)	9,283	26,881	18,375	86,977	13,955	31,133
Annual fuel consumption (tonnes)	2,969	8,597	5,876	27,816	4,463	9,957
Category 'E' ship						
AER boundaries	7.65	2.44	15.01	5.03	7.73	3.57
AER deviation with reference to a C ship (%)	145%	141%	146%	138%	156%	150%
Annual CO_2 emissions (tonnes)	11,997	33,566	23,630	103,903	18,472	39,604
Annual fuel consumption (tonnes)	3,837	10,735	7,557	33,229	5,908	12,666
Outliers (%)	6.7%	7.0%	8.6%	0.0%	17.2%	16.3%

4.3 Costs of improving D and E ships

This section assesses the costs of improving D and E labelled ships to the required CII. The cost assessments are done in two ways:

1. A techno-economic analysis of the capex and opex to improve the ships, using the marginal abatement cost curve from the Fourth IMO Greenhouse Gas Study. This method has the benefit of being able to identify the technical and operational options that ships will choose to meet the target. However, the MACC does not always contain a sufficient number of options to be able to bring every ship to a C label. Moreover, assumptions need to be made about the state of the ship which may not always be representative of actual D and E labelled ships. This assessment is presented in Section 4.3.1.
2. An analysis of the foregone revenues of ships if they reduce their speed to improve their CII. This method has the advantage that it is generic and can be applied to every ship, and that it will in all cases result in C labelled ships. However, assumptions have to be

made about the division of costs between the ship owner and the charterer. This assessment is presented in Section 4.3.2.

4.3.1 Technical and operational improvements

This section presents an assessment of the costs of improving D and E labelled ships to a C label by technical and operational improvements such as hull polishing, wind-assisted propulsion, engine tuning et cetera. In each case, the change in the total costs of ownership of a reference ship is calculated.

The method used to calculate the costs comprises seven steps.

1. For each reference ship, the emission reduction options are selected from the MACC of the Fourth IMO Greenhouse Gas Study which can be implemented by the ship.
2. Because the measures are applied to existing ships, the maximum lifetime of each option is capped at 10 years (several operational options have a shorter lifetime).
3. For each of the reference ships, the required efficiency improvements are determined on the basis of the information from Table 3.
4. The CE Delft MACC model is run in order to list the options in the order of their cost-effectiveness.
5. For each option, the change in annuitized capex and opex are determined.
6. The cost-effective options are disregarded because if shipping companies would have cost-effective options to improve the CII of their ships, it would be rational to implement those first before considering fleet-level compliance and the use of low- and zero-carbon fuels. The situations of shipping companies differ, and we assume that only shipping companies that have exhausted the cost-effective improvement options will consider fleet-level compliance.
7. For the remaining options, the change in cost of ownership is determined.

Table 4 presents for each ship the measures which would improve a D and an E labelled ship to a C labelled ship, alongside with the AER improvement and the change in the annual total cost of ownership, defined as the additional operational expenditures per year plus the annuity of the capital expenditures minus the fuel savings.

Two caveats are important to understand the table. First, that in this case we have calculated the change in total cost of ownership to get a ship to the threshold of the C label, rather than to the required CII, because the abatement potential of the selected measures was not large enough to improve ships to the required CII. None of the ships could reach the required CII due to the fact that cost-effective measures were not taken into account. As demonstrated in Annex B, without this restriction most reference ships could reach the required CII.

Second, the MACC from the Fourth IMO Greenhouse Gas Study assesses the abatement potential and costs for generalised ships. Not all measures may yield the same benefits or have the same costs for specific ships.

Table 4 - Costs of technical and operational improvements

Ship type		Measures D ship
Small bulk carrier	Measures	Hull coating, common rail upgrade, frequency converters & reduced auxiliary power usage
	CII improvement	5.7%
	Minimum required CII improvement	5.5%
	TCO change (USD/year)	55,724
Large bulk carrier	Measures	Electric engine control, reduced auxiliary power usage, frequency converters & hull coating
	CII improvement	7.9%
	Minimum required CII improvement	6.3%
	TCO change (USD/year)	135,502
Small container ship	Measures	Reduced auxiliary power usage, common rail upgrade & frequency converters
	CII improvement	4.0%*
	Minimum required CII improvement	5.5%
	TCO change (USD/year)	54,725
Large container ship	Measures	Frequency converters
	CII improvement	3.0%*
	Minimum required CII improvement	7.4%
	TCO change (USD/year)	27,954
Small oil tanker	Measures	Common rail upgrade, frequency converters & solar panels
	CII improvement	2.9%*
	Minimum required CII improvement	8.1%
	TCO change (USD/year)	203,497
Large oil tanker	Measures	Hull coating, frequency converters & solar panels
	CII improvement	5.2%*
	Minimum required CII improvement	8.4%
	TCO change (USD/year)	245,538

Note: *these ships do not meet the minimum threshold for C label.

4.3.2 Slow steaming

Reduction of the operational speed can also be used to improve the carbon intensity of a ship. Speed reduction also reduces the amount of transport work that a ship can provide. This results in a loss of revenue. In this section we study the necessary speed reduction to upgrade a D or E ship to a C ship and the revenue lost by taking this measure for each of the reference ships.

The Fourth IMO GHG study 2020 provides data regarding the average speed of different ship types and sizes at sea and the corresponding CO_2 emissions. We assume that the reference ships operate at this speed, regardless of their label. Subsequently we calculate for each reference ship the required speed reduction to upgrade a Category D or E ship to a Category C ship, taking into account that there is approximately a quadratic relation between speed and emissions per tonne-mile or CII (MEPC 62/INF.7).

Transport work is reduced by the same proportion as speed. We assume that the relative loss of transport work is equal to the relative loss of income. We use the time charter rates corresponding to the reference ships as a measure of the income a ship generates.
The freight rates fluctuate greatly per ship type, per period and per type of contract (time charter versus spot market). This study has used the average value of a one year time charter contract over the last ten years according to Clarksons. For large container ships, a time charter rate is not available from this source. Therefore, we have assumed it to be US$ 70,000 per day.

The revenue lost by slow steaming depends on the division of costs between the charterer and the ship owner. This section assumes that the fuel costs are borne by the charterer and that the time charter rate is independent of the fuel-efficiency of a ship. The total costs of ownerships of slow-steaming ships are reported in Annex C. The loss of revenues resulting from the speed reduction required to upgrade E ships to C-ships are presented in Table 5, and results of D ships to C ships in Table 6.

Table 5 - Required speed reduction for CII E category ships

Ships	Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small oil tanker	Large oil tanker
TEU or DWT	27,303 DWT	169,868 DWT	1,500 TEU (19,051 DWT)	17,250 TEU (179,871 DWT)	43,750 DWT	155,878 DWT
CII required (C ship)	6.49	2.07	12.61	4.23	6.08	2.81
Deviation E ships	145%	141%	146%	138%	156%	150%
Required improvement of AER (%)	31%	29%	31%	28%	36%	33%
Required speed reduction (%)	17%	16%	17%	15%	20%	18%
Original yearly ton mileage (x10^6)	1,276	11,506	1,287	17,807	1,952	9,383
Yearly loss of ton mileage after speed reduction (x10^6)	216	1,824	221	2,654	387	1,723
Historical daily charter costs	$ 8,400	$ 14,800	$ 8,400	$ 70,000	$ 14,300	$ 22,600
Yearly revenue loss after speed reduction	$ 520,000	$ 856,500	$ 525,500	$ 3,808,000	$ 1,034,600	$ 1,514,900

Source: historical daily charter rates are from Clarksons Shipping Intelligence Network.

The required improvement in AER for the E category reference ships lie between 28 and 36%. The required speed reduction lies consequently between 15 and 20%. We observe that E category small oil tankers have the largest deviation of AER to the required C category CII. The required speed reduction results in a significant loss in ton mileage per year for each reference ship. The yearly loss in revenue for upgrading an E ship to a C ship using speed reduction is $ 520,000 for small bulk ships to $ 3,808,000 for large container ships.

Table 6 - Required speed reduction for CII D category ships

Ships	Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small tanker	Large tanker
TEU or DWT	27,303 DWT	169,868 DWT	1,500 TEU (19,051 DWT)	17,250 TEU (179,871 DWT)	43,750 DWT	155,878 DWT
CII required (C ship)	6.49	2.07	12.61	4.23	6.08	2.81
Deviation D ships	112%	113%	113%	116%	118%	118%
Required improvement of AER (%)	11%	12%	12%	14%	15%	15%
Required speed reduction (%)	6%	6%	6%	7%	8%	8%
Original yearly ton mileage ($x10^6$)	1,276	11,506	1,287	17,807	1,952	9,383
Yearly loss of ton mileage after speed reduction ($x10^6$)	71	687	78	1,245	151	744
Historical daily charter costs	$ 8,400	$ 14,800	$ 8,400	$ 70,000	$ 14,300	$ 22,600
Yearly revenue loss after speed reduction	$ 172,000	$ 324,000	$ 185,000	$ 1,787,00	$ 405,000	$ 655,000

Source: historical daily charter rates are from Clarksons Shipping Intelligence Network.

The required improvement in AER for the D category reference ships lie between 11 and 15%. The required speed reduction lies consequently between 6 and 8%. We observe that D category oil tankers have the largest deviation of AER to the required C category CII. The yearly loss in revenue for upgrading a D ship to a C ship using speed reduction ranges from $ 172,000 for small bulk ships to $ 1,787,000 for large container ships.

4.4 Costs of using low- and zero-carbon fuels

This section presents the results of the cost calculations of a reference ship sailing on bio-FAME, e-ammonia and e-methanol. For this, we assume that the ship sails the same distance as the average similar ship in 2018 according to the Fourth IMO GHG Study. In order to compare the cost effectiveness of using low- and zero-carbon fuelled ships, we will also calculate the costs for the reference ships on very low sulphur fuel oil (VLSFO) as the baseline cost.

We calculate the additional operational expenditure (OPEX), subdivided into fuel costs, and bunkering and M&R costs. Furthermore, we calculate the additional capex for newbuilt ships and the additional total cost of ownership (TCO). All these costs are yearly occurring costs. The additional costs are on top of the baseline costs of the VLSFO reference ship. In Table 7 the additional cost calculations for alternative fuelled reference ships are presented.

The capex per kW of the alternative fuel technologies are based on the costs predictions for these technologies as stated in (Horvath, et al., 2018). The cost of these alternative fuels is derived from the Marginal Abatement Cost analysis of the Fourth IMO GHG Study (Faber, et al., 2020), also stated in Table 1. The bunkering costs are derived from (TNO, 2020; Zomer, et al., 2020), and yearly maintenance & repair (M&R) cost is a percentage[3] of the total capex of the technology system.

Bio-FAME is a drop-in fuel and can be used in conventional internal combustion engines (ICE), bunkered like VLSFO and stored on board in conventional fuel tanks. Therefore, additional capex, bunkering and M&R costs are zero for all reference ships for this fuel. The additional TCO comprises therefore only of the additional fuel costs, which are still significant.

For the use of e-methanol, a conventional ICE can be used. However, the system requires additional safety procedures and components may need to be prepared for the use of this highly inflammable liquid. Therefore, the capex for e-methanol engines, storage and piping installation are slightly higher than that of a system for VLSFO/HFO. The energy price of e-methanol is currently and predicted to remain significantly higher than other fuels and the conventional VLSFO in the near future. This causes a reference ship sailing on e-methanol to have the highest additional costs of all alternative fuel options.

The reference ships on e-ammonia using an ICE have different engines, storage and piping technology than conventional ships. Because ammonia needs to be stored at or below the boiling point of -33°C, and because of its corrosiveness, the capex is much higher than for a conventional reference ship on VLSFO (see Table 8 for a comparison). Also fuel costs are high, resulting the total TCO of these ships to amount twice the TCO of the baseline ships.

Finally, e-ammonia on fuel cells are a technology not yet produced and applied at large scale, needing a higher level of market readiness to be a realistic alternative. Capex and opex of this technology are yet the highest of all considered alternatives.

3 1.5% for VLSFO, Bio-FAME, e-ammonia. 3% for e-methanol; see (Kim, et al., 2020).

Table 7 - Additional yearly costs for alternative fuelled reference ships (compared to reference ships using fuel VLSFO[4])

Ship type			Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small oil tanker	Large oil tanker
TEU or DWT			27,303 DWT	169,868 DWT	1,500 TEU (19,051 DWT)	17,250 TEU (179,871 DWT)	43,750 DWT	155,878 DWT
Fuel type	Total avg. fuel consumption (kton)		3.2	10.1	7	31	7.2	13.3
Bio-FAME	Additional CAPEX per year		$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
	Additional OPEX per year	Fuel costs	$ 1,543,000	$ 4,869,000	$ 3,375,000	$ 14,946,000	$ 3,471,000	$ 6,412,000
		Bunkering and M&R	$ 0	$ 0	$ 0	$ 0	$ 0	$ 0
	Additional TCO		**$ 1,543,000**	**$ 4,869,000**	**$ 3,375,000**	**$ 14,946,000**	**$ 3,471,000**	**$ 6,412,000**
e-Methanol	Additional CAPEX per year		$ 9,000	$ 25,000	$ 18,000	$ 89,000	$ 13,000	$ 26,000
	Additional OPEX per year	Fuel costs	$ 3,747,000	$ 11,826,000	$ 8,196,000	$ 36,297,000	$ 8,430,000	$ 15,573,000
		Bunkering and M&R	$ 68,000	$ 197,000	$ 125,000	$ 601,000	$ 116,000	$ 221,000
	Additional TCO		**$ 3,824,000**	**$ 12,048,000**	**$ 8,339,000**	**$ 36,987,000**	**$ 8,559,000**	**$ 15,820,000**
e-Ammonia (ICE)	Additional CAPEX per year		$ 290,000	$ 817,000	$ 546,000	$ 2,723,000	$ 438,000	$ 851,000
	Additional OPEX per year	Fuel costs	$ 1,837,000	$ 5,797,000	$ 4,018,000	$ 17,793,000	$ 4,132,000	$ 7,634,000
		Bunkering and M&R	$ 91,000	$ 270,000	$ 184,000	$ 866,000	$ 167,000	$ 316,000
	Additional TCO		**$ 2,218,000**	**$ 6,884,000**	**$ 4,748,000**	**$ 21,382,000**	**$ 4,737,000**	**$ 8,801,000**
e-Ammonia (Fuel cell)	Additional CAPEX per year		$ 351,000	$ 1,293,000	$ 930,000	$ 9,482,000	$ 576,000	$ 1,368,000
	Additional OPEX per year	Fuel costs	$ 1,837,000	$ 5,797,000	$ 4,018,000	$ 17,793,000	$ 4,132,000	$ 7,634,000
		Bunkering and M&R	$ 102,000	$ 353,000	$ 251,000	$ 2,047,000	$ 191,000	$ 406,000
	Additional TCO		**$ 2,290,000**	**$ 7,443,000**	**$ 5,199,000**	**$ 29,322,000**	**$ 4,899,000**	**$ 9,41,000**

4 For yearly costs of VLSFO reference ships see Annex A.1.

4.5 Fleet-level compliance examples

In this section we analyse how the business case for using low- and zero-carbon fuels can be improved by allowing for fleet-level compliance. Because the condition for fleet-level compliance is that the CO_2 emissions should not be higher than the CO_2 emissions of the fleet when every ship complies individually (as indicated in Chapter 3), we first calculate the amount of excess emissions that can be compensated by a ship sailing on bio-FAME or e-ammonia, the two low- and zero-carbon fuels with the smallest additional costs.[5] We assume that the bio-FAME ship is a reference ship which uses the same amount of energy as a CII C label ship. As the additional TCO only comprises the additional fuel cost, for this case we can either assume drop-in or new-build bio-FAME ship. The e-ammonia ship is also a reference ship of the CII C label for which the TCO also include additional costs for engine, fuel system and bunkering infrastructure. We compare this with the excess emissions of D and E level ships to calculate the maximum number of D or E level ships that can be pooled in a fleet of one ship sailing on bio-FAME or e-ammonia, under the condition that the total emissions are not higher than in the case of individual compliance of ships. Subsequently, we calculate the amount of money saved by not having to upgrade these ships to a C-level, and compare this with the additional total cost of ownership of the ships sailing on low- or zero-carbon fuels.

The results of the calculations are shown in Section 4.5.1 for D level ships of which the carbon intensity is improved to a C label by means of technical and operational improvements (note that it was not possible to bring E-level ships up to C level when we assumed that E level ships had exhausted their cost-effective options to improve the carbon intensity). Section 4.5.2 presents the calculation for D and E level ships which slow-steam to improve their label.

4.5.1 Fleet-compliance versus technical and operational improvements

Table 8 presents the calculations for D label bulk carriers which could be improved to C label by implementing technical and operational options. The D label small bulk carrier emits over 9000 tonnes CO_2 per year, a C label ship sailing on fossil fuels over 8000 tonnes. A ship using the same amount of energy in the form of bio-FAME emits a little over 1600 tonnes calculated over the lifecycle of the fuel; a ship sailing on e-ammonia zero tonnes. Thus, a ship sailing on bio-FAME creates over 6,600 tonnes of CO_2 room for excess emissions in a fleet; and a ship sailing on e-ammonia almost 8,300 tonnes. Therefore, a fleet comprising of 1 bio-FAME small bulk carrier per 6.57 D label small bulk carriers would emit the same amount of CO_2 as a fleet in which all ships have a C label.

Improving the carbon intensity of a small bulk carrier from D to C label by implementing technical and operational options would cost USD 56,000 per year. Multiplying this sum with the 6.57 ships per bio-FAME ship and comparing this amount with the additional TCO of a bio-FAME ship, we find that the saving in expenses covers almost a quarter of the additional TCO of a bio-FAME ship. For the e-ammonia ship, 21% of the additional costs are covered by allowing for fleet-wide comparison.

[5] It is assumed that bio-FABE emits 80% less than fossil fuels; and that e-ammonia has zero GHG emissions over its lifecycle.

Table 8 - Fleet-level compliance for D label ships compared to improving the label by implementing technical and operational options

Reference ships	Small bulk carrier	Large bulk carrier
TEU or DWT	27303 DWT	169868 DWT
CO_2 emissions (in ton) D ship	9,283	26,881
CO_2 emissions (in ton) C ship	8,275	23,766
CO_2 emission reduction	1,008	3,116
Max no. of D ships per bio-FAME ship for C-cat. Compliance	6.57	6.10
Max no. of D ships per e-Ammonia ship for C-cat. Compliance	8.21	7.63
Business case		
Revenue loss per slow steaming D ship	$ 56,000	$ 136,000
Additional TCO bio-FAME ref. ship	$ 1,543,000	$ 4,869,000
Additional TCO e-ammonia ref. ship	$ 2,217,000	$ 6,883,000
Business case of bio-FAME ship in pooled compliance	$ 1,177,000	$ 4,043,000
Business case of e-Ammonia ship in pooled compliance	$ 1,760,000	$ 5,850,000
Share of additional costs bio-FAME ship	0.24	0.17
Share of additional costs e-Ammonia ship	0.21	0.15

Note: this analysis only includes bulk carriers with a D label because these are the only reference ships that can be improved to C label by implementing technical and operational options under the assumptions mentioned in Section 4.3.1.

4.5.2 Fleet-compliance versus slow steaming

This section presents similar calculations as the previous one. Table 9 shows that fleet-level compliance of E label ships would generate funds which are able to cover 6 to 60% of the additional costs of a sufficient number of ships sailing on low- and zero-carbon fuels so that the collective CO_2 emissions would be the same as when all ships comply individually. Table 10 presents the same calculation for D label ships.

Table 9 - Business case for fleet-compliance of E category ships, compared to slow steaming

Reference ships	Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small tanker	Large tanker
TEU or DWT	27303 DWT	169868 DWT	1500 TEU	17250 TEU	43,750 DWT	155878 DWT
CO_2 emissions E ships (tonnes)	11,997	33,566	23,630	103,903	18,472	39,604
CO_2 emissions C ship (tonnes)	8,275	23,766	16,224	75,239	11,875	26,394
CO_2 emission reduction (tonnes)	3,721	9,800	7,406	28,664	6,597	13,210
Max no. of E ships per Bio-FAME ship for C-cat. compliance	1.78	1.94	1.75	2.10	1.44	1.60
Max no. of E ships per e-Ammonia ship for C-cat. compliance	2.22	2.43	2.19	2.62	1.80	2.00
Business case						
Revenue loss per slow steaming E ship	$ 520,000	$ 856,000	$ 526,000	$ 3,808,000	$ 1,035,000	$ 1,515,000
Additional TCO bio-FAME ref. ship	$ 1,543,000	$ 4,869,000	$ 3,375,000	$ 14,946,000	$ 3,471,000	$ 6,412,000
Additional TCO e-ammonia ref. ship	$ 2,217,000	$ 6,883,000	$ 4,748,000	$ 21,381,000	$ 4,737,000	$ 8,801,000
Business case of bio-FAME ship in pooled compliance	$ 619,000	$ 3,208,000	$ 2,454,000	$ 6,949,000	$ 1,981,000	$ 3,991,000

Reference ships	Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small tanker	Large tanker
Business case of e-Ammonia ship in pooled compliance	$ 1,062,000	$ 4,806,000	$ 3,597,000	$ 11,385,000	$ 2,875,00	$ 5,774,000
Share of additional costs bio-FAME ship	0.60	0.21	0.27	0.07	0.22	0.13
Share of additional costs e-Ammonia ship	0.52	0.18	0.24	0.06	0.20	0.12

One small bulk carrier bio-FAME ship can compensate in a fleet-compliance situation for the emissions of 1.78 similar bulk carriers on VLSFO to reach a CII C label.

The business case in pooled compliance indicates the excessive costs of fleet-compliance (per year) compared to the slow steaming option to comply to the CII C label requirement.

Table 10 - Business case for fleet-compliance of D category ships, compared to slow steaming

Reference ships	Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small tanker	Large tanker
TEU or DWT	27303 DWT	169868 DWT	1500 TEU	17250 TEU	43,750 DWT	155878 DWT
CO_2 emissions E ships (tonnes)	11,997	33,566	23,630	103,903	18,472	39,604
CO_2 emissions C ship (tonnes)	8,275	23,766	16,224	75,239	11,875	26,394
CO_2 emission reduction (tonnes)	3,721	9,800	7,406	28,664	6,597	13,210
Max no. of E ships per bio-FAME ship for C-cat. compliance	6.57	6.10	6.03	5.13	4.57	4.45
Max no. of E ships per e-Ammonia ship for C-cat. compliance	8.21	7.63	7.54	6.41	5.71	5.57
Business case						
Revenue loss per slow steaming E ship	$ 172,000	$ 324,000	$ 185,000	$ 1,786,000	$ 405,000	$ 655,000
Additional TCO bio-FAME ref. ship	$ 1,543,000	$ 4,869,000	$ 3,375,000	$ 14,946,000	$ 3,471,000	$ 6,412,000
Additional TCO e-ammonia ref. ship	$ 2,217,000	$ 6,883,000	$ 4,748,000	$ 21,381,000	$ 4,737,000	$ 8,801,000
Business case of bio-FAME ship in pooled compliance	$ 414,000	$ 2,894,000	$ 2,260,000	$ 5,785,000	$ 1,621,000	$ 3,496,000
Business case of e-Ammonia ship in pooled compliance	$ 806,000	$ 4,414,000	$ 3,354,000	$ 9,930,000	$ 2,425,000	$ 5,155,000
Share of additional costs bio-FAME ship	0.73	0.41	0.33	0.61	0.53	0.46
Share of additional costs e-Ammonia ship	0.64	0.36	0.29	0.54	0.49	0.41

4.6 Conclusion

In several instances, improving the label of a ship raises the total cost of ownership. This can be either because a there are costs associated with implementing technical and operational improvements, or because reducing speed reduces the earnings of ships.

If there is a possibility to comply with the CII regulation at a fleet-level, in addition to the possibility of complying on an individual basis, not all ships have to achieve the required CII, and this would fee up funds for improving ships which can then be used to invest in ships sailing on low- and zero-carbon fuels.

The generalised cases presented in this chapter show that fleet-level compliance can contribute to the business case for investing in low- and zero-carbon fuelled ships. The share of the additional costs of low- and zero-carbon fuels varies per ship type. In a fleet of D level ships, 30-70% of the additional costs of sailing on low- and zero-carbon fuels can be recovered by not investing in the improvement of the CII of non-compliant ships, while collectively emitting the same amount of CO_2. For a fleet of E level ships, the share is lower at 5-60%. The lower share is due to the fact that more emissions have to be compensated for E ships.

In the cases analysed here, fleet-level compliance is more costly than compliance of individual ships. However, shipping companies may derive other benefits from using low- and zero-carbon fuels which may result in a positive business case. Moreover, this analysis focusses on generalised ships. It is possible that for some fleets, the cost of improving ships may be larger.

5 Conclusion

Fleet-level compliance can help to improve the business case for investing in low- and zero-carbon fuels. Fleet-level compliance frees up money that would be required to improve the CII of D and E labelled ships or prematurely retire them and uses this money to cover the additional costs of using low- and zero-carbon fuels. Currently, there are very few ways in which to cover the additional costs of low- and zero-carbon fuels and consequently, the projections of the use of these fuels are low.

The case-study analysis finds that fleet-level compliance can contribute to the business case for investing in low- and zero-carbon fuelled ships. In the best cases, over 70% of the additional costs of using low- and zero-carbon fuels can be covered by not investing in the improvements of other ships in the fleet (in the worst case, it is about 5%). The total emissions of the fleet will then be the same as when all ships would have had a C label. This would be an improvement over the current situation, in which it is hard to make a case for using low- and zero-carbon fuels.

Fleets of 2 to 3 ships or more can help the business case for ships sailing exclusively on low- and zero-carbon fuels. Taking into account that in some cases fuels can be blended with conventional fuels, fleet-level compliance could be an option for many shipping companies.

In reality, investments to bring ships to a C-level or foregone revenues may be higher or lower than those estimated here. When the costs are higher, the business case for investing in ships sailing on low- and zero-carbon fuels will improve. This will further encourage the uptake of these fuels and have positive impacts on the development of technology, fuel production and bunkering infrastructure.

Without fleet-level compliance or other incentives to invest in low- and zero-carbon fuels in this decade, the uptake of these fuels will not increase, thus jeopardizing meeting the levels of ambition which IMO has agreed on.

Fleet-level compliance does not have an impact on the total emissions of the fleet and does not jeopardize meeting the levels of ambition of the initial strategy because it can be designed in a way that requires the total CO_2 emissions of the fleet to be equal to or less than when all ships would comply individually.

A TCO of VLSFO fuelled reference ships

Table 11 - Yearly costs for conventional VLSFO fuelled reference ships

Ship type		**Small bulk carrier**	**Large bulk carrier**	**Small container ship**	**Large container ship**	**Small oil tanker**	**Large oil tanker**
TEU or DWT		27,303 DWT	169,868 DWT	1,500 TEU (19,051 DWT)	17,250 TEU (179,871 DWT)	43,750 DWT	155,878 DWT
Total avg. fuel consumption (kton)		**3.2**	**10.1**	**7.0**	**31.0**	**7.2**	**13.3**
CAPEX per year		$ 269,000	$ 758,000	$ 456,000	$ 2,272,000	$ 406,000	$ 790,000
OPEX per year	VLSFO Fuel costs	$ 1,102,000	$ 3,478,000	$ 2,411,000	$ 10,676,000	$ 2,479,000	$ 4,580,000
	Bunkering and M&R	$ 56,000	$ 161,000	$ 100,000	$ 486,000	$ 92,000	$ 176,000
TCO per year		$ 1,427,000	$ 4,398,000	$ 2,966,000	$ 13,433,000	$ 2,978,000	$ 5,546,000

B Change in TCO of technical and operational measures

Table 12 shows the impacts of Technical and operational carbon-intensity improvement options on the CII and TCO of the reference ships. It identifies the most cost-effective measures. In contrast to Table 4, the options in Table 12 are all options included in the Fourth IMO GHG Study MACC, and not only the costly ones.

Table 12 - Technical and operational carbon-intensity improvement options and their impact on the CII and TCO

Ship type		Measures D ship	Additional Measures E ship
Small bulk carrier	Measures	Hull hydro blasting, propeller polishing & optimization water flow hull openings	Hull hydro blasting, propeller polishing, optimization water flow hull openings, propeller boss cap fins, air lubrication, hull coating, common rail upgrade, frequency converters, reduced auxiliary power usage & exhaust gas boilers on auxiliary engines
	CII improvement	11.6%	22.4%*
	Required CII improvement	10.9%	31.0%
	TCO change (USD/year)	-77,608	-26,901
Large bulk carrier	Measures	Hull hydro blasting, propeller polishing, optimization water flow hull openings & propeller boss cap fins	Hull hydro blasting, propeller polishing, optimization water flow hull openings, propeller boss cap fins, wind engine (Flettner Rotor), air lubrication, electric engine control, reduced auxiliary power usage & frequency converters
	CII improvement	13.4%	29.8%
	Required CII improvement	11.6%	29.2%
	TCO change (USD/year)	-183,947	-153,264
Small container ship	Measures	Hull hydro blasting, propeller polishing, optimization water flow hull openings & exhaust gas boilers on auxiliary engines	Hull hydro blasting, propeller polishing, optimization water flow hull openings, exhaust gas boilers on auxiliary engines, air lubrication, propeller boss cap fins, hull coating, reduced auxiliary power

Ship type		Measures D ship	Additional Measures E ship
			usage, common rail upgrade & frequency converters
	CII improvement	13.1%	25.1%*
	Required CII improvement	11.7%	31.3%
	TCO change (USD/year)	-218,208	-257,365
Large container ship	Measures	Hull hydro blasting, propeller polishing, exhaust gas boilers on auxiliary engines, optimization water flow hull openings & reduced auxiliary power usage	Hull hydro blasting, propeller polishing, exhaust gas boilers on auxiliary engines, optimization water flow hull openings, reduced auxiliary power usage, propeller boss cap fins, air lubrication, electric engine control, hull coating & frequency converters
	CII improvement	13.6%	26.6%*
	Required CII improvement	13.5%	27.6%
	TCO change (USD/year)	-1,416,158	-2,094,859
Small oil tanker	Measures	Steam plant operation improvements & hull hydro blasting	Steam plant operation improvements, hull hydro blasting, propeller polishing, optimization water flow hull openings, propeller boss cap fins, exhaust gas boilers on auxiliary engines, air lubrication, reduced auxiliary power usage, hull coating, common rail upgrade, frequency converters & solar panels
	CII improvement	15.1%	33.9%*
	Required CII improvement	14.9%	35.7%
	TCO change (USD/year)	-231,362	-192,150
Large oil tanker	Measures	Steam plant operation improvements, hull hydro blasting & propeller polishing	Steam plant operation improvements, hull hydro blasting, propeller polishing, optimization water flow hull openings, propeller boss cap fins, exhaust gas boilers on auxiliary engines, reduced auxiliary power usage, air lubrication, wind engine (Flettner Rotor), electric engine control & hull coating
	CII improvement	15.6%	36.0%
	Required CII improvement	15.2%	33.4%
	TCO change (USD/year)	-451,018	-742,375

C Total cost of ownership of slow-steaming ships

Table 13 and Table 14 present the TCO of ships that reduce their speed to meet the CII requirement for 2030. In contrast to Table 5 and Table 6, these tables include the fuel cost savings.

Table 13 - TCO of slow E category steaming ships

Reference ships	Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small tanker	Large tanker
TEU or DWT	27303 DWT	169868 DWT	1500 TEU	17250 TEU	43,750 DWT	155878 DWT
Fuel cost savings E ships	$ 410,000	$ 1,079,000	$ 816,000	$ 3,157,000	$ 727,000	$ 1,455,000
Revenue loss D ships	$ 520,000	$ 856,000	$ 526,000	$ 3,808,000	$ 1,035,000	$ 1,515,000
Balance E ships	$ -110,000	$ 223,000	$ 290,000	$ -651,000	$ -308,000	$ -60,000

Table 14 - TCO of slow D category steaming ships

Reference ships	Small bulk carrier	Large bulk carrier	Small container ship	Large container ship	Small tanker	Large tanker
TEU or DWT	27303 DWT	169868 DWT	1500 TEU	17250 TEU	43,750 DWT	155878 DWT
Fuel cost savings D ships	$ 111,000	$ 343,000	$ 237,000	$ 1,293,000	$ 229,000	$ 522,000
Revenue loss D ships	$ 172,000	$ 324,000	$ 185,000	$ 1,786,000	$ 405,000	$ 655,000
Balance D ships	$ -61,000	$ 19,000	$ 52,000	$ -494,000	$ -176,000	$ -133,000