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“IMPLICATIONS OF IMO EEXI COMPLIANCE AND CARBON INTENSITY REDUCTION IN SHIPPING OPERATIONS”

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Abstract

The aim of the present research is to analyze the two new IMO indexes, the EEXI and CII, as well as the implications of which will affect the operational processes of a shipping company and the efficiency of the ship. Firstly, this paper describes the main Greenhouse Gases and their impact to the environment, as well as the contribution of Shipping Industry in the worldwide Greenhouse Gas levels. Furthermore, the research presents the legislations of EEXI and CII, which oblige all ships over 5,000 GT to meet new requirements in technical and operational levels. In addition, the paper demonstrates EEXI and CII calculations for two Ultramax bulk carriers which do not comply with the new regulations and their shipowners are obliged to proceed with mitigation measures. Moreover, based on the data resulting from the calculations, this research analyses the challenges that shipowners will need to face in the near future, such as the legal aspect and the relation of the shipowner with the charterer. Finally, the paper presents some efficient and alternative green methods of reducing CO2 emissions from shipping, such as Alternative Fuels, Wind Propulsion and Waste Heat Recovery Systems.

Περίληψη

Στόχος της παρούσας έρευνας είναι η ανάλυση των δύο νέων δεικτών IMO, των EEXI και CII, καθώς και οι επιπτώσεις των οποίων θα επηρεάσουν τις λειτουργικές διαδικασίες μιας ναυτιλιακής εταιρείας και την αποτελεσματικότητα του πλοίου. Αρχικά, η παρούσα εργασία περιγράφει τα κύρια αέρια θερμοκηπίου και τις επιπτώσεις τους στο περιβάλλον, καθώς και τη συμβολή της ναυτιλιακής βιομηχανίας στα παγκόσμια επίπεδα αερίων θερμοκηπίου. Επιπλέον, η έρευνα παρουσιάζει τις νομοθεσίες των EEXI και CII, οι οποίες υποχρεώνουν όλα τα πλοία άνω των 5.000 GT να πληρούν νέες απαιτήσεις σε τεχνικό και λειτουργικό επίπεδο. Στη συνέχεια, η εργασία παρουσιάζει τους υπολογισμούς EEXI και CII για δύο πλοία μεταφοράς χύδην φορτίου, τύπου Ultramax, που δεν συμμορφώνονται με τους νέους κανονισμούς και οι πλοιοκτήτες υποχρεούνται να προχωρήσουν σε μέτρα μετριασμού. Επιπλέον, με βάση τα στοιχεία που προκύπτουν από τους υπολογισμούς, η παρούσα έρευνα αναλύει τα συμπεράσματα σχετικά με τις προκλήσεις που θα χρειαστεί να αντιμετωπίσουν οι πλοιοκτήτες στο άμεσο μέλλον, όπως οι νέες νομικές διαδικασίες των ναυλοσυμφώνων και η σχέση του πλοιοκτήτη με τον ναυλωτή. Τέλος, η εργασία παρουσιάζει ορισμένες εναλλακτικές πράσινες μεθόδους μείωσης των εκπομπών CO2, όπως τα Ενναλακτικά Καύσιμα, η χρήση της αιολικής ενέργειας και τα Συστήματα Ανάκτησης Απορριπτώμενης Θερμότητας.

Λέξεις – Κλειδιά

EEXI;CII;IMO;Decarbonization

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Abbreviations

CH_4: Methane

CII: Carbon Intensity Indicator

CO_2: Carbon Dioxide

DCS: Data Collection System

DWT: Dead Weight Tonnage

EU: European Union

EEOI: Energy Efficiency Operational Indicator

EEDI: Energy Efficiency Design Index

EEXI: Energy Efficiency Existing Ship Index

EPL: Engine Power Limitation

GHG: Greenhouse Gas

GWP: Global Warming Potential (A term used to measure how much energy 1 ton of a gas will absorb over a certain amount of time compared to 1 ton of carbon dioxide (CO2)) [1]

GT: Gross Tonnage

HFCs: Hydrofluorocarbons (any of a range of organic compounds containing hydrogen, fluorine, and carbon. HFCs are manufactured artificially and are predominantly utilised as refrigerants.) [2]

HFO: Heavy Fuel Oil

IAPP: International Air Pollution Prevention

IMO: International Maritime Organisation

ICE: Internal Combustion Engine

MARPOL: The International Convention for the Prevention of Pollution from Ships

MECP: Marine Environment Protection Committee

MRV: Monitoring, Reporting, Verification

MGO: Marine Gas Oil

MDO: Marine Diesel Oil

N_2O: Nitrous Oxide

NF3: Nitrogen trifluoride

NH3: Ammonia

PFCs: Perfluorocarbons

PS: Poseidon Principles

SEEMP: Ship Energy Management Plan

SF6: Sulfur hexafluoride

UNCTAD: United Nations Conference for Trade and Development

LNG: Liquefied Natural Gas

WHR: Waste heat recovery system

1 Introduction

IMO has introduced ambitious new targets to reduce CO2 emissions, and shipowners have already started planning for compliance. Two new IMO indexes, the EEXI and CII will play a major role in pushing the shipping industry toward decarbonization. The IMO has set a goal to cut carbon intensity by 40% by 2030, and 50% by 2050, as part of its Greenhouse Gas Strategy for the shipping industry. MARPOL Annex VI was amended in June 2021 at MEPC 76, adding an Energy Efficiency Design Index for current vessels (EEXI), the Carbon Intensity Indicator (CII), and the enhanced Ship Energy Efficiency Management Plan (SEEMP). The requirements took effect on January 1st, 2023.

This study provides both theoretical and practical knowledge about the assessment and the compliance of EEXI and CII indexes. For that reason, a theoretical background of the greenhouse gas emissions is provided. The percentage that shipping operations currently contribute to the Global Warming Effect is also mentioned.

1.1 The GHG effect

Combating greenhouse gas (GHG) emissions is currently one of the world's most crucial challenges. The urgent need to adopt climate change mitigation measures to maintain global temperature rises below 1.5 degrees Celsius (in comparison to pre-industrial temperature rates of 13.9 °C) has become more apparent to politicians, scientists, and citizens from all over the world, since the current situation demands significant and realistic solutions [3].

The GHG effect can be positive for the Earth’s climate as it maintains life on the planet by heating it to an average temperature of 15 degrees Celsius. However, since the beginning of the industrial revolution and the invention of coal-powered steam engines, human actions have significantly increased the quantity of greenhouse gases released into the atmosphere. The outcome of the excessive burning of fossil fuels is the rise of greenhouse gases that is drastically rising the planet's average temperature.

1.1.1 The main GHGs

Greenhouse gases are compounds that trap the heat within the Earth's atmosphere. The primary gases causing the greenhouse effect are:

1.1.1.1 Carbon dioxide (CO2)

CO_2 is a long-lasting gas that accounts for roughly 76% of all emissions caused by human activity. After being emitted, 40% of it remains into the atmosphere for up to 100 years, 20% for 1,000 years, and 10% can remain for up to 10,000 years. Between 1750 and 2011, carbon dioxide concentrations in the atmosphere are thought to have grown by 40%.

1.1.1.2 Methane (CH4)

Methane (CH4), which has been in the atmosphere for only around 10 years, has a much stronger warming effect than CO_2. When measured over a period of one hundred years, its impact on the warming of the planet is twenty-five times more significant than that of carbon dioxide. On a global basis, it is accountable for about 16% of GHG emissions. It is claimed that there was a 150 percent increase in the amount of methane in the atmosphere from the year 1750 to 2011.

1.1.1.3 Nitrous oxide (N2O)

On a time scale of 100 years, It has a global warming potential (GWP) that is three hundred times higher than that of carbon dioxide, and it stays in the atmosphere for around a century on average. It is responsible for around 6% of the world's emissions. Between 1750 and 2011, nitrous oxide concentrations have increased by 20%.

1.1.1.4 Fluorinated gases

Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3) are the four basic categories. Even though they are produced in much lesser amounts (they only make up about 2% of total GHG emissions), they trap a lot more heat. Additionally, they can remain in the atmosphere for up to tens of thousands of years.

1.1.1.5 Water vapor

Its atmospheric levels are warmed not directly by human activity, but by existing greenhouse gases. Warm air contains more water. In addition, since water vapor is a greenhouse gas, an increase in the amount of water generates an even higher absorption of heat [3].

1.1.2 The contribution of Shipping Industry in GHG

According to United Nations Conference for Trade and Development (UNCTAD), almost 80% of global trade by volume operates at sea. According to the findings of the 4th IMO GHG Study, the percentage of global greenhouse gas emissions caused by shipping has increased from 2.76 percent in 2012 to 2.89 percent in 2018. In 2020, the shipping industry produced 1.48 billion metric tons of CO2 annually, which is the same as placing 65 million new cars on the road [4].

Simpson Spence Young Shipbrokers Company supports that despite the tightening regulatory environment, worldwide shipping CO2 emissions rose 4.9% from 2020, surpassing 2019 levels and rebounding from 2020 Covid lows. The major reasons for that increase have been the improving post-covid economy as well as the increasing demand of goods and services all around the world. Also, the increased port congestion caused higher steaming speeds in some cases, increasing fuel consumption per ton-mile [13].

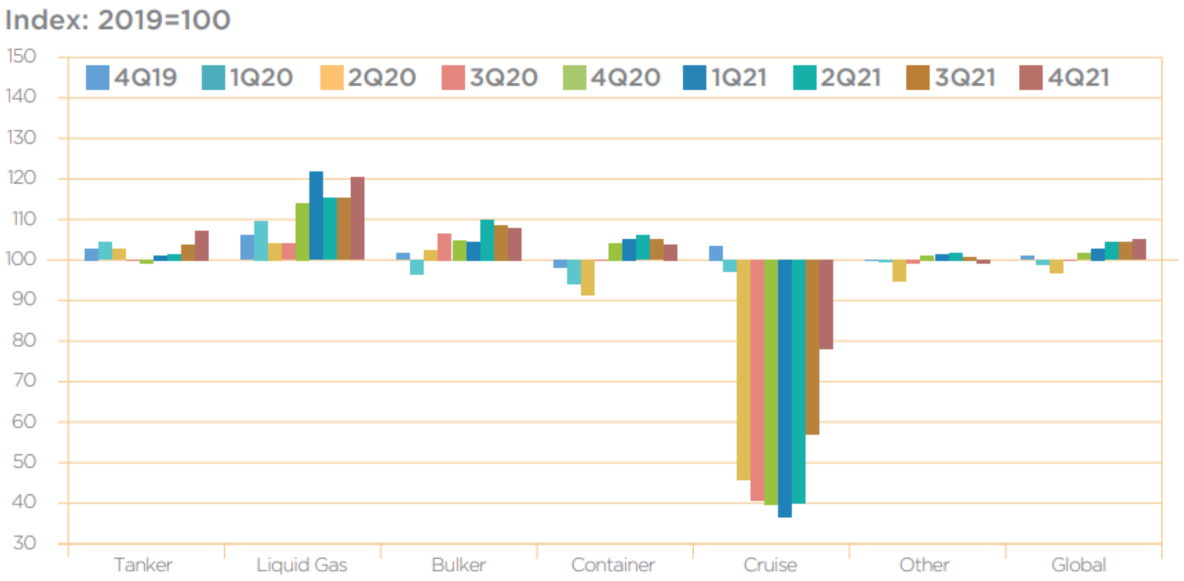


Figure 1.: Quarterly International Shipping CO2 Emissions [13]

The graphic summarizes current worldwide shipping emissions in comparison to 2019 levels. The fall in cruise ship operations, which is gradually recovering as global lockdowns have abated, appears to be the highlight at first glance. Liquid gas dominates on the CO2 emissions, as more gas capacity, high demand, and longer ton-mile trading all result in higher emissions. Due to a number of factors such as faster steaming speeds, lengthier trade routes, and increased port congestion, emissions from containerships and Bulk carriers have continued to rise as long as the demand for durable products is increasing. Last, by the time worldwide lockdowns loosened and transportation demand increased, tanker emissions began to climb again in the 2nd semester of 2021.

Table 1: Total shipping and voyage-based and vessel-based international shipping CO2 emissions 2012-2018 (million tons) [6]

Year	Global anthropogenic CO$_2$ emissions	Total shipping CO^2	Total shipping as a percentage of global	Voyage-based International shipping CO$_2$	Voyage-based International shipping as a percentage of global	Vessel-based International shipping CO$_2$	Vessel-based International shipping as a percentage of global
2012	34,793	962	2.76%	701	2.01%	848	2.44%
2013	34,959	957	2.74%	684	1.96%	837	2.39%
2014	35,225	964	2.74%	681	1.93%	846	2.37%
2015	35,239	991	2.81%	700	1.99%	859	2.44%
2016	35,380	1,026	2.90%	727	2.05%	894	2.53%
2017	35,810	1,064	2.97%	746	2.08%	929	2.59%
2018	36,573	1,056	2.89%	740	2.02%	919	2.51%

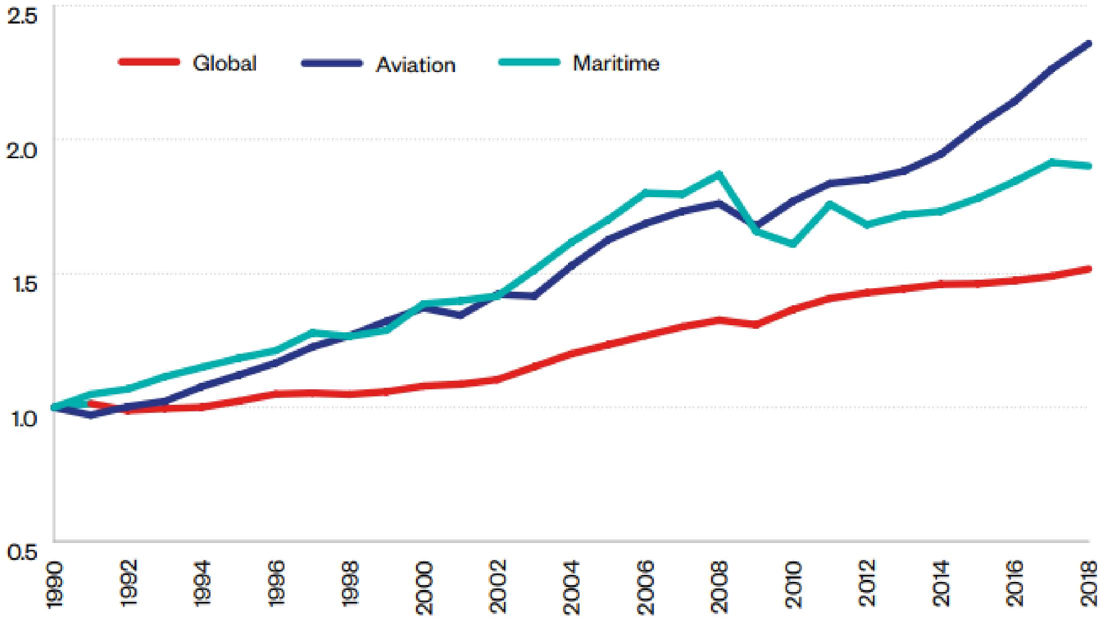


Figure 2: The development of global GHG emissions and emissions from international aviation and international maritime transport. [6]

International shipping is not governed by national laws, and its emissions are regulated by IMO and its signatory countries. Also, the European Union is another important player, which imposes additional regulations on vessels passing by the EU waters.

Companies can also be considered as significant stakeholders, and they are putting increased pressure on the international shipping industry to cut emissions, as freight emissions are counted as part of a company’s overall emissions under the GHG protocol (Scope 3 Emissions).

Under the Paris Agreement, states are required to reduce greenhouse gas emissions to keep global temperature increases below 1.5 degrees Celsius in order to prevent the worst consequences of climate change. The GHG Protocol was designed to aid governments and corporations in accounting for, reporting, and reducing emissions in response to a report that outlined a plan of actions to combat climate change, including the need for standardized monitoring of greenhouse gas (GHG) emissions. Scope 3 emissions are the outcome of activities by assets, which are not controlled or owned by the reporting corporation, but that the organization indirectly impacts in its value chain. [7]

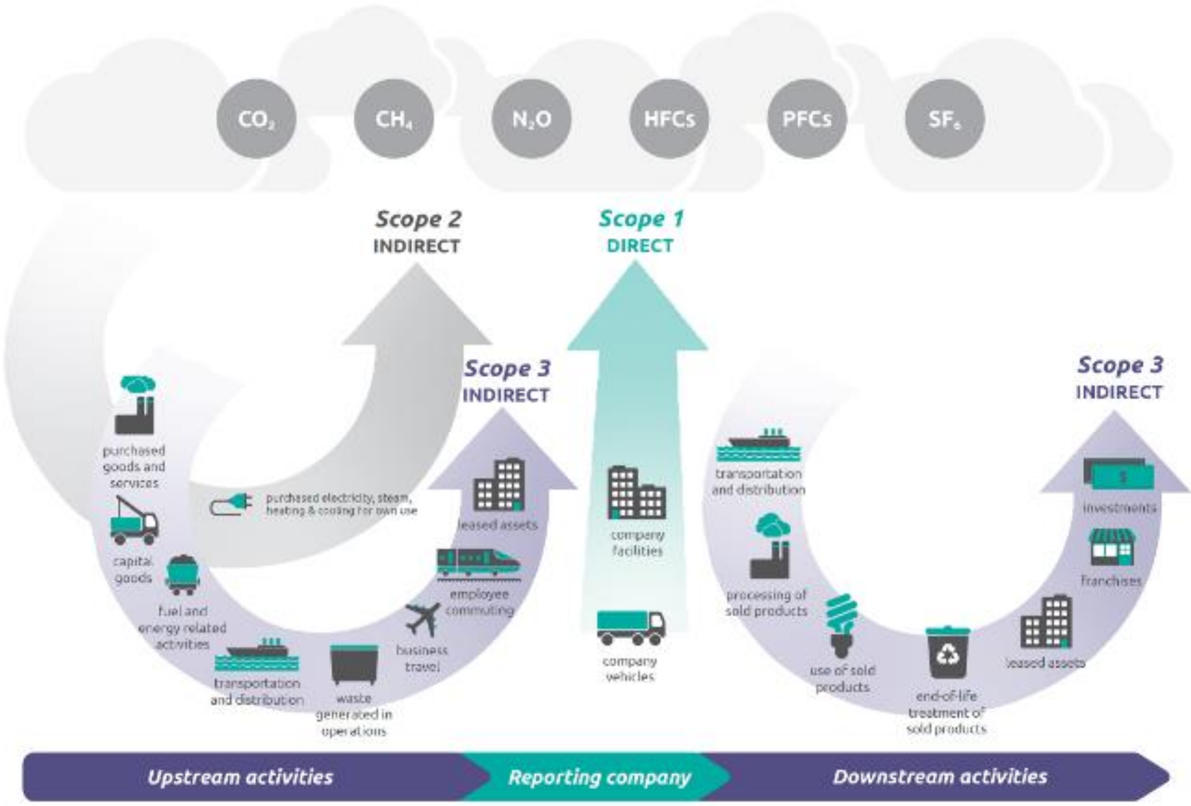
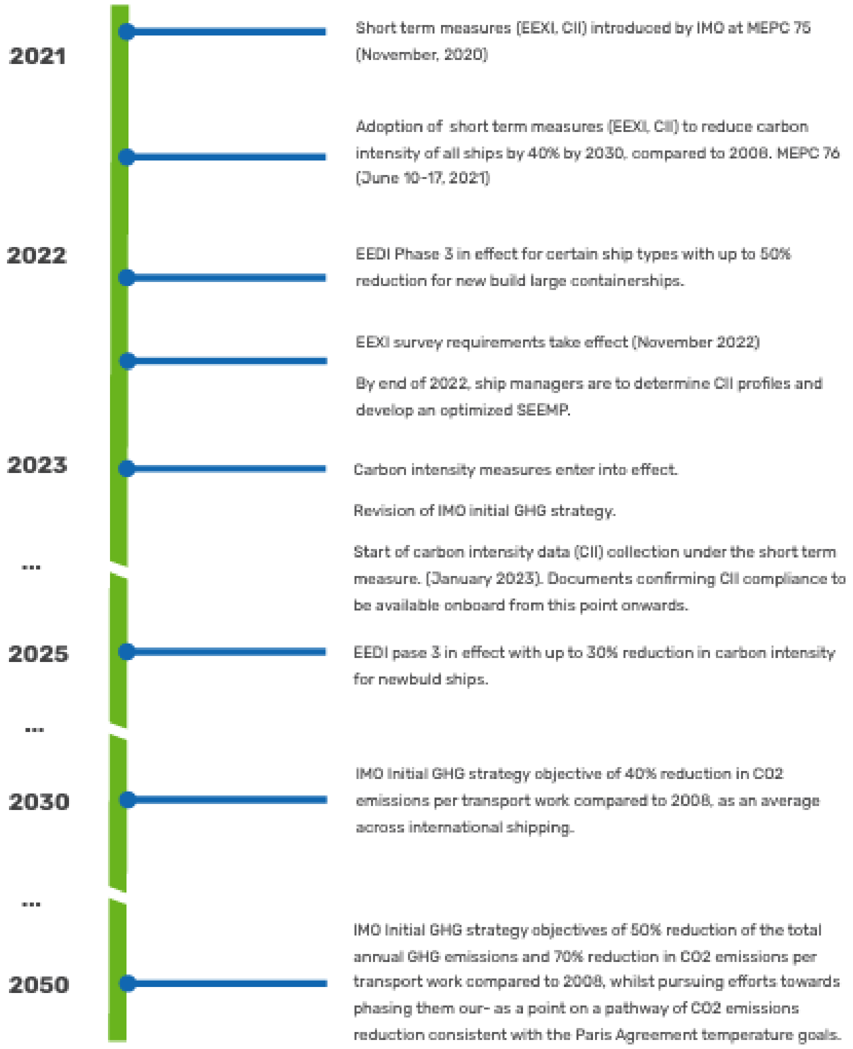


Figure 3: A summary of the GHG Protocol's scop es and emissions along the production process. [7]

1.2 New IMO Regulation

According to IMO’s Marine Environment Protection Committee (MEPC 76), which took place online from June 10 to June 17, 2021, the MEPC 76 decisions are separated in short-term, medium-term and long-term measures. Two metrics were produced by the IMO, one focusing on vessel’s design and the other on vessel’s operations. Similar to the present EEDI 2, which has been used for new vessels since 2013, the new EEXI design index applies to all ships. Additionally, the IMO has created the CII (Carbon Intensity Index) that is graded from "A" to "E" and is based on the Poseidon Principle's (PS) AER4 metric. CO2 / nautical mile divided by boat’s size is used for both EEXI and CII calculations. The primary difference is that the CII calculates CO2 emissions based on real vessel operations per year, whereas the EEXI evaluates emissions at a fixed engine rating. [4] In June of 2021, the 76th meeting of the IMO Marine Environment Protection Committee (MEPC 76) adopted additional revisions to MARPOL Annex VI. Measures aim to reduce CO2 emissions per transport work by at least 40 percent by 2030 and 70 percent by 2050 compared to 2008 levels. By implementing technological solutions, the EEXI regulatory framework intends to raise the energy efficiency of existing ships.



2021

Short term measures (EEXI, CII) introduced by IMO at MEPC 75 (November, 2020)

Adoption of short term measures (EEXI, CII) to reduce carbon intensity of all ships by 40% by 2030, compared to 2008. MEPC 76 (June 10-17, 2021)

2022

EEDI Phase 3 in effect for certain ship types with up to 50% reduction for new build large containerships.

EEXI survey requirements take effect (November 2022)

By end of 2022, ship managers are to determine CII profiles and develop an optimized SEEMP.

2023

Carbon intensity measures enter into effect.

Revision of IMO initial GHG strategy.

Start of carbon intensity data (CII) collection under the short term measure. (January 2023). Documents confirming CII compliance to be available onboard from this point onwards.

...

2025

EEDI pase 3 in effect with up to 30% reduction in carbon intensity for newbuld ships.

...

2030

IMO Initial GHG strategy objective of 40% reduction in CO2 emissions per transport work compared to 2008, as an average across international shipping.

...

2050

IMO Initial GHG strategy objectives of 50% reduction of the total annual GHG emissions and 70% reduction in CO2 emissions per transport work compared to 2008, whilst pursuing efforts towards phasing them our- as a point on a pathway of CO2 emissions reduction consistent with the Paris Agreement temperature goals.

Figure 4: CII, EEXI, and IMO actions after 2021 [8]

2 Literature Review

A part of the existing literature on EEXI and CII implementation is deeply reviewed in this chapter. This research pinpoints the issue’s general aspects, hypotheses, and disputes. It includes a synthesis of earlier studies as well as an appraisal of the general methodological approach, the legal framework and the economic factor in the usage of EEXI and CII regulations. This study analyzes prior studies both quantitatively and qualitatively, in order to discover the most appropriate solutions for compliance, effective vessel’s design, and operational energy efficiency, as well as the consequences of EEXI and CII compliance and its commercial and legal issues. In addition, the conducted research is based on studies in international scientific journals, which are analysing the impact of the EEXI and CII regulations on vessels and ship-owning companies.

2.1 Overview of EEXI Regulation

The aim of the present chapter is to analyze in detail the two new IMO indexes, the implications of which will affect the operational processes of a shipping company and the efficiency of the ship and to propose various alternative methods in order to enhance the above-referred indexes.

According to IMO’s Marine Environment Protection Committee (MEPC 76) [9], EEXI is defined as the quantity of CO_2 emissions from a vessel while the ship transfers one ton of cargo for one nautical mile. Vessels with 400 gross tons or more engaged in international voyages are subject to the EEXI regulations, and each ship's EEXI must be calculated regardless of when it was delivered. As the EEXI is the expansion of the EEDI for existing ships, the majority of procedures will remain the same as for the EEDI, except that there will be limited access to design data. Vessels must fulfill an Energy Efficiency Existing Ship Index (EEXI) based on a specified reduction factor (compared to the EEDI baseline, represented as a percentage), which will be presented later.

According to the above-referred source, a ship must take any necessary measures, for example the Engine Power Limitation (EPL) or by installing an energy-saving equipment, if it does not meet the requirements of EEXI. Until the first periodic survey of the IAPP (International Air Pollution Prevention) Certificate on or after January 1, 2023, ships delivered prior to that date must comply with the EEXI regulations. On the other hand, EEXI regulations must be followed at delivery for vessels delivered on or after January 1, 2023.

The EEXI regulations apply to vessels of 400 GT or more which are operating in international seawaters. Ships delivered on January 1, 2023 or after - when the EEXI regulations start - as well as ships delivered before that date, are subject to the regulations. Vessels that are delivered on January 1, 2023 and after, must at delivery adhere to both the EEDI and EEXI regulations [9].

Individual ships subject to EEXI regulations are to be assigned an energy efficiency index based on the Energy Efficiency Existing Ship Index (also referred as "Attained EEXI"). The Attained EEXI can also be determined by using the same formula as for the Attained EEDI. The last can be used instead of the Attained EEXI if the ship's Attained EEDI is equal than the allowed limit of the Attained EEXI (also referred as “Required EEXI”) or less [9].

As of 2023, vessels of certain capacity and above are subject to the regulations of EEXI and must adhere to the Required EEXI, which is the same as the Required EEDI. (However, as of 2023, the Required EEXI of some particular vessel types is a little laxer than the Required EEDI.) The average of the Attained EEDI for each vessel’s type in the EEDI (hereinafter referred to as the "EEDI Reference Line") is multiplied by the reduction factor designated for each vessel’s type and capacity to determine the Required EEXI [9].

If ship's Attained EEXI is higher than Required EEXI, the vessel must take corrective actions, for example: an EPL (Engine Power Limitation) or by installing an energy-saving device [9].

At delivery, vessels must adhere to both the EEDI and EEXI regulations if they are delivered on or after January 1, 2023. The International Energy Efficiency Certificate (hereinafter mentioned as the "IEE Certificate") will be issued once the survey has confirmed compliance with both regulations [9].

A survey (annual, intermediate, or periodic survey) of the International Air Pollution Prevention Certificate (usually mentioned as "IAPP Certificate") on January 1st 2023 and after will confirm compliance with the EEXI regulation for ships delivered prior to that date, and the IEE (International Energy Efficiency) Certificate will be issued once again [9].

2.1 Attained EEXI

According to MEPC76, each vessel subject to the EEXI requirements shall calculate its Attained EEXI in accordance with the "2021 GUIDELINES ON THE METHOD OF CALCULATION OF THE ATTAINED ENERGY EFFICIENCY EXISTING SHIP INDEX (EEXI)" (IMO Resolution MEPC.333(76), as amended). The Attained EEXI is calculated by using the same method as Attained EEDI. If the Attained EEDI is equivalent to or below the Required EEXI, it may be used as an alternative to the Attained EEXI [9].

$$\frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE} *\right) + \left(\left(\prod_{j=1}^{n} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME} **\right)}{f_i \cdot f_c \cdot f_l \cdot Capacity \cdot f_w \cdot V_{ref}}$$

2.1 Required EEXI

For the ships that fall into EEXI regulations, the attained EEXI shall be as follows:

$$\text{Attained EEXI} \leq \text{Required EEXI} = \left(1 - \frac{y}{100}\right) \bullet \text{EEDI reference line value}$$

y: EEXI Reduction Factor (percent) in relation to EEDI Reference Line

Table 2: Parameters for EEDI Reference Line Value Determination for Each Type Of vessel [9].

Vessel Type		**EEDI Reference Line**
Bulk carrier	DWT ≤ 279,000	961.79 x $DWT^{-0.477}$
	DWT > 279,000	961.79 x $279{,}000^{-0.477}$
Gas carrier		1120.00 x $DWT^{-0.456}$
Tanker		1218.80 x $DWT^{-0.488}$
Containership		174.22 x $DWT^{-0.201}$
General cargo ship		107.48 x $DWT^{-0.216}$
Refrigerated cargo carrier		227.01 x $DWT^{-0.244}$
Combination carrier		1219.00 x $DWT^{-0.488}$
Ro-ro cargo ship (vehicle carrier)	DWT/GT < 0.3	$(DWT/GT)^{-0.7}$ x 780.36 x $DWT^{-0.471}$
	DWT/GT ≥ 0.3	1812.63 x $DWT^{-0.471}$
Ro-ro cargo ship	DWT ≤ 17,000	1686.17 x D $WT^{-0.498}$
	DWT > 17,000	1686.17 x $17{,}000^{-0.498}$
Ro-ro passenger ship	DWT ≤ 10,000	902.59 x $DWT^{-0.381}$
	DWT > 10,000	902.59 x $10{,}000^{-0.381}$
LNG carrier		2253.7 x $DWT^{-0.474}$
Cruise passenger ship (having non-conventional propulsion)		170.84 x $GT^{-0.214}$

Table 3: Reduction Factors (in percentage) for the EEXI relative to the EEDI Reference Line [9].

Ship type	**Size**	**EEXI Reduction factor** **X (%)**

Bulk carrier	200,000 DWT and above	15
	20,000 – 200,000 DWT	20
	10,000 – 20,000 DWT	0-20*
Gas carrier	15,000 DWT and above	30
	10,000 – 15,000 DWT	20
	2,000 – 10,000 DWT	0-20*
Tanker	200,000 DWT and above	15
	20,000 – 200,000 DWT	20
	4,000 – 20,000 DWT	0 – 20*
Containership	200,000 DWT and above	50
	120,000 – 200,000 DWT	45
	80,000 – 120,000 DWT	35
	40,000 – 80,000 DWT	30
	15,000 – 40,000 DWT	20
	10,000 – 15,000 DWT	0 – 20*
General cargo ship	15,000 DWT and above	30
	3,000 – 15,000 DWT	0 – 30*
Refrigerated cargo carrier	5,000 DWT and above	15
	3,000 – 5,000 DWT	0 – 15*
Combination carrier	20,000 DWT and above	20
	4,000 – 20,000 DWT	0 – 20*
Ro-ro cargo ship (vehicle carrier)	10,000 DWT and above	15
Ro-ro cargo ship	2,000 DWT and above	5
	1,000 – 2,000 DWT	0 – 5*
Ro-ro passenger ship	1,000 DWT and above	5
	250 – 1,000 DWT	0 – 5*
LNG carrier	10,000 DWT and above	30
Cruise passenger ship (having non-conventional propulsion)	85,000 GT and above	30
	25,000 – 85,000 GT	0 – 30*

* Reduction factor to be linearly interpolated between the two values dependent upon ship size.

2.2 CII (Carbon Intensity Indicator)

After the completion of 2023 and after the completion of each succeeding calendar year, all vessels of 5,000 tons GT or more will have to calculate their yearly operational CII from January 1st until December 31st for the preceding calendar year. After the end of each calendar year and within three months time, the vessel must report its annual operational CII to its Classification Society.

The attained annual operational CII must be documented and compared to vessel’s required CII.

A scale operational carbon intensity rating will be provided, as per below:

- A, major superior;
- B, minor superior
- C moderate,
- D marginally inferior, or
- E unsatisfactory performance

The degree of performance would be documented in the vessel's Ship Energy Efficiency Management Plan (SEEMP).

A vessel receiving a rating of D or E for three consecutive years would be obliged to submit a corrective action plan outlining how the necessary index (C or above) would be obtained.

Administrations, port authorities, and other relevant parties are urged to offer incentives to ships with an A or B rating [10].

2.1 Attained CII

The Attained CII is computed by dividing the total mass of CO2 (M) released by the total transport work (W) performed in a particular calendar year.

$$CII = \frac{social\ cost\ of\ shipping\ activity}{social\ benefit\ of\ shipping\ activity} = \frac{total\ CO2\ emitted}{tranport\ work\ done}$$

2.1 Required CII

The required operational CII is calculated as per below:

$$\text{Required annual operational CII} = \left(1 - \frac{Z}{100}\right) \bullet \text{CII}_R$$

Z is the yearly reduction factor that ensures ongoing improvement of the vessel's operative carbon intensity within a fixed rating level; CIIR is the reference value. (ClassNK Marine GHG Certification Department, 2021)

CIIR = $a\ Capacity^{-C}$

Table 4: Parameters for calculating the 2019 CII reference line [9]

Vessel Type		Capacity	A	C
Bulk carrier	279.000 DWT	279.000	4745	0.622
	<279.000 DWT	DWT	4745	0.622
Gas carrier	≥ 65.000	DWT	14405E+7	2.071
	< 65.000 DWT	DWT	8104	0.639
Tanker		DWT	5247	0.610
Container Ship		DWT	1984	0.489
General Cargo Ship	DWT ≥ 20,000	DWT	31948	0.792
	DWT < 20,000	DWT	588	0.3885
Refrigerated cargo carrier		DWT	4600	0.557
Combination carrier		DWT	40853	0.812
LNG carrier	≥ 100,000 DWT	DWT	9.827	0

	≥ 65,000 DWT, but <100,000 DWT	DWT	14479E+10	2.673
	<65,000 DWT	65,000	14479E+10	2.673
Ro-ro cargo ship (vehicle carrier)		GT	5739	0.631
Ro-ro cargo ship		DWT	10952	10952
Ro-ro passenger ship		GT	7540	0.587
Cruise passenger ship		GT	930	0.383

The method to develop the CII reference lines is described in Res.MEPC.337(76).

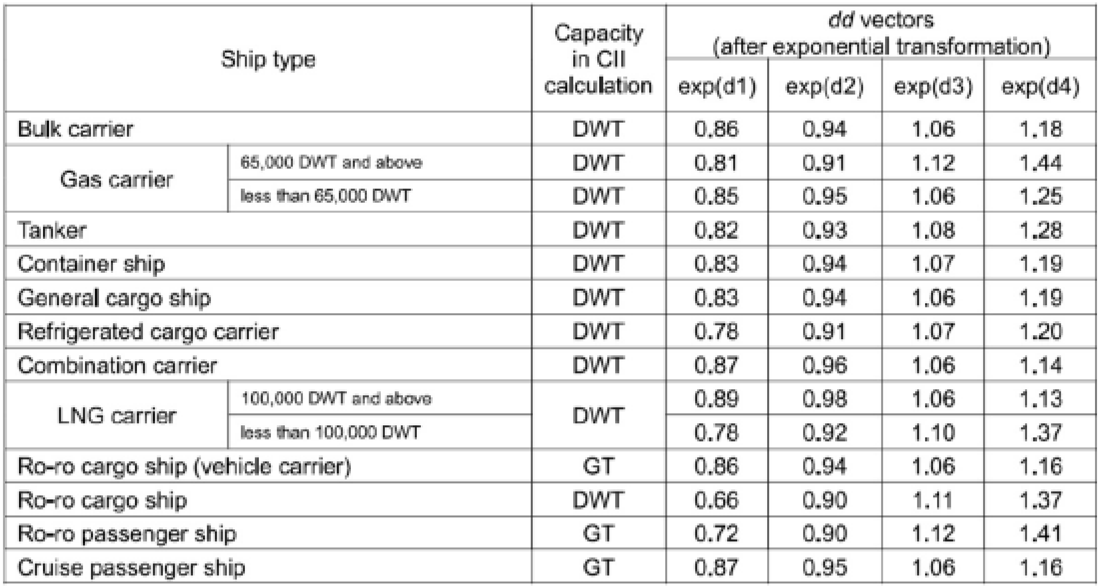
Table 5: CII Reduction Factor (Z%), in relation to CII reference line of 2019 [9]

Year	Reduction factor (in relation to year 2019)
2023	5%*
2024	7%
2025	9%
2026	11%
2027	-**
2028	-**
2029	-**
2030	-**

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

** For the years of 2027 until 2030, Z factor will be further refined taking into consideration the examination of the short-term legislation.

Table 6: CII Rating Boundaries [9]



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		DWT	0.66	0.90	1.11	1.37
Ro-ro passenger ship		GT	0.72	0.90	1.12	1.41
Cruise passenger ship		GT	0.87	0.95	1.06	1.16

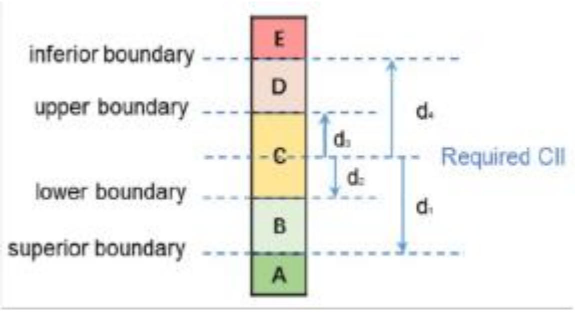


Figure 5: CII Rating with Boundary Values

The vessel's CII performance rating is determined by comparing the attained annual CII with boundary values. There are still pending items to be decided in IMO for CII. Final decisions are expected to be made in MEPC. 78 in 2022.

2.2 SEEMP

Omboga et al. [11] supported that the SEEMP provides a method for assessing vessel and fleets efficiency performance through time and pushes shipping companies to consider new methods and technologies through each stage of the plan in order to increase vessel performance. At the first renewal or intermediate survey after January 1st 2023, the SEEMP is required for both existing and new ships with a gross tonnage larger than 400 Gross Tons, irrespective of flag.

SEEMP follows guidelines for the vessel’s fuel-efficient operation, with the results of fuel consumption reduction. [11]

Figure 6: SEEMP Stages

2.2.1 **Stage 1 – Planning**

Furthermore, Omboga et al. stated that planning is SEEMP’S most critical part, since it essentially defines the existing condition of vessel’s energy consumption and the anticipated energy efficiency improvement. As a result, sufficient time should be devoted to planning so that shipowners can produce the most effective and strategic plan. There are many ways to promote efficiency, such as the optimization of vessel’s speed, weather routing, and a proper technical maintenance of the vessel. The most efficient group of measures for a vessel varies, as it is based on vessel’s type, cargos, voyage, and other reasons. [11]

2.2.2 **Stage 2 – Implementation**

Once the shipping company decides the package of measures, it is necessary to construct a plan for executing them by designing energy management procedures, i.e. by defining duties and allocating them to specialists. Consequently, the SEEMP must explain the way that each measure will be executed and identify the accountable party(ies). Finally, record keeping for each measure's implementation is important for later self-evaluation. If the company’s measures cannot be executed for any reason, that reason must be documented for in-house reference. [11]

2.2.3 Stage 3 – Monitoring

A ship's energy efficiency must be measured quantitatively. This should be accomplished using a defined procedure, preferably an international standard. The EEOI (Energy Efficiency Operational Indicator) is one of the widely recognized tools that may be used to generate a quantitative indicator of the vessel’s energy efficiency. It is a voluntary rating to quantify existing vessel’s efficiency created by IMO. It is the ratio of the amount of CO 2 released per unit of transport activity ("capacity mile") to the amount of transport work. Consequently, EEOI might be viewed as the main monitoring method, but other indicators may also be applicable. In case it is used, the EEOI should be carried out in compliance with the Organization's MEPC 1 /Circ 684 Guidelines. When alternative monitoring instruments are employed, the concept and technique of monitoring may be decided during the planning phase. [11]

2.2.4 Stage 4 - 4. Self-evaluation and improvement

This step must generate useful feedback for the subsequent first phase, which is the planning step of a second cycle.

The purpose of the self-evaluation is to:

- evaluate the efficacy of the proposed measures and their implementation.
- acquire a deeper understanding of the general features of the vessel's operations, such as what sorts of techniques can/cannot accomplish a work successfully and how.
- understand the pattern of the vessel's efficiency improvement; and
- establish an improved SEEMP for the subsequent cycle.

Some shipping companies may choose to publicly announce the outcomes of the actions outlined in their SEEMP and the effect those actions had on their ship's performance. These initiatives should be recognized in the form of reporting and evaluation, which could offer a variety of advantages. Some national administrations, ports, or partnerships may desire to acknowledge the contributions of these foremost shipping companies. For instance, several ports now provide environmentally discounted harbor fees or other incentives to green vessels.[11]

2.1 Mitigation measures

Shipowners are called to proceed with mitigation measures to keep their vessels compliant and competitive with the use of various methods, some of which are mentioned below.

2.1.1 Engine Power Limitation (EPL)

Rutherford et al. supported that EPL (Engine Power Limiting) is a technique used in shipping to reduce fuel consumption and emissions by limiting the engine's power output. The concept of EPL is to restrict a ship's speed by reducing the amount of power its engines can generate, without compromising the ship's maneuverability or safety. This permits the ship to operate at a more efficient pace, which can result in substantial fuel savings and a decrease in emissions. EPL is typically achieved through engine management systems that restrict the quantity of fuel supplied to the engines. By restricting the flow of fuel, the power output of the engines is reduced, so slowing the ship. As a method for decreasing the environmental impact of shipping, EPL is gaining significance in the shipping sector. Numerous shipping firms are adopting EPL as part of their sustainability activities, and some nations have enacted legislation requiring ships to operate with EPL in order to cut emissions. [12]

Many shipowners will probably opt for engine power limitation EPL since it decreases the vessel's operating expenses and, as a conversion efficiency, lowers fuel expenses for the vessel's main engines, which represent a significant portion of the vessel's operating costs. In addition, an EPL is implemented with much less effort than other recommended solutions. However, EPL coincides with limiting the operating revolution range. The new operational RPM may create resonance conditions, leading to an increase in structural or mechanical vibrations. This can result in discomfort of the crew members and machinery damages. If power limitation is achieved by deactivation cylinders, the engine's dynamics will be significantly altered, requiring a reassessment of shaft torsional vibrations. [11]

2.1.2 Alternative Fuels

Agarwala et. al. [13] performed research on the application of alternative fuels in commercial shipping. Heavy fuel oil (HFO) is the main fuel used to run marine diesel engines in the shipping industry. HFO burns with a high level of dangerous SOx emissions because of its high viscosity and high sulfur concentration. Other fuels with lower viscosities and sulfur contents are also utilized, such as marine gas oil (MGO) and marine diesel oil (MDO), with the former being used for smaller vessels.

2.1.2.1 Liquefied Natural Gas (LNG)

More specifically, the option of LNG was examined, as a solution for decarbonised shipping. With 30% fewer GHG emissions and no SOX or NOX, LNG has been considered as the best fossil alternative to HFO and MGO. LNG is now the greenest accessible fuel for shipping that can be generated in meaningful amounts. It can meet the standards for SOx and NOx whilst still reducing Carbon footprint by 20–30%. Since LNG has a lower specific gravity than air, it makes it a safe fuel. As a result, it may quickly diffuse in the air, which makes it less dangerous during an explosion. LNG is a feasible alternative as a fuel for the maritime sector, since it can provide a steady supply for more than 50 years. In addition, possible LNG leaks have less of an environmental impact than heavy fuel oil pollution as they don't remain on the ocean's surface.

On the other hand, to make sure that the desired benefits may be maximized, certain disadvantages need to be recognized and decreased. For instance, the Well-to-Wake (whole cycle) benefits mainly rely on the installed engine technology. When compared to VLSFO0.5-fueled engines, the predicted reduction in greenhouse gas emissions for gas-powered engines ranges from 14 to 23% for 2-stroke slow-speed engines to 6 to 14% for 4-stroke medium-speed engines. Such a gap reveals that LNG cannot be characterized as a decarbonizing fuel and a potential option for a future with zero emissions when assessed over the complete lifecycle (production, distribution, processing, transportation, receipt, storage). Even if LNG has a minor negative impact on the environment, there are still some drawbacks that discourage its use as a fuel for maritime transport, such as the necessity to install new engines that can use LNG fuel, the capital cost (CAPEX) to store and liquefy LNG before consumption, as well as the increased construction costs that are likely to rise by 15% to 30% compared to conventional ships. [13]

2.1.2.2 Ammonia

Sonker [14] supported that due to the absence of direct CO2 emissions, ammonia (NH3) has received considerable interest as an alternative fuel. It has the ability to be utilized in fuel cells or internal combustion engines (ICE). Ammonia is the second most produced industrial chemicals in the world, as it is a chemically necessary molecule which is widely used and largely consumed. More than 235 million tons were produced in 2019. As a result, ammonia’s production and distribution is an easy task as it is already taking place. It may be carried in the same pipelines that are used to trade gas and oil.

Before being used for commercial purposes, a lot of the characteristics of ammonia need to be further investigated, such as:

- Decreased ignition and low flame propagation.
- Toxic and corrosive. Updated safety measures and crew training is necessary.
- Higher NOx emissions, unless they're reduced by after-treatment or combustion process optimization.
- New legislation must be created to support its use as marine fuel.

Research on international shipping has examined the potential to use hydrogen and ammonia as a source of CO2 emission reduction that might reach 70% by 2035.

Given the aforementioned limitations, industry tests in the coming years will determine if ammonia will live up to its potential towards decarbonization (either as a single or as a dual fuel) for ICE applications. [14]

2.1.2.3 Hydrogen and fuel cells

As per Atilhan [15], the use of hydrogen as a marine fuel on board ships is being researched, since proponents of hydrogen believe it may support an important component of the decarbonization process. Compressed or liquefied hydrogen fuel emits no CO2 or GHGs and is non-toxic, transparent, and odorless. Hydrogen, on the other hand, has a large flammability range and a low ignition energy. Furthermore, since hydrogen does not occur naturally, it must be generated via energy-intensive methods. The majority of hydrogen is now created from coal or natural gas, however it is crucial to note that there are various methods for producing hydrogen:

Gray and brown hydrogen: Gray hydrogen is quite affordable, despite the fact that it is sourced from natural gas and is often powered by fossil fuels. It is derived from natural gas by steam methane reformation, while brown hydrogen is derived from coal gasification.

Blue hydrogen is created from fossil fuels such as natural gas and coal, in a process similar to gray hydrogen, but the majority of the carbon exhaled during synthesis is "caught" and not released into the environment.

Green hydrogen: Green hydrogen is created using alternative sources and hydrogen generated from a clean source. Green hydrogen, for example, may be created using water electrolysis and is regarded green but costly.

Aside from some serious safety problems, hydrogen is not viable for deep-sea travel since its power density is around half that of other typical marine fuels, and low energy density fuels present a storage issue, limiting the potential range of operations. This is exacerbated by the fact that space aboard boats is limited, making availability a critical concern, especially because larger fuel storage tanks would reduce cargo carrying capacity. Given that there is just one hydrogen-powered vessel in the United States, the bunkering network required to support hydrogen as a marine fuel remains underdeveloped. Furthermore, liquid hydrogen bunkering facilities may have greater capital costs than LNG bunkering facilities. While the costs of alternative fuels remain unpredictable, new studies show that hydrogen fuels may be less expensive than gasoline and biofuels, though much more work is required throughout the industry to establish cost stability and economies of scale. [15]

2.1.2.4 Methanol and biomethane

Svanberga [16] declares that methanol, being the most basic type of alcohol, remains liquid at standard temperature and pressure. It burns simply into co2 and h2o, releasing no sulphur oxides (SOx) and much decreased nitrous oxides (NOx) and particulate matter (PM). Methanol has been successfully implemented as a fuel in a number of successful sea trials, demonstrating suitability with both spark ignition and compression ignition engines.

It has been shown that that the use of biomass for the production of sustainable methanol for the maritime sector is a technically realistic solution. Also, there have been no serious technical issues in the distribution, or usage aboard ships. Similarly, there are no substantial problems within possible supply chains, and although some financial obstacle remain, it does not seem to be prohibitive. The use of methanol may help to ease the transition from fossil fuel to renewable methanol, although due to methane emissions during manufacture and burning, methanol may not be a net-zero choice, and it may only deliver a quite limited reduction in carbon dioxide emissions when compared to typical marine fuels. Finally, infrastructure for both storage and transportation is already in place or may be quickly modified from current infrastructure. [16]

2.1.2.5 Hybrid-electric and electric vessels

Ruggiero [17] claimed that the energy in hybrid-electric and electric vessels is stored in lithium batteries that are recharged at ports during port operations. When it comes to installation and maintenance, electric engines are easier to use than ICE. They also demand a small space in the engine room. They are fully "green," and they minimize the noise produced by the propulsion.

The application of hybrid-electric power for propulsion and other electrical equipment on vessels may decrease carbon pollution by minimizing fuel consumption. there are several cases where hybrid power generation and propulsion are practical. Particularly for the fixed voyages, hybrid propulsion system is a desirable approach. Reliability and different propulsion methods are two major benefits of hybrid propulsion (e.g. mechanical or electrical). Additionally, hybrid and electrical propulsion may improve the vessel’s ability to maneuver. They can also support vessel’s efficiency by providing greater control and prompt response to instructions.

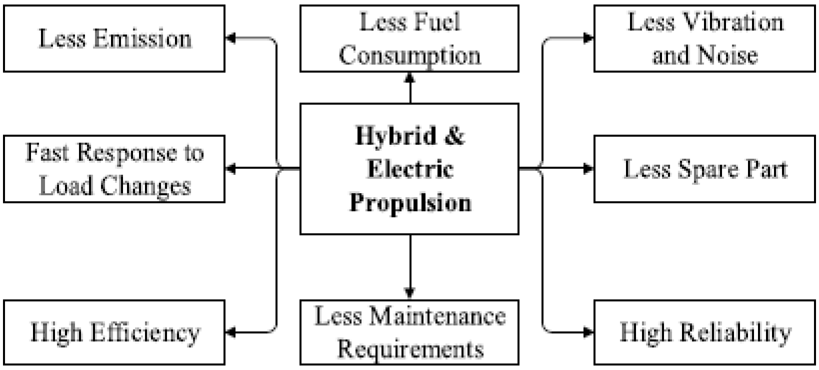


Figure 8: The advantages of hybrid-propulsion and full-electric propulsion

However, the ideal outcome for hybrid systems is only a 14% decrease in emissions for dry bulk carriers, which is not significantly greater than the current energy saving methods. Also, due to their long, continuous voyages and their large consumption, battery storage for seafaring vessels can be considered as difficult and does not seem to be economically viable in the foreseeable future. HPS or fully electric propulsion still need more study and technical development. For short-range or inland transportation (such as passenger ships or ferries), HPS technology is highly promising and seems to be readily accessible.

It is undeniable that the pace of the switch to hybrid and electrical systems will be accelerated by stricter IMO standards and limitations on GHG emissions. The development of potential HPS for every kind of vessel is still ongoing, but advances in electronic and smart systems will be essential to the shift from ICE to a fully electric, or emission-free maritime sector. [17]

2.1.3 **Wind Propulsion**

Chou et al. [18] supported that the three main types that can be used for wind propulsion on vessels are: Sails, Flettner rotors, and towing kites. The strength of the wind at a great height is harnessed by a towing kite that is thrown from the bow of a ship to pull the ship along. Landscape forces, notably the price of oil, drive interest in wind propulsion; as a result, when oil prices have been high, as they were in the 1980s, wind propulsion technologies have been on business radars, but they tend to fade when the crisis has passed. Although there hasn't been much commercial wind propulsion for commercial shipping, research on technical and economic modeling demonstrate the potential for wind propulsion. [18]

2.1.3.1 Flettner rotors

Using rotors mounted on a vessel's deck, the so-called Magnus effect may be used to provide propulsion. What we call Flettner rotor is a spinning cylinder that uses the Magnus Force to turn wind energy into a propulsion. It was developed in the 1920s but it had been unable to compete with ICE at that time. [18]

2.1.3.2 Towing kites

It is a kite that is connected to the ship's bow, and wind energy may be utilized to boost the engine power. Can be exploited on ships that are at least 30 meters long, and it performs best on boats whose average speed is no more than 16 knots. Only tankers (crude oil, product, chemical, LPG, LNG, other, and bulk carriers) are being regarded as prospective users as a result of this speed limitation. It's possible to retrofit the system. [18]

2.1.4 **Waste heat recovery (WHR) system**

Vallis et al. [19] examined the application of Waste Heat Recovery System as a mean to reduce gaseous emissions and, consequently, to improve vessel's efficiency. This system uses rejected heat from multiple sources, which is being converted into electrical power, and it can support or even replace diesel generators. WHR systems are systems that harness heat from multiple sources from the main engine of a vessels, using heat exchangers. These sources can be: exhaust gases, compressed intake air, the engine coolant and the lubricating oil of the main engine. According to Vallis and al., exhaust gases can reject more than 30% of the fuel supplied energy. According to that and given the fact that the efficiency of these systems is above 10%, and WRH can increase the total efficiency at least 3-4%. This technology is based on various thermodynamic cycles, such as organic Rankine cycle, and Brighton cycle and uses organic fluids or carbon dioxide as working mean. It requires high CAPEX, and its payback period is highly dependant from fuel-cost. [19]

Despite its high capital cost, the proposed WHR system installation is feasible because the payback period can be capped at less than eight years and, in any case, can be further lowered based on the total annual time of the proposed system operation and the annual time of the mission of the vessel. Also, They can be installed on the majority of ships because they only take up a little amount of room in the engine room. It is simple to understand why many shipowners consider waste heat recovery to be a more advantageous means of EEXI compliance given its proven performance, retrofit improvements, and financial and environmental advantages. [19]

3 Methodology

This study used a methodical review of the literature through multiple rounds of data collection. Significant articles from EEXI, CII, operational, technical measurements, design energy improvement, and energy efficiency were obtained. The initial search was conducted using Elsevier, Clarkson Research and Google Scholar as these databases provide reliable evidence of a scientific, academic, technical, and professional resources. So as to approach the issue of EEXI and CII compliance, the definitions and formulas of EEXI and CII are presented, based on information collected from scientific journals and IMO MEPC. The case studies of two non-compliant vessels are used to implement the above referred EEXI and CII formulas and in order to highlight the need to take additional measures. Finally, the research highlights the challenges arising from the application of the proposed methods.

Mallouppas et al. [20] explained the EEXI and CII indexes, providing further details on their variables and the relation between those two regulations. This research highlights that both regulations utilise common units of measurement and they also divide vessels according to their size. On the other side, the research states that while EEXI has a fixed engine rating, CII calculating is dynamic and based on vessel’s annual operational data.

Based on the current literature, no research is observed that calculates the EEXI and CII regulations in detail on existing ships. Also, there do not appear to be any papers summarizing the remedial methods for vessels not complying with the forthcoming legislation. This study performs calculations on two Ultramax bulk carriers, detailing the technical and operational data of each vessel. Furthermore, it proposes a wide range of operational and technical corrective measures.

3.1 EEXI Calculation for M/V GRACE (Case Study)

The EEXI Technical Report of Motor Vessel GRACE has been developed following below characteristics.

3.1.1 **Vessel Data**

3.1.1.1 Characteristics

Vessel Name	
Vessel Type	Bulk Carrier
Year of build	2018
Length Between Perpendiculars	192.90 [m]
Breadth, moulded	36.00 [m]
Depth, main deck, moulded	18.45 [m]

Summer Load Draught, moulded	12.90 [m]
Deadweight at Summer (Scantling) Draught	66622.0 [ton]
Gross Tonnage	38217.0 [ton]
Lightship Weight	11502.0 [ton]
Tank/Hold Capacity	83102.1 [m3]

3.1.1.2 Main Engine Characteristics

Manufacturer	Mitsui engineering & Shipbuilding Co., Ltd.
Maximum Continuous Rating	8470.00 [kW]
Rotational Speed at MCR	99.0 [RPM]
Specific Fuel Consumption @ 75% (SFC)	167.00 [g/kWh]
CO2 Conversion Factor	3.206 [t/t]

3.1.1.3 Auxiliary Engine Characteristics

Number of Auxiliary Engines: 3

Manufacturer	Daihatsu Diesel Mfg. Co., Ltd.
Maximum Continuous Rating	660.00 [kW]
Rotational Speed at MCR	900.0 [RPM]
Specific Fuel Consumption @ 50% (SFC)	235.30 [g/kWh]
CO2 Conversion Factor	3.206 [t/t]

3.1.2 EEXI Calculation

3.1.2.1 Auxiliary Engine Power Calculations – P(AE)

For ships for which the total propulsion power is below 10000.0 kW, Auxiliary Engine Power P(AE) is defined as:

$$P_{AE\,(\sum MCR_{ME(i)}<10{,}000kW)} = \left(0.05 \times \left(\sum_{i=1}^{nME} MCR_{ME(i)} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75} \right) \right)$$

Here, P(PTI) = 0.00 kW and P(MCR) = 8470.00 kW, therefore, P(AE) = 423.50 kW.

3.1.2.2 Main Engine Power - P(ME)

The maximum allowable deduction for the calculation of ΣP(ME) is to be no more than P(AE). For this case, ΣP(ME(i)) is calculated as:

$$\sum_{i=1}^{nME} P_{ME(i)} = 0.75 \times \left(\sum MCR_{ME(i)} - \sum P_{PTO(i)} \right) \quad with\ \ 0.75 \times \sum P_{PTO(i)} \le P_{AE}$$

Here,

0.75 x ΣP(PTO) = 0.75 x 0.00 kW = 0.00 kW.

P(AE) = 423.50 kW.

Therefore, final ΣP(PTO) = 0.00 kW.

Finally, ΣP(ME) = 6352.50 kW.

3.1.2.3 Certified specific fuel consumption

Specific Fuel Oil Consumption of the Main Engines SFC(ME) is given: 167.00 g/kWh.

Specific Fuel Oil Consumption of the Auxiliary Engines SFC(AE) is given: 235.30 g/kWh.

3.1.2.4 Coefficients

3.1.2.4.1 fj ; Ship specific design elements

For Bulk Carriers, fj = 1.000.

3.1.2.4.2 fw ; Factor for speed reduction at sea

No specific weather conditions apply to the present ship. Therefore, fw = 1.000.

3.1.2.4.3 Capacity factor for technical/regulatory limitation on capacity

f_{iCSR} ; Ships under the Common Structural Rules (CSR)
The present vessel is a Bulk Carrier built in accordance with the Common Structural Rules (CSR) of the classification societies and assigned the class notation CSR, therefore, according to MEPC.

$$f_{iCSR} = 1 + (0.08 \cdot LWT_{CSR} / DWT_{CSR})$$

Fi is calculated as 1.014.

3.1.2.4.4 fc ; Cubic capacity correction factor

For Bulk Carriers, fc = 1.000

3.1.2.5 Reference Ship Speed

V_{ref} is obtained from the Power-Speed curve of the vessel based on reliable results of tank tests / sea trials, at the propulsion power P(ME) = 6352.50 kW. This corresponds to 75% of the MCR.

Here, V_{ref} is calculated equal to 14.06 knots.

3.1.3 **Calculation of Current and Required EEXI**

3.1.3.1 Calculation of Current EEXI

The current ship Energy Efficiency Existing Ship Index (EEXI) is calculated by the following formula:

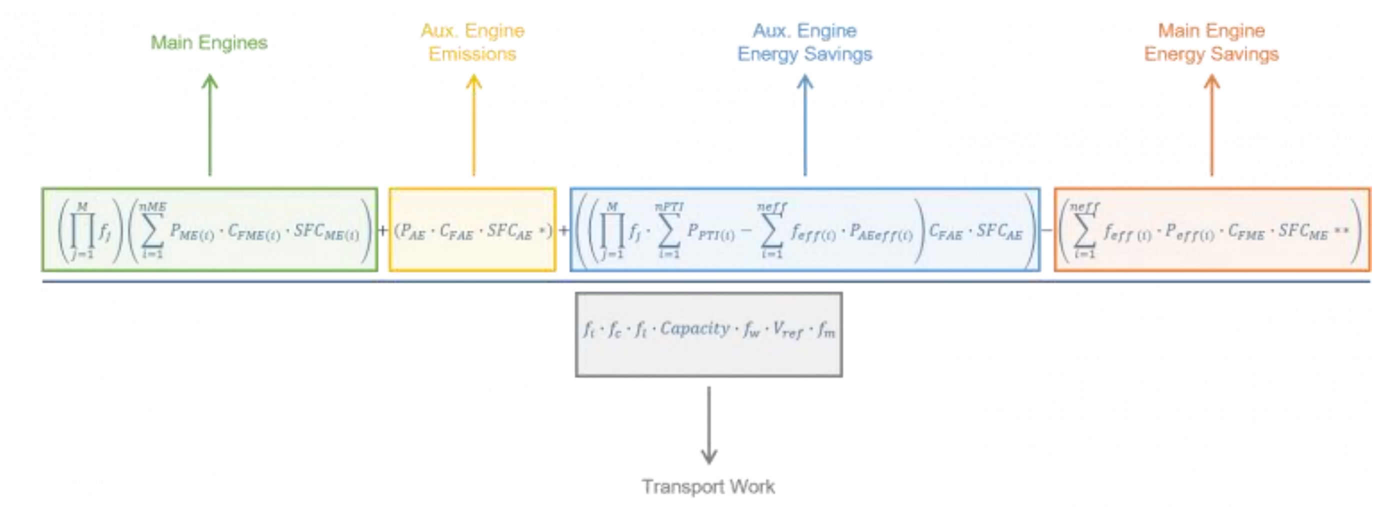


Figure 7: Vessel's current EEXI formula [9]

$$= \frac{1 \text{ x } (6352.50 \text{ x } 3.206 \text{ x } 167.00) + (423.50 \text{ x } 3.206 \text{ x } 235.30) + 0 - 0}{1.014 \text{ x } 1 \text{ x } 1 \text{ x } 66622.0 \text{ x } 1 \text{ x } 14.06 \text{ x } 1}$$

= 3.92 g-CO2/ton.mile.

The Current EEXI of the vessel is 3.92 g-CO2/ton.mile.

3.1.3.2 Calculation of Required EEXI

Firstly, we need to calculate respective EEDI Reference line value.

The EEDI reference line value shall be as follows:

Table 7. EEDI Reference line value. [9]

Ship Type	A	B	C
Bulk Carrier	961.79	66622.0	0.477

EEDI Reference line value = a x b^(-c) = 961.79 x 66622.0^(-0.477) = **4.81 (g-CO2/ton.mile)**

Then, we can calculate Required EEXI by using below formula:

Required EEXI = (1 - Y / 100) x EEDI Reference line value

Y = Reduction Factor for the Required EEXI compared to the EEDI Reference Line

Table 8. Reduction factor (in percentage) for the EEXI relative to the EEDI reference line. [9]

Ship Type	Deadweight	Reduction Factor
Bulk Carrier	66620.0	20

Required EEXI = (1 - 20 / 100) x 4.81 = 3.85 (g-CO2/ton.mile)

The Required EEXI of the vessel is 3.85 g-CO2/ton.mile.

3.2 CII Calculation of M/V DESPOINA (Case Study)

3.2.1 Vessel’s Data

3.2.1.1 Vessel Characteristics

Vessel Name	M/V DESPOINA
Vessel Type	Bulk Carrier
Year of build	2018
Length Between Perpendiculars	192.90 [m]
Breadth	36.00 [m]
Depth	18.45 [m]
Summer Load Draught	12.90 [m]
Deadweight at Summer Draught	66585.0 [ton]
Gross Tonnage	38219.0 [ton]
Lightship Weight	11539.0 [ton]
Hold Capacity	83102.1 [m3]

3.2.1.2 Main Engine Characteristics

Number of Main Engines: 1

Manufacturer	Mitsui engineering & Shipbuilding Co., Ltd.
Maximum Continuous Rating	8470.00 [kW]
Rotational Speed at MCR	99.0 [RPM]
Specific Fuel Consumption @ 75% (SFC)	168.20 [g/kWh]
CO2 Conversion Factor	3.206 [t/t]

3.2.1.3 Auxiliary Engine Characteristics

Number of Auxiliary Engines: 3

Manufacturer	Daihatsu Diesel Mfg. Co., Ltd.
Maximum Continuous Rating	660.00 [kW]
Rotational Speed at MCR	900.0 [RPM]
Specific Fuel Consumption @ 50% (SFC)	235.30 [g/kWh]
CO2 Conversion Factor	3.206 [t/t]

3.2.2 **Calendar Year 2023 based on DCS data of 2019**

3.2.2.1 Calculation of Reference CII

The reference Carbon Intensity Indicator (CII) is calculated with the following formula, according to Res. MEPC.338(76):

$CII_{ref} = aCapacity^{-c}$

Here, a=4745, Capacity= 66585 tonnes and c=0.622, therefore CII(ref)=4,697 g CO2/ton.mile.

3.2.2.2 Calculation of Required Annual CII

The required annual operational CII for vessel M/V DESPOINA is calculated using the following formula:

Required annual operational CII = (1-Z/100) x CII_{Ref}

For the calendar year 2023, Z=5; thus, the following value is attained for the Required annual operation CII: CII=4.51 g CO2/ton.mile.

3.2.2.3 Calculation of Attained CII

The attained Carbon Intensity Indicator (CII) is a measure of the operational energy efficiency (g- CO2/ton.mile) of a ship, calculated by the following formula, according to RES. MEPC .336(76):

Attained $CII_{ship} = M/W$

Where:

- M is the total mass of CO_2 emmited (g-CO_2); and
- W is the total transport work (in ton.mile) undertaken in the given calendar year.

The total fuel consumption, M, of the vessel M/V DESPOINA over the calendar Year 2023 can be calculated by the following formula, according to Res. MEPC.336(76):

$M = FC_j \times C_{Fj}$

Where, the fuel oil consumption and conversion factor for the different fuels used are given in Table 9.

Table 9. Annual fuel consumption and fuel conversion factors for Calendar Year 2019.

Fuel	Annual Consumption	Conversion Factor
	(ton)	(ton – CO2 / ton-Fuel)
HFO	4634	3.206
MGO/MDO	77	3.206

The total transport work, W, of the vessel M/V DESPOINA over the calendar Year 2019, is calculated from the following formula, RES. MEPC.338(76):

$Ws = C \times D_t$

Where:

vessel's capacity is C= 66585 tonnes, and;

total travelled distance over the calendar year 2019 is Dt=49116 miles.

4 Results

On this chapter, the results of the two cases studies are analysed. In addition, the chapter includes the options available for ship-owners, as well as the implications raised from the new legislation.

4.1 EEXI Results

The Current EEXI of vessel M/V GRACE is 3.92 g-CO2/ton.mile.

The Required EEXI of vessel M/V GRACE is 3.85 g-CO2/ton.mile.

Motor Vessel GRACE does not meet the requirements of EEXI Regulation. A reduction to EEXI of 3.92 - 3.85 = 0.07 g-CO2/ton.mile is further required.

A solution to meet the EEXI requirements is EPL (Engine Power Limitation). EPL is the modification which applies load limitation to the engine. The factors that influence the evaluation of GHG ratings are engine output and fuel consumption. With EPL, it is possible to improve the rating by reducing the max limit of engine output. Engine performance is unchanged with the new load limit, and it can be operated the same as before below the new load limit. However, Ship's speed will also be limited, as the load above the limit cannot be output. By application of an Overridable Electronic Engine Power Limitation (Electronic EPL) of 13%, Vessel GRACE meets the requirements of EEXI Regulation, with a margin of 3.85 - 3.85 = 0.00 g-CO2/ton.mile.

Another possible solution for ship-owners would be the use the alternative fuels. Agarwala depicted that even if LNG cannot be characterized as a decarbonizing fuel and a potential option for a future with zero emissions, it can be considered as an efficient solution for the transitional level of decarbonization.

Also, shipowners may cut the ship's fuel consumption and, consequently, its CO2 emissions by utilising waste heat from the ship to generate clean electrical power. This tried-and-true energy-saving technology is already in use on a number of oceangoing ships and offers a workable solution to lower global fleet emissions and improve sustainability in the shipping sector.

4.2 CII Results

For the vessel M/V DESPOINA, the attained CII is 4.6 g-CO2/ton.mile.

According to CII rating boundaries given in Res. MEPC.339(76), and after the exponential transformation (Attained CII / Required CII = 1.01) the CII status of M/V DESPOINA will be D for the annual year of 2023.

According to IMO, as of 1 January 2023, all vessels above 5,000 GT will be required to have a CII based on historical data. Ships that received a D rating for three consecutive years or an E rating for a single year will be required to adopt an upgraded Ship Energy Efficiency Management Plan (SEEMP) that outlines how they will reduce their fuel consumption below the threshold.

4.3 Implications of EEXI and CII in Shipping Operations

4.3.1 **EEXI Implications**

Shipowners and operators should examine the impact that EEXI will have on their present and future trade patterns, as well as whether additional or alternative energy-saving equipment or arrangements are required to meet the EEXI criteria. Compliance with EEXI may result in potential competitiveness difficulties. For instance, power limitation could have an effect on the speed and performance as well as the vessel description warranties; consequently, these will need to be thoroughly examined. Time charters that extend beyond 2023 may necessitate careful analysis and renegotiation and may need to address issues such as who is accountable for the expenses and time associated with implementing such revisions. [11]

Furthermore, if the ship-owners decide to invest on alternative fuels, they should take into consideration the necessary time of engine modification / installation and the respective CAPEX. [11]

4.3.2 **CII Implications**

Charterers, bankers, and authorities will be capable of assessing the ships. All vessels that do not fulfill CII standards are significantly less likely to be hired or financed due to their expected higher operating costs. In addition, those with a poor CII rating will be required to use SEEMP to catch up, which might compromise their operating capabilities by requiring them to run at reduced speeds. In addition, authorities might penalize those with poor CII ratings. No charterer or financial institution is willing to take any of these risks.

Owners may be obliged to choose the most fuel-efficient route, not the quickest one, as well as to limit the volume of cargo carried on particular voyages. They may also have to choose longer voyages over shorter ones so that the ratio of idling time in port to sailing time is minimized. Also, ship operators will probably adopt a variety of fouling management techniques to increase efficiency. When it comes to biofouling control, it's crucial to make sure that, should any idle arise, the vessel hull is still in good shape to operate at its best without producing more emissions. They will also have to avoid busy ports for the exact same reason. [21]

In addition, the DNV reports that just 3% of current ships have an A rating. This demonstrates that ship owners and operators will need to make significant changes over the next few years in order to fulfill these requirements; otherwise, they will face significant financial and operational difficulties. [22]

4.3.3 Legal Aspect

The CII is believed to have the potential to create legal disputes between shipowners and their time charter counterparties. A vessel will receive CII ratings that are impacted by the technical specifications and operational features of the vessel, which contributes to the litigation risk. Undoubtedly, the shipowners are responsible for the vessel's technological capabilities. However, the control over how the ship has been operated and how effectively it has been operated typically remains with the charterers. The route, speed, and amount of cargo a ship will carry are often all determined by the charterer. If bad weather or congested ports have an impact on the carbon intensity of the voyage, the vessel's CII score could be further decreased. Retroactive evaluation of CII ratings raises the possibility of legal action if they have an impact on vessel values in the future. The current scenario calls for a solid legal structure that will support a revised contractual relationship that includes the two crucial elements of cooperation and transparency.

Bimco is creating a time charter provision for CII in order to strike the ideal balance between shipowners and the charterers. The final contract clause is anticipated to include language requiring owners and charterers to collaborate, which necessitates the sharing of data. Charterers could have to put up with restrictions on how freely they can trade a vessel. [23]

5 Conclusions

The Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator (CII) are two regulatory measures that have significant implications on shipping operations. With the goal of reducing greenhouse gas emissions in the shipping industry, these regulations have become crucial in the industry's efforts to meet its sustainability targets. This thesis has provided an overview of the regulations, their impact on the industry, and the challenges that shipping companies may face in implementing them.

Also, the research highlighted various prospective approaches and technologies that are currently available and will assist the shipping industry in meeting the deep decarbonization targets set by the IMO by the year 2050. There has been a rise in interest in significant decarbonization from the main stakeholders in the shipping sector.

This study’s methodology was the presentation of the definitions and formulas of EEXI and CII, based on information collected from scientific journals and IMO MEPC. Also, the case studies of two non-compliant vessels were used to implement EEXI and CII formulas and in order to highlight the need to take additional measures, such as the alternative fuels. Finally, the research highlighted the challenges arising from the application of the proposed methods.

Based on our case studies, it has been proved that the examined vessels, which are built in 2018, cannot be compliant with the upcoming regulation and further actions need to be taken. The difficulty of compliance to the new regulations is also mentioned to previous studies [4, 8, 14].

The dominance of Internal Combustion Engines (ICE) in the shipping industry makes it unlikely that they will be replaced very soon. Therefore, it is clear that, at least in the short term, a high percentage of the existing worldwide fleet will be forced to adopt at least one of the above-referred corrective measures in order to be compliant.

The objectives of the IMO will be accomplished by the implementation of a significant shift in technological practice, in addition to the use of social pressure, financial incentives, and legislative and regulatory changes on a national and global scale.

Despite these challenges, the research shows that there are a variety of strategies that shipping companies can adopt to successfully comply with EEXI and CII regulations, including adopting more energy-efficient technologies, investing in renewable energy sources, and prioritizing sustainability in their operations.

The findings of this thesis have important implications for the field of shipping operations and the broader effort to combat climate change. By adopting innovative strategies and investing in sustainable practices, shipping companies can significantly reduce their carbon footprint and contribute to a more sustainable future.

Through this research, it is evident that complying with EEXI and CII regulations is not only a legal obligation but also a moral responsibility for shipping companies to contribute to the fight against climate change. In order to achieve successful implementation, shipping companies need to adopt innovative strategies that prioritize efficiency and sustainability, while also seeking collaboration and knowledge-sharing among industry stakeholders. In conclusion, EEXI and CII regulations are a step towards a greener shipping industry, and their successful implementation will benefit the environment, the shipping industry, and society as a whole.

This thesis acknowledges that there are limitations to this research and that future research is necessary to fully understand the impact of EEXI and CII regulations on the shipping industry. However, by building on the findings of this thesis, future research can continue to contribute to the ongoing development of knowledge in this field. This study had no access to techno-economic data of the proposed corrective measures. Thus, a recommended future study would be an analytical techno-economic research on the implantation measures for EEXI and CII compliance.

In conclusion, this thesis highlights the importance of complying with EEXI and CII regulations in the shipping industry, and the significant benefits that can be achieved by adopting more sustainable practices. It is clear that, by working together and prioritizing sustainability, the shipping industry can contribute to a more sustainable future for all.-

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