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MSc in Shipping Management

THE IMPACT IN SHIP OPERATION AS IMPOSED BY THE ENERGY EFFICIENCY EXISTING SHIPPING INDEX

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Περίληψη

Από την αρχαιότητα, η ναυσιπλοΐα ήταν ο κυρίαρχος τρόπος μεταφοράς ανθρώπων και αγαθών. Σύμφωνα με τις πιο πρόσφατες έρευνες *(Introduction to the International Maritime Organization, IMO, 2023)*, πάνω από 80% του παγκόσμιου εμπορίου πραγματοποιείται μέσω θαλάσσης. Το θαλάσσιο εμπόριο είναι ο πιο οικονομικός και ενεργειακά αποδοτικός τρόπος σε σύγκριση με άλλα μέσα μεταφοράς, αλλά έχει και ένα σημαντικό μειονέκτημα. Την εξάρτησή του από τα ορυκτά καύσιμα, τα οποία οδηγούν στην εκπομπή επιβλαβών αερίων. Ο Διεθνής Οργανισμός για την Ναυτιλία – IMO έχει εισάγει αρκετά μέτρα για τη μείωση αυτών των εκπομπών. Τα πιο πρόσφατα και σημαντικά είναι ο EEXI– Energy Efficiency eXisting Ship Index και ο CII – Carbon Intensity Indicator, που τέθηκαν σε ισχύ από τον Ιανουάριο του 2023. Οι δύο αυτοί κανονισμοί αποσκοπούν στη μείωση της πυκνότητας του άνθρακα και ως αποτέλεσμα, των εκπομπών αερίων του θερμοκηπίου μέσω μεθόδων ενεργειακής απόδοσης. Η παρακάτω έρευνα στοχεύει στη δημιουργία μιας ολοκληρωμένης κατανόησης των επιπτώσεων που προκαλεί η εφαρμογή του κανονισμού EEXI στη λειτουργία του πλοίου, μέσω της ανάλυσης πραγματικών δεδομένων που συλλέχθηκαν κατά τη διάρκεια της λειτουργίας του επί ενάμιση χρόνο. Μέσω της ανάλυσης αυτού του συνόλου δεδομένων, θα εξεταστούν λεπτομερώς οι αλλαγές που έχουν εφαρμοστεί και πρέπει να εφαρμοστούν, καθώς και η αποτελεσματικότητά τους.

Λέξεις κλειδιά:

- Εκπομπές αερίων διοξειδίου του άνθρακα
- Διεθνής Οργανισμός Ναυτιλίας
- Δείκτης Ενεργειακής Απόδοσης Υφιστάμενων Πλοίων
- Ταχύτητα του πλοίου

Abstract

Since ancient times, shipping has been the dominant means of transportation of goods. Based on the latest research *(Introduction to the International Maritime Organization, IMO, 2023)*, over 80% of the global trade in conducted via marine routes. Sea Trade is the most cost effective and energy efficient method compared to other modes of transportation, but it also has an influential drawback, its dependence on fossil fuels, which finally leads to harmful GhG emissions. The International Maritime Organization – IMO has introduced several measures to reduce these emissions. The most recent and noteworthy are the EEXI – Energy Efficiency Existing Ship Index and the CII – Carbon Intensity Indicator entering into force since January 2023.Both regulations strive for the reduction of carbon intensity and as a result the GHG emissions through energy efficiency methods. This research aims to create a comprehensive understanding of the impact caused from the implementation of the EEXI regulation to the operation of the vessel, using real time data from ship operation over a period of one and a half year. Through the analysis of this set of data, the changes which have been and will be implemented as well as the effectiveness of them will be examined in detail.

Key words:

- Greenhouse Gas emissions
- IMO –International Maritime Organization
- EEXI – Energy Efficiency eXisting Ship Index
- Speed of the vessel

Keywords

Greenhouse Gas emissions

IMO –International Maritime Organization

EEXI – Energy Efficiency eXisting Ship Index

Speed of the vessel

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1. INTRODUCTION

This thesis describes and analyzes the new regulations as these are implied by the IMO to reduce the Greenhouse Gases emissions deriving from vessels. The organization has set new measures into force since January 2023 aiming at the improvement of the energy efficiency of ships. The EEXI, which will be more explicitly analyzed is a technical regulation which measures the energy efficiency of a vessel compared to the baselines as these are set by the IMO. The aim of the study is to present the way these methods are used and how they are calculated based on different factors like fuel consumption, distance travelled, cargo carried and the type of vessels in which these regulations and mainly the EEXI applies. In addition, the several technical measures which are used to comply with these standards are presented. The effectiveness of these measures to comply with the EEXI varies, but the most effective one appears to be the engine power limitation. This measure is analyzed and presented, aiming at the creation of a broad understanding of its impact at the ship level. Regarding the depiction of the results through graphical means, real time data during the operation of the vessel are used. These data cover a period of one and a half year and compare the operation of the vessel before and after the entry into force of the regulation, mainly in terms of speed (speed limit as a means to achieve the goals set by the EEXI regulation).

1.1. Aim of the research

This work presents the effect and changes caused by the new regulations of the IMO concerning the optimization of the vessel's efficiency. The study is focusing on specific aspects of a ship's operation such as the targeted speed and the utilization of the main and the auxiliary engines. Using specialized software for the comparison of ship parameters before and after the enforcement of EEXI is presented. In this way, will be given a clear and broad picture of how the shipping enterprises and their fleet are affected. At the same time through the review of EEXI and other environmental regulations, the changes at the shipping industry as imposed by the IMO will be broadly imposed and understood. The research basically constitutes an extensive Case Study, using real time data from vessels which are currently operating.

In particular, the diploma thesis is structured as per below:

Chapter 1 – at the beginning of the below essay, the environmental regulations and the goals set by the IMO are briefly described. Later on, the aim of the research as well as the methods that will be used in order to reach the outcomes are clearly stated.

Chapter 2 – extensive description of the Greenhouse effect and its impact to the climate change. In this chapter the type of gases and their impact to the environment are analyzed, while at the same time there is a particular focus on the Carbon Dioxide emissions deriving from vessels. The collection data systems and the categorization of the emissions by type of vessel, voyage and fuel is presented through diagrams and boards. Finally some more types of maritime pollution and their impact are briefly described. The sources from where these gases derive, as well other types of pollution are also described. Later on, the same chapter, the evolution of the marine fuels since the time of coal engines is summarized. The goals which have been set by the International Maritime Organization are also imposed in conjunction with a prediction for the achievement of these goals by 2050. After the analysis of the actions taken by the IMO, first by creating MARPOL – International Convention on Marine Pollution Control against all types of marine pollution like Chemical Oil pollution, Water Management pollution etc is described. Later on the same chapter, the ways in which the organization faces the GHG from shipping is extensively analyzed. The action of the MEPC – Marine Environment Protection Committee and the goals set by the organization are clearly imposed. At the same time, the contribution of other supportive actions initiated by the IMO is also imposed. At the end of the second chapter, the regulations regarding Energy Efficiency and Carbon Intensity are described. The way that they are calculated, the factors which affect them and the means which should be used in order to comply with them are clearly stated in this chapter.

Chapter 3 – this chapter, concerns the methods used for the completion of the diploma thesis. The main method of data collection is the quantitative research while literature survey is also used. In addition, the type of data collected and the means used to analyze them is also briefly described. Finally, the chapter of the methodology is completed with the description of the next two chapters, the conclusions and the discussion which reflect the impact of these regulation to the industry.

Chapter 4 – real time analysis of the speed modifications during the operation of a tanker is made. Data from the daily operation of the vessel are inserted into specialized software and diagrams and boards which imply the behavior of the vessel as affected by the EEXI are created. At the end of this chapter these graphical means are described verbally and conclusions on the impact of the EEXI on this specific vessel is made.

Chapter 5 – a recapitulation of the outcomes which derived from the case study and the literature review. Through these outcomes a broad picture is created and the fact that the newly introduced regulations will play a significant role in the maritime operation is clearly stated

Chapter 6 – after clear outcomes regarding the influence of these regulations have been reached, the impact of them on the shipping market is analyzed. The operational changes will and have already begun to affect the whole shipping cycle, beginning from the freight market and the rates of the freights, and proceeding to the market of Sale and Purchase of vessels. Through these fundamental changes, the prices of the products will also be affected.

Chapter 7 – bibliography

2. LITERATURE REVIEW

The literature review focuses on two main aspects. The first one is the environmental impact of shipping and the second is the means and ways with which IMO is trying to limit this impact, paying great attention in one of the regulations created for this cause, the EEXI and its effect on the vessel operation. At a first stage the greenhouse effect on a general basis is described, the main Greenhouse gases and their origin is identified. The impact of these emissions on climate change and the rise of temperature is also discussed. Later, these greenhouse gases and their impact is combined with the shipping industry. Discrimination between the emissions produced per type of vessel, voyage and fuel is made so that a clear view of the topic can be created. On the next stage of the diploma thesis, a small introduction to the evolution is made. The progress from coal to oil and alternative fuels is described, while at the same time predictions for the consumption of marine fuels until 2050 are being made (Cavalcante, 2020).

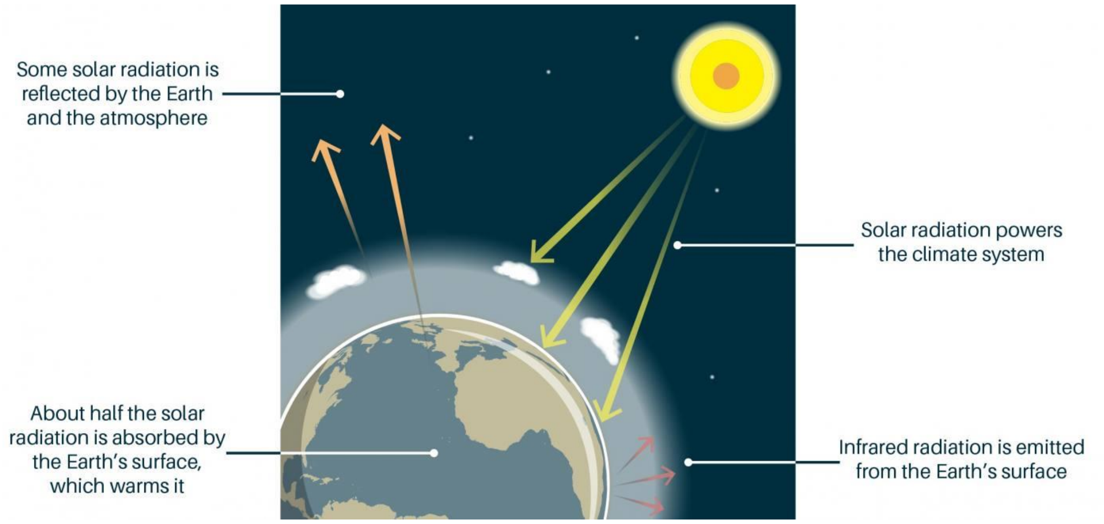
In the third stage of the article, the prevention measures and actions as these imposed and implied by the International Maritime Organization are explained. The specialized conventions like MARPOL – International Convention for the Prevention of Pollution from Ships and their committees MEPC – Marine Environment Protection Committee are introduced and their past, present and future action for eliminating the GHG emissions is highlighted.

The next and most important chapter describes the most recent regulations of EEXI and CII as well as some other regulations created to enhance ship efficiency and reduce the carbon intensity. The way in which they are being calculated and the ways in which they can be achieved is described in detail.

Finally, the Case Study Analysis is presented. With the use of data such as speed, consumption of main and auxiliary engines and other technical aspects abstracted from the noon reports and the technical documentation of a Handysize tanker, the changes in speed required, so that the vessel complies with the EEXI are presented. This analysis is performed with the contribution of a specialized commercial software provided by ShipReality to the University. The results are displayed through graphical means and analyzed further verbally, to come to a final conclusion regarding the impact of the EEXI before and after it's application.

2.1.The Greenhouse effect

The Greenhouse effect (NASA Climate) (NASA, n.d.)is a phenomenon during which certain types of gas trap the sun's heat inside the atmosphere and in this way the temperature remains higher than she should normally be and, in this way, creating a warmer climate. The phenomenon is basically acting like a covering, placed around the earth. The GHG are Carbon Dioxide, Methane, Nitrous Oxides and Water Vapor or otherwise called feedback due to its physical or chemical response to temperature changes. The most significant GHG is the carbon dioxide. Under normal circumstances it is produced from the earth itself and it is responsible for maintaining the temperature in levels approximately 15°C which makes the earth a friendly habitat. Although, through the human activity and mainly the burn of fossil fuel the carbon dioxide is constantly being increased through the 20th and 21st century. As a result, more heat is trapped and the temperature is constantly rising. It is estimated that without carbon dioxide temperature on the surface of the earth would be 33°C lower(NASA, n.d.).



Picture 1 - The Greenhouse effect*(British Geological Survey, 2017)*

2.2.The major Greenhouse Gases

2.2.1. Carbon Dioxide (CO2)

CO2 is the most important GHG, which derives from human activities in a percentage of 80%. Its impact is very crucial especially if we consider that it does not have an average life span. About 40% of the emissions will continue to exist after 100 years, 20% after 1000 years and 10% can even last up to 10.000 years. Same as it's life span which is not a specific one and may even continue to exist after thousands of years is the way in which CO_2 is stored. More specifically the gas is constantly moving and remains in oceans, the land and the atmosphere. The main sources of carbon dioxide are the Fossil Fuel Combustion, the Deforestation, several Industrial Procedures like chemical production, Waste Management and Agriculture*(United States Environmental Protection Agency, 2021).*

2.2.2. Methane (CH_4)

Methane is a another GHG with a shorter lifespan. Due to its decomposition after approximately 12 years. Although its impact lasts less, it is much more powerful than the one of CO2and more specifically about 30 times bigger during a 100 years period.

It derives from many sources, both human and natural. In the US it is estimated that it is the 12% of all gases created by human activities*(Natural Resources Defense Council, 2023)*. In global scale, over 50% derives from human activities like natural gas production and livestock-based agriculture and the rest from natural sources like wetlands or even certain insects*(Crown Oil, 2023).*

2.2.3. Nitrous Oxide (N_2O)

Another very powerful GHG is Nitrous Oxide, with a GWP – Global Warming Potential of about 270 times more than CO2 and a life span of about a century. This type of oxide derives from many different sources, both human and natural activities. The biggest source is agriculture, where approximately 60% of the global emissions come from. There is also the Fossil Fuel combustion which is responsible for the 20% - 30% of N2O and smaller sources like the Wastewater and Wastewater treatment and the Biomass Burning which produce a percentage from 3% to 10%. In addition, Nitrous Oxide is not only responsible for the Greenhouse effect, but it can also cause serious damage to the ozone layers *(Crown Oil, 2023)*

2.2.4. Fluorinated gases

There are 3 main types of fluorinated gases, hydrofluorocarbons – HFCs, perfluorocarbons – PFCs and Sulphur hexafluoride – SF6. These types of gases are met extensively in our everyday life and the products that we use. Although they are met in smaller quantities, approximately 3% in the US, Fluorinated gases can trap more heat than the rest GHG, sometimes even 25.000 more times than Carbon dioxide. This increases their GWP by far something which combined with their huge lifespan of thousands of years makes their limitation of huge importance. F gases can be met in a very extensive variety of products like refrigerants in refrigeration, air-conditioning and heat pump equipment, fire extinguishers and aerosols, but also in even more common products like cosmetics and medicines. Finally, many products of the construction industry like insulating gas and high voltage switchgear contain these types of substance. While they are also met in the production of magnesium and aluminum *(United States Environmental Protection Agency, 2021).*

2.2.5. Water Vapor

The amplest GHG that can be spotted everywhere around us and is connected indirectly with human activities. The process of vaporizing water is a result or combination of the production of all the rest GHG. It is otherwise called feedback because of the way it is created. The warm air produced via vaporization can capture more heat than the cold one due to moisture. In this way the atmosphere temperature is increased, while at the same time more and more clouds appear and as a result the effects of solar energy are being limited (Bazari, 2023 b).

2.3.Regions and their GHG production

Since 1750, human activities have produced approximately 1.5 trillion tones of CO_2. First in the ranking of all time emissions is USA with 25% of the global production, in the second place we have EU and UK, while China is into the third place with about 15%. Nevertheless, and due to its huge financial and industrial growth China seems to pass both US – 14% and EU – 8% with a percentage close to 31% for the time being. In the fourth place there is the emerging economy of India with 7% and the Russia with 5%. Finally comes Africa and other smaller regions of the world(The Natural Resources Defense Council, July 2023).

2.4.Climate change and the Greenhouse effect

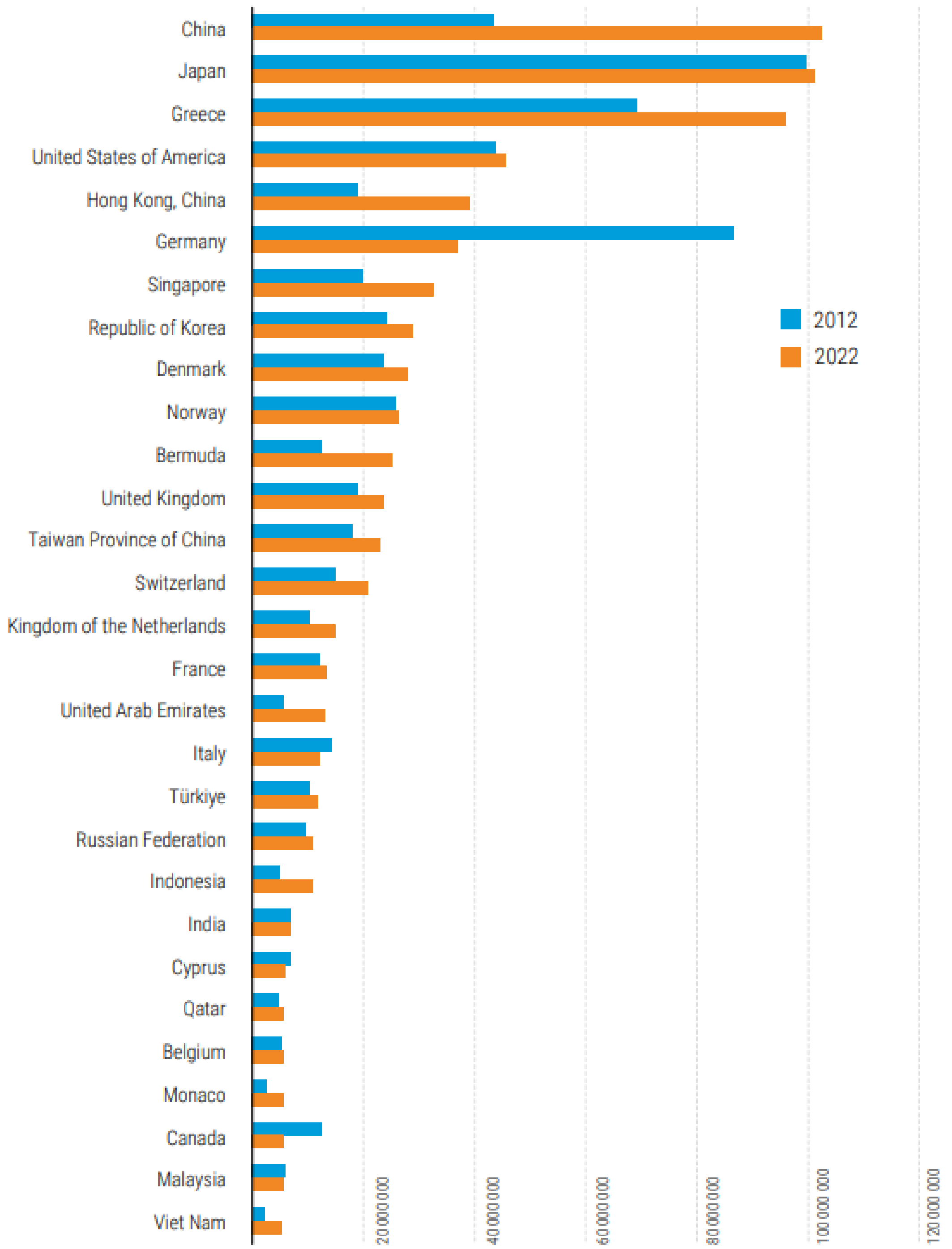
Together with the passage of the years, the production of GHG is also increasing and our planet is heating up. The industrial evolution has played a crucial role in this increase, as the earth’s average temperature has been increased by 2 Fahrenheit degrees, with the biggest part of this increase done during the last decades. Based on the forecasts of IPCC – Intergovernmental Panel on Climate Change our planet can bare 400 billion tons of CO_2 more, if the emissions of Carbon Dioxide do not decrease by 50% then by 2030 the average temperature will be increased by 2.7 degrees Fahrenheit more.

The effects of the Greenhouse effects are known to the majority of the population,

- Dangerous increase of adverse weather conditions like floods, droughts, heat waves and hurricanes
- Melting of the ice leading to increase of ocean’s temperature and finally raising of the sea levels

- Changes in the climate which affect eco systems and their resident creatures

All the above are a live example of the climate change and affects all the parts of our life. First in the list comes the nutrition, floods and droughts heavily affect the agricultural production, it is estimated that the production of grains will be decreased by 3% to 7% every time the average temperature of the earth is increased by 1 degree Celsius. At the same time the increase of temperature benefits the growth of diseases and bacteria. All the above can turn many regions of the world unbearable to live in and create huge migration waves (EEA, 2021).



Graphic 1 –CO_2 emissions by main economies of ownership 2012 -2022 *(Review of Maritime Transport, UNCTAD, 2021).*

2.5. The environmental impact of the emissions deriving from shipping

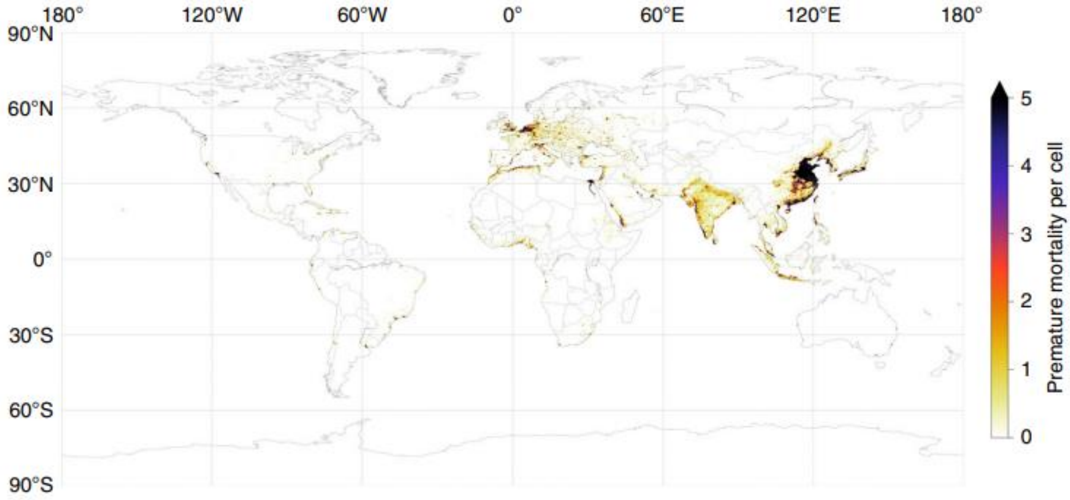
2.5.1. Air pollution

Due to its efficiency, marine transportation has been assessed as the main and safest way of transporting goods since the ancient years, as it cannot be easily affected by geographical and weather conditions. Since the time of Industrial revolution when the demand of products started to rise rapidly, due to the simultaneous growth of the population globally a lot have changed. The steam powered engines have been replaced with oil powered ones. These oil engines use fuels with high conciseness of hydrocarbons and sulfur compounds. The most popular marine fuels are the HFO – Heavy fuel Oil, the MFO – Marine fuel oil, the IFO – Intermediate Fuel Oil, the MDO – Marine Diesel Oil and some variations of them. For the engine to operate, the fuel is injected into the combustion chamber where with the contribution of air a mixture is created. This mixture creates a combustion *(Marine Insight, May 2019)*and the heat released powers the engine. The result of this process is the emission of various hazardous and pollutant gases like CO2 – Carbon Dioxide, NOx – Nitrogen Oxide, SO_X – Sulphur Oxide, N_2 – Nitrous Oxide, CO – Carbon Monoxide, O_2 – Oxygen, HC – non combusted Hydrocarbons, PM – Particular Matters and water vapor H2O through the exhaust system. All the above-mentioned gases and especially the Carbon Dioxide and the Sulphur gases play a significant role in the Greenhouse effect and the overheating of the planet which leads to climate change*(Denchak, 2023).*

Type of fuel	Carbon content	C_F, (t CO_2) / (t fuel)	Approx. LCV, kJ/kg
Diesel / Gas oil	0.8744	3.206	42,700
Light fuel oil, LFO	0.8594	3.151	41,200
Heavy fuel oil, HFO	0.8493	3.114	40,200
Liquefied petroleum gas, LPG	0.8213	3.015	46,000
Liquefied natural gas, LNG	0.7500	2.750	48,000
Methanol	0.3750	1.375	19,900
Ethanol	0.5217	1.913	26,800

Table 1 - Carbon Content per type of fuel*(The fourth IMO GHG study, 2020)*

Whatever affects the environment although affects the human health too. During research performed by Sofiev*(Mikhail Sofiev, February 2018)*, it was found out that 403.300 premature deaths were caused from lung cancer and cardiovascular disease due to shipping activities, this number of deaths is expected to decrease by approximately 34% to 266.300 people in the upcoming years. Moreover, 14 million children suffered from childhood asthma during the same year, a number which is likely to drop at 6.4 million children (DNV, 2022). The areas in which most of the deaths are recorder is Asia (80%), Africa (12%) and Latin America, including Caribbean Area (5%). Most children's ailments caused by shipping activity are recorded in the same areas by 54%, 33% and 12% respectively. The Greenhouse Gases which are believed to be the most harmful for the human health are SO_x – Sulphur Oxide, NO_x – Nitrous Oxide and PM – Particulate Matters. The first category is created during the process of combustion, due to the presence of Sulphur in marine fuels. In this ways SO_2 and SO_3 are produced and released into the atmosphere. The higher the percentage of Sulphur in the marine fuel, the highest are the emissions of these gases into the atmosphere. The Sulphur Oxides are considered as dangerous for the human health due to their ability to create aerosol gases which are responsible for various health problems in the respiratory system as well as cardiovascular and lung disease. The Sulphur Oxides are also particularly responsible for the phenomenon of acid rain which causes deforestation and pollution of the oceans. The second oxide significantly dangerous for the human and the nature is the NO_x – Nitrous Oxide, it is produced in the same way with the Sulphur ones, through the process of combustion and has the same impact on the human health, respiratory problems, cardiovascular and lung disease as well as the environment, by contributing to the phenomenon of acid rain. Finally, due to their impact on human health important emissions are the PM – Particulate Matters. They consist of leftovers from non-combusted hydrocarbon components, heavy metals, elemental carbon and ash minerals. Their impact to human health is direct and harmful. In case of inhalation, they affect the lungs and the heart causing heart and lung diseases including cancer. They can remain in the human as they are absorbed into the bloodstream*(Bazari, 2023).*



Graphic 2 - Mortality due to shipping(Cleaner fuels for ships provide public health benefits with climate tradeoffs, Mikhail Sofiev, 2018)

2.5.2. CO2 emissions and carbon intensity

As per the last IMO official publication in 2020, the Greenhouse Gases emissions (Carbon Dioxide -CO2, methane - CH2, Nitrous Oxide N2O) have been increased from 977 million tons in 2012 to 1.076 million tons in 2018. From these amounts the 962 million tons were CO2 in 2012, which increased at 1.056 million tones later in 2018. Although the above numbers seem huge, they only consist of the 2.76% of the global emissions deriving from human activity in 2012 which increased at 2.89% in 2018.In terms of consumption, the Container ships are on top of the list, as at an average voyage they use approximately 69.906 tons of HFO, then comes the Bulk Carriers with 54.359 tones and the Oil Tankers with 37.045 tones. At the bottom of the list, we have the offshore vessels with 1.747 tones, of course there are also intermediate categories in this classification such as Cruise Ships, LNGs – LPGs, Ro - Ro Vessels etc. The emissions of Green House Gases also vary not only from vessel to vessel but also from one phase of operation to another. For example, an LNG or LPG tanker creates more GHG during normal cruising, while on the other hand an Oil Tanker produces more GHG during slow transit. During the last GHG emissions study, a new apportionment based on voyage was introduced. This allocation proved that the CO2 emissions have also been increased from 701 million tons to 740 million within 6 years from 2012 to 2018. Nevertheless, the rate remains lower the one of global shipping emissions and stands for approximately the 2% of the global shipping emissions. Using the same approach for the same period, it has also been found out that for the same period the CO2 emissions have been increased by 8.4% from 848 million to 919 million tones until 2018*(IMO, 2020).*

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%

Table 2 - CO2 Emissions based on voyage and vessel type*(The fourth IMO GHG study, 2020)*

Year	EEOI ($gCO_2/t/nm$)				AER ($gCO_2/dwt/nm$)				DIST ($kgCO_2/nm$)				TIME (tCO_2/hr)			
	Vessel-based		Voyage-based		Vessel-based		Voyage-based		Vessel-based		Voyage-based		Vessel-based		Voyage-based	
	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change	Value	Change
2008	17.10	–	15.16	–	8.08	–	7.40	–	306.46	–	350.36	–	3.64	–	4.38	–
2012	13.16	-23.1%	12.19	-19.6%	7.06	-12.7%	6.61	-10.7%	362.65	18.3%	387.01	10.5%	4.32	18.6%	4.74	8.1%
2013	12.87	-24.7%	11.83	-22.0%	6.89	-14.8%	6.40	-13.5%	357.73	16.7%	380.68	8.7%	4.18	14.6%	4.57	4.1%
2014	12.34	-27.9%	11.29	-25.6%	6.71	-16.9%	6.20	-16.1%	360.44	17.6%	382.09	9.1%	4.17	14.4%	4.54	3.5%
2015	12.33	-27.9%	11.30	-25.5%	6.64	-17.8%	6.15	-16.9%	366.56	19.6%	388.62	10.9%	4.25	16.6%	4.64	5.7%
2016	12.22	-28.6%	11.21	-26.1%	6.58	-18.6%	6.09	-17.7%	373.46	21.9%	397.05	13.3%	4.35	19.3%	4.77	8.7%
2017	11.87	-30.6%	10.88	-28.2%	6.43	-20.4%	5.96	-19.5%	370.97	21.0%	399.38	14.0%	4.31	18.2%	4.79	9.2%
2018	11.67	-31.8%	10.70	-29.4%	6.31	-22.0%	5.84	-21.0%	376.81	23.0%	401.91	14.7%	4.34	19.1%	4.79	9.2%

Table 3 - Carbon Intensity based on voyage and vessel type*(The fourth IMO GHG study, 2020)*

The fourth IMO GHG study has also taken advantage of the new data collection and analyzing methods to discriminate emissions deriving from domestic and international shipping and in this way, it is now fully complied with the IPCC - Intergovernmental Panel on Climate Change standards and procedures. Through the application of the new allocation in the 2008 emissions, researchers found out that the CO2 emissions were increased from 794 million tons to 940 million tones for the period from 2008 to 2014*(IMO, 2020).*

While the emissions kept rising, the carbon intensity in international shipping has been decreased for the period 2012 to 2018. More specifically it was 21% lower in terms of AER – Annual Efficiency Ratio and 29% in terms of EEOI – Energy Efficiency Operating Indicator. The decrease in carbon intensity does not follow a steady pace. Less than the half of what was initially set as a goal has been achieved until 2012. This pace has been slowed down even more since 2015, as the changes in carbon intensity per year, now range from 1% to 2% decrease per year. The carbon intensity range differs per type of vessel too. For tankers, bulk carriers and container ships the fluctuation is approximately 20%, 15% and 10% respectively. For the rest types of vessels, the range per quartile is generally above 5%. Nevertheless, in many cases and especially for containerships, the data given is inaccurate and the range possibly differs because of weather and fouling conditions and irregular updates of the AIS – Automatic Identification System on draught*(IMO, 2020; Wartsila, 2023).*

The maritime emissions are likely to increase by 90% from the rates recorded from 2008 until 2018 and by 90% - 130% until 2050, depending on financial and energy factors. The alteration in these rates depends on economic growth and the changes in the emissions of land base human activity which affects the global temperature. A typical example of the above is the period of COVID – 19 pandemics where the emissions in 2020 and 2021 where significantly decreased. The outcome is not clear yet, but it is estimated that in the next decades emission rates will face small decreases*(Carlton, 2023).*

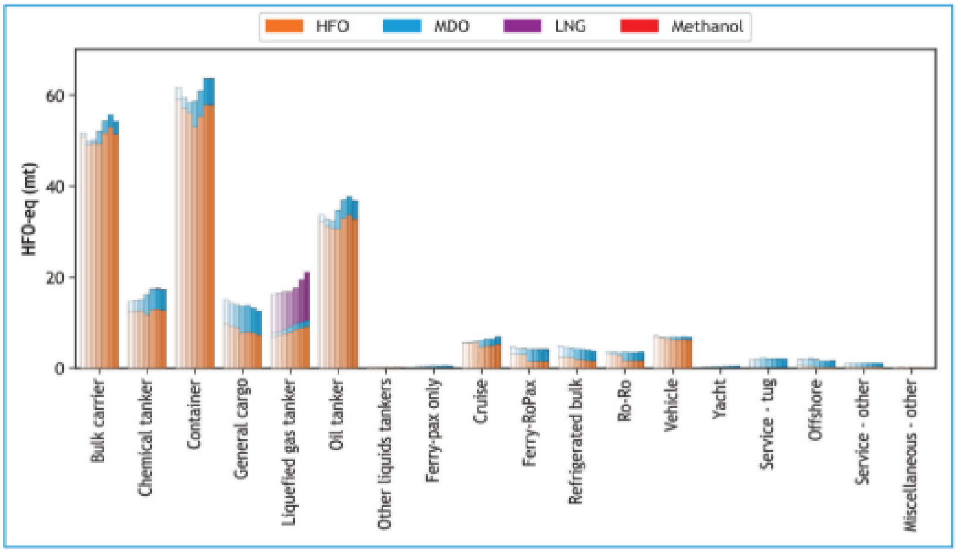
2.5.3. CO2 emissions and carbon intensity 1990 -2020

For the period 1990 to 2008 there is an obvious increase at the CO2 emissions which is linked with the expansion of the seaborn trade as advised by the UNCTAD – United Nations Conference on Trade and Development. For the period 2008 – 2014 the results are the opposite, although the seaborn trade is constantly growing, the CO2 emissions tend to decrease, as a result there is a simultaneous decrease of the carbon intensity rates too. This decrease will continue for the period 2014 to 2018 but this time on lower paces, this pace together with the continuous growth of trade will lead to the increase of the CO2 emissions again*(UNCTAD, 2022).*

2.5.4. Emission inventory

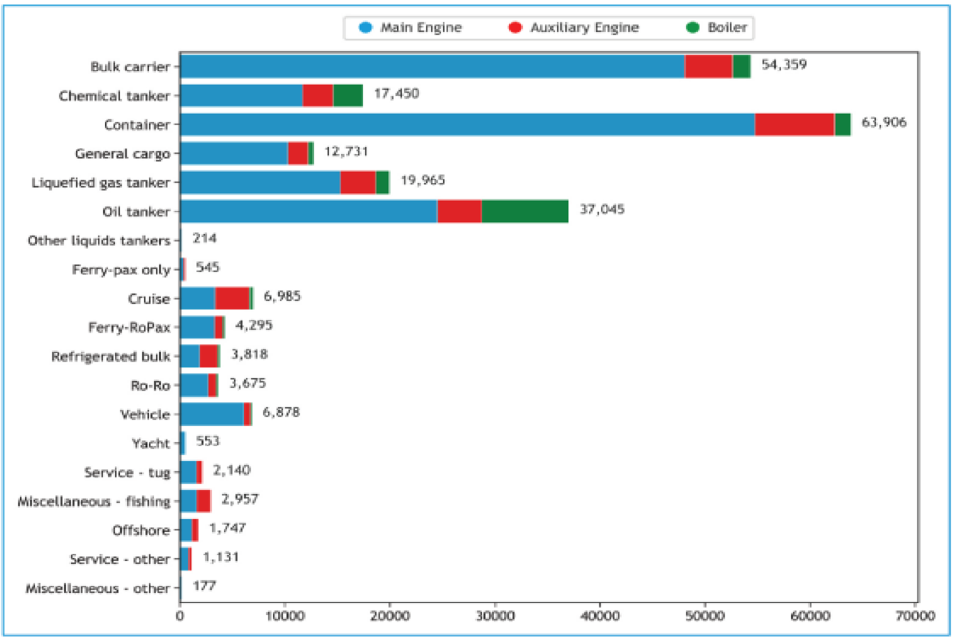
There are more than one way in which we can categorize and compare the emission numbers. More specifically, through the previous IMO GHG study a new method of categorization was used. This time, instead of using vessel’s characteristics like the size and the type, the place which they operate was used as a criterion. This method is based on suppositions regarding the way of operations of vessels with alike characteristics. Through a first analysis, this method appeared to have various aberrations and for this reason it was combined with previous IMO GHG studies in order to provide more reliable outcomes. In the below figure we can see the analysis using both the new voyage-based estimation but also the previous vessel based one. To sum up, the voyage – based allocation is the one calculating the emissions of a vessel during a trip between two international ports, while the voyage – based is the one using the types of vessels as a figurative. The voyage – based allocation cannot be used for voyages within the same country*(NKK, 2021).*

To achieve high – quality and accurate results, it would be better to separate the two methods and draw results only from one of them in order to extract the desirable data. In this case only the newly inserted voyage – based estimation is used, as it appears to have only minor differences in the results compared with the vessel – based one, while using the same data. In the below figure, the fuel consumption based for each vessel type is being reflected for the period 2012 – 2018. Through these 6 years, the types of vessels which remain on top of the GHG emissions are the most known ones, Bulk carriers, Container carriers and Oil tankers. Summed up with General cargo ships, LNGs and Chemical tankers they seem to create a percentage of 86.5% of the total GHG emissions deriving from the shipping industry. These rates are calculated upon the voyage – based method. The HFO – Heavy fuel oil remains on top of the chain, as it is used by the 79% of the global fleet. Although, through the last few years and due to new regulation, changes have occurred to this fuel's composition. As a result, its consumption has been decreased, while simultaneously the use of MDO – Marine Diesel Oil and LNG – Liquefied Natural Gas has been increased by 6% and 0.9% respectively. The introduction of methanol as a marine fuel through the last two years has also affected the consumption of the commonly known fuels. Calculated on voyage-based estimation, 130 thousand tones were used in 2018*(NKK, 2021).*



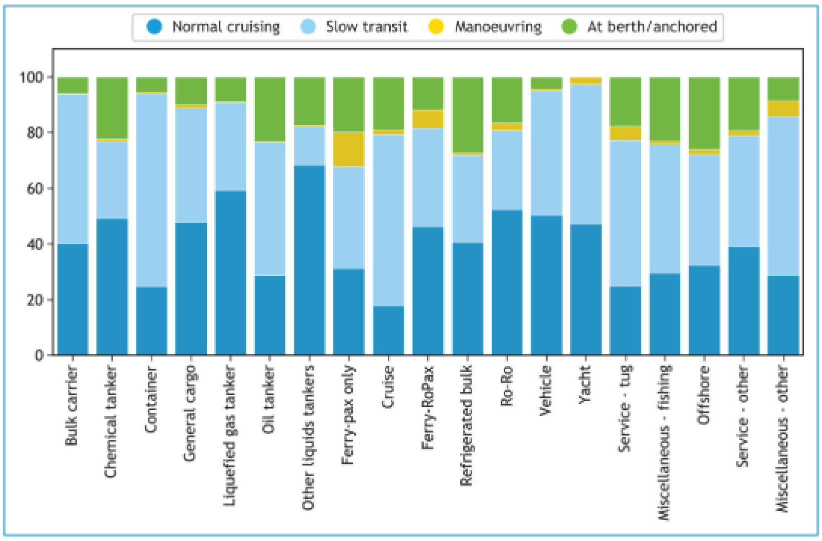
Graphic 3 - Fuel Consumption per ship type, based on voyage*(The fourth IMO GHG study, 2020)*

The voyage-based allocation can also use other criteria to extract outcomes. An alternative of this method is to use the consumption of the mechanisms used for the operation of the vessel and more specifically the main engines – propulsion, auxiliary engines – electrical power and boilers – heat as described in the below figure. This method applies to all type of ships except of cruise ships, refrigerated bulk and fishing vessels.



Graphic 4 - Fuel Consumption split by main engine, auxiliary engine, and boiler, per voyage*(The fourth IMO GHG study, 2020)*

Another alternative of the voyage – based method is to count on the GHG emissions recorded in each phase of a voyage. Each type of vessel consumes different number of fuels during the different phases of the operation and as a result different amount of GHG are emitted while being underway, maneuvering, being at berth or anchored. Between the known types of vessels Oil and Chemical tankers emit the largest portion of their total GHG emissions when approaching ports and terminals. At the same time, Container and cruise ships produce smaller amounts while cruising as during a large phase of their voyage, slow steaming is preferred. Finally, LPGs, LNGs and other liquid tankers appear to have high GHG emissions during cruising,



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Graphic 5 - Emissions for each operational phase of a vessel based on voyage*(The fourth IMO GHG study, 2020)*

2.6.The evolution of marine fuels

The fuels used for the movement of ships or otherwise called bunkers. The term derives from the time when the vessels were still using coal to power their movement and was the storage where the coal was placed(*Mitsui O.S.K Lines, August 2021).*

2.6.1. Steamships and coal

During the industrial revolution, the first steam powered engines were developed and used to power ships. The first successful attempt belongs to Robert Fulton in 1807, who created the “Clemornt” a paddle wheel steamship carrying passenger along Hudson River from New York to the committee of Albany. Although, these types of vessels were facing big difficulties especially in cargo transportation as they were equipped with huge boilers to ensure that they will have efficient thermal energy. Moreover, the space which this equipment was occupying was dramatically decreasing the storage capacity of cargo and coal. Another huge difficulty which the first steamships were facing was the fact that during adverse weather condition the steering system and the paddle wheel of the vessels was tearing apart easily. The construction of the hull was also not allowing the vessel to obtain full power during stormy weather and big waves. Finally, the explosions of the heating boilers were a very usual phenomenon and because of all the above the early steamships were used mainly for routes along rivers and lakes and during calm weather, but they were still unable to compete with the railway system developed especially in the United Stated mainly because of its cost effectiveness. The first apparent improvement of steamships came in to focus in 1845 when the first transatlantic passing took place. This event meant the beginning of a huge competition in cargo transportation speed and quantities between Atlantic nations and especially UK and US*(Mitsui O.S.K Lines, August 2021).*

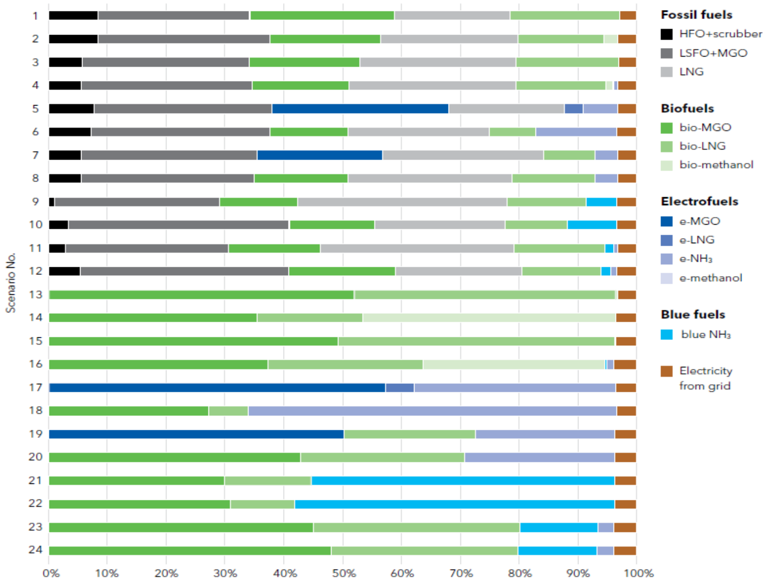
2.6.2. From Coal to Oil

At the beginning of the 20th century, the transaction from steam engines to marine diesel engines began. The developing fuel industry made easy to understand that using diesel can lead to improved efficiency for the same or even smaller capacity of fuel. It was at that time when the coal powered engines began being replaced by internal combustion engines. Except of the increased efficiency and the lower consumption of fuel, the new fuel tanks were smaller giving in this way more space for cargo and at the same time reducing the number of crew as there was no longer need for people to constantly supply the boilers with coal. All the above led into a parallel increase of profit and decrease of the operational expenses. At the same time the ships were able to travel longer ranges without the need for additional bunkering.

After World War II almost all types of external combustion engines had been replaced with internal combustion engines, which led to a constantly increasing demand of cheap fuel. This led to the creation of the HFO – Heavy Fuel Oil, which is mainly made by the leftovers of the refining process. There are also other types of fuels which are being used for different purposes on a vessel and have different characteristics (MGO – Marine Gas Oil, MDO – Marine Diesel Oil, IFO – Intermediate Fuel Oil, MFO – Marine Fuel Oil). In January 2020 a new regulation was submitted by the IMO – International Maritime Organization, which was aiming to reduction of Sulphur oxide emissions by 70%. To achieve this a new type of fuel was introduced, the LSFO (Low Sulphur Fuel Oil) as well as the VLSFO (Very Low Sulphur Fuel Oil) were significantly lower in Sulphur conciseness. More specifically the content was reduced from 3.5% to 0.5% when it comes to LSFO, lower than 0.5% for VLSFO and lower than 0.10% for ULSFO (Ultra Low Sulphur Oil). It is very important to clarify that the maximum percentages of Sulphur conciseness depend on the ECA – Emission Control Areas (Baltic Sea, North American Sea, United States Caribbean Sea), established by MARPOL - International Convention for the Prevention of Pollution from Ships(*Mitsui O.S.K Lines, August 2021).*

2.6.3. A prediction for the future of Marine fuels

Various goals are being set for the future use of marine fuels*(DNV Maritime Forecast, 2022),* based mainly on timetables. The first milestone set by 2030 concerns the energy used by the shipping industry, which should come from carbon neutral fuel at a percentage of approximately 5%, without eliminating at the same time vessels using HFO and its byproducts. This will be achieved mainly by slow steaming. The second and even more ambitious milestone is by 2050 all the



Graphic 6 - Scenarios for the marine energy mix until 2050 ***(DNV Forecast 2023 edition)***

fossil fuel to be eliminated and the movement of the ships to be based on electricity (7% - 8%) and carbon neutral fuels approximately 92% - 93%. Reasonable care is already taken in various ways, mainly through regulations imposed by IMO, the most of them have already began to apply (EEXI – Energy Efficiency eXisting ship Index, CII – Carbon Intensity Indicator, SEEMP – Ship Energy Efficiency Management Plan). At the same time, there are principles and regulations which are likely to be applied in the close future, some of them concern the collection and processing of data, while other concentrate on the emissions of the vessel (GHG standards, EU ETS – European Union Emissions Trading System, Black Carbon and VOC – Volatile Organic Compounds). To be even more clear, at the time being there are 11 vessels using Methanol, 19 vessels using LPG, 396 using Battery (Hybrid), 923 vessels using LNG and the rest of them (approximately 98.8%) are still using conventional fuels. Taking into consideration all the aspects of an operating vessel (Logistics, Hydrodynamics, Machinery, Energy and After Treatment) the IMO is aiming to turn all these vessels using conventional fuels into using alternative fuels so that the goals mentioned above are finally achieved. The most widely known alternative fuels are Ammonia, Hydrogen and Methanol. Of course, all the above cannot be achieved without efficient capital, the cost for on shore facilities is estimated to increase about 2.5 times, while at the same time orders for technology advanced new building vessels will be the only solution possible (IMO, 2023).

2.7. Acts for prevention of marine pollution deriving from GHG emissions

2.7.1. Air pollution from ships

The pollution caused from gases deriving from vessels may not be that intense compared to disasters caused by oil spills but plays an indirect role to the degradation of the air quality and causes phenomena like acid rain. Once again MARPOL Annex VI intervenes and through regulations is attempting to confine pollutant gases like Sulphur oxides SOx and nitrous oxides NOX while at the same other exhaust gases harmful for the ozone are being prohibited. Many changes and amendments have been made to the original MARPOL Annex VI since the first time of its implication, trying to further reduce the NOX and SOx emissions, while at the same time the geographical factor is taken into consideration as ETCAs – Emission Control Areas have been established in order to protect certain regions and ecosystems of the world. Under MARPOL Annex VI the vessels sailing in ECAs are prohibited from using fuels with more than 0.1% Sulphur, while since 2020 the maximum limit of Sulphur is 0.5% outside ECAs. The only category exempted is the passenger ships, as their fuel can contain up to 1.5% Sulphur. The above can be achieved by choosing different types of oil like LSFO or ULSO lower in Sulphur than the usual oil but also by installing exhaust systems with scrubbers or exhaust gas cleaning technologies. As last resort shipowners can consider changing the motors of their fleet into LNG or methanol using ones (Bazari, 2023).

2.7.1.1.Strategy on reduction of GHG emissions

The 2023 IMO Strategy on Reducing GHG emissions from ships is a part of the greater aim of the International Maritime Organization to reduce and finally eliminate Greenhouse Gases Emissions from shipping worldwide. This strategy is based upon previous measures and policies like the Assembly Resolution A 963 (23), established on December 5, 2003. This and many other resolutions are inciting the MPEC to elaborate new mechanisms to achieve the IMO's greater commitment regarding the reduction and eradication of GHG from the global shipping industry. The initial strategy for the reduction of GHG in shipping was first imposed by the International Maritime Organization at the MPEC 304 (72) and was basically indicating the inceptive steps for the above-mentioned aim. This strategy is only a part of the whole master plan as approved in MPEC 70 and contains constant changes and amendments. Some of them have been introduced in 2023 MPEC 80 and many more are yet to come. The IMO GHG 2023 Strategy is the most recent landmark set in the general strategy of the organization in order to fulfill his commitment towards environmental sustainability and GHG emissions in shipping(IMO Annex 1 Resolution MEPC.377 – 80, July 2023).

The revised IMO GHG strategy provides clear guideline in order to lead its members towards carbon clear emissions and reduction of the Greenhouse Gases. During the implementation of the strategy, goals are set, future targets are stated, and guidance is provided. The strategy also proposes measures and deadlines for their implementation as well as the possible impact of them. In addition, it underlines factors which can act as deterrents for the implementation of the strategy. Finally supportive measures initiated by the organization are also described.

A fundamental position of the strategy is the organization's purpose to decrease Carbon Intensity - CO_2 emissions per transport work by at least 40% up to 2030. The strategy also pays great attention to the use of technologies, fuels and energy sources which emit zero or near zero GHG emissions. As per the organization the use of these means should be increased by 5% - 10% by 2030.

Finally, the strategy highlights the importance of reducing and finally eliminating the above-mentioned technologies and fuels in order to achieve the temperature goal who is set in the Paris Agreement.

2.7.2. MEPC and MEPC 80

All the above measures and politics are examined tactically through conventions established by the IMO. The responsible committee for examining environmental issues, generating solutions, setting goal and monitoring them, is the Marine Environment Protection Committee, MEPC. The MEPC aims into protecting the marine environment under the auspices of the International Maritime Organization IMO. It covers a wide range of different marine activities which can be proved harmful to the environment as imposed by MARPOL. Some of them are the emissions of Greenhouse and other air pollutant gases, sewage, garbage, oil pollution and pollution from chemicals carried in bulk. At the same time MEPC acts against other harmful shipping activities such as ballast water management, anti – fouling systems and ship recycling. Finally, the convention addresses plans for the prevention and handling of pollution in case of accidents and established specific areas which should be protected due to their sensitive marine environment. To sum up, the IMO remains on his course trying to reduce the GHG emissions of international shipping as soon as possible, facing this as a matter of urgency. At the same time special care is given to ensure that the changes and the goals set in the industry will be fair and tangible for all.

Through this last meeting, the most important matters discussed regarding the GHG emissions are the below:

- Vessels' Energy Efficiency, approval of changes to IMO system for collection of data (DCS) of the oil consumption
- Biofouling Management, approval of updated guidelines
- Establishment of new Sensitive Sea Areas in the North – Western Mediterranean aiming at the protection of cetaceans
- Underwater noise, approval of revised guidelines
- Prevention of marine litter, progress on tracking lost containers and use of plastic pallets
- Ship to ship transfers, proposed Assembly resolution
- Special areas, the dates from which the Red Sea and the Gulf of Aden will be considered as Special Areas

2.7.3. Generic framework of the IMO and the EU policy

During his recent committees, the International Maritime Organization, has established new measures to further enhance its effort toward the elimination of GHG emissions from the shipping industry. These regulations have been decided after continuous negotiations and are based on 4 guiding principles. The first one is the assessment of the lifetime of the GHG intensity. Through the last conference, new guidelines based on a WTW – Well To Wake approach are introduced. Using this approach the GHG emissions are calculated through all the stages of fuel's life, from the production, transportation, transformation and distribution of the fuel up to the combustion by the vessel. There are also some sub – models such as the WTT – Well To Tank and TTW – Tank To Wake. The first sub – model refers to the stage of the extraction and supply of the vessel, while the second model category refers to the emissions produced only during the stage of fuel burning. The second principle concerns the use of eco – friendly biofuels, through revised guidelines introduced and approved during the last 3 committees. These guidelines refer to the DCS – Data Collection Systems used to gather the necessary data and calculate the CII – Carbon

Intensity Indicator, after the calculation of the CII, it's compliance with the organization's standards is assessed and a SEEMP – Ship Energy Efficiency Management Plan is organized. The third principle of the committee concerns the ISWG (Intersessional Working Group) – GHG, a committee created to analyze and prepare proposals which will be discussed in the upcoming MEPC. This meeting will take place during the next MEPC 81. The last guiding principle regarding the elimination of GHG emissions is the OCC – Onboard CO_2 Capture. A method through which the exhaust gases released are being processed and cleaned from CO_2. They are later being stored and finally released in different forms depending on the available technology*(Piernext, 2023)*

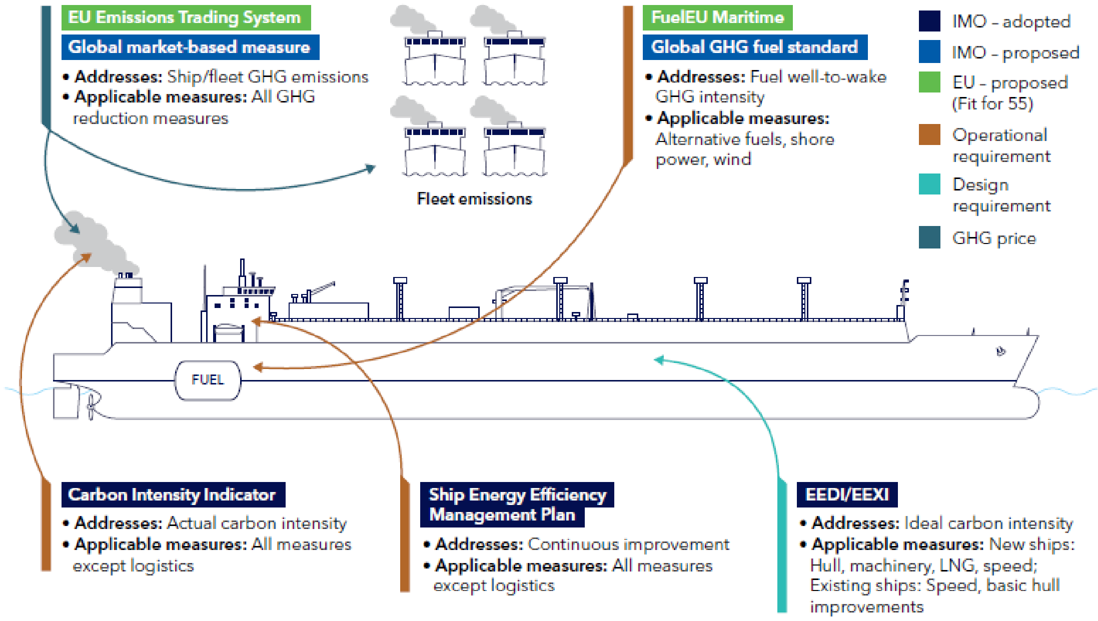
The Greenhouse Gases strategy of IMO is part of an expanded framework of collaboration and decision making which includes:

- The participation of other regulating organizations responsible for maritime, climate and sea protection issues. Some of them are the United Nations Convention on the Law of the Sea UNCLOS, the United Nations Framework Convention on Climate Change UNFCCC and the Paris Agreement.

- The Agenda of the United Nations for Sustainable development in 2030

- The standout position of the Organization in the creation, implementation, evaluation and monitoring of new regulations applicable to the international shipping

- The decision of the thirty second Assembly (A32) at December 2021, set and adopted a broad strategic direction for the organization, called "Respond to climate change"*(IMO, 2023)*



Graphic 7 - Regulatory Framework for the reduction of GHG emissions*(DNV Maritime Forecast 2023 edition)*

Through the examination of the above graphic, we can notice that measures concerning both technical, operational and design aspects have been or will be proposed and applied. Regarding the operational measures, regulations about the fuels used in vessels and the GHG that they product have already been implied. Further on, every vessel of 5000 GT or more, must have a SEEMP – Ship Energy Efficiency Management Plan which is constantly being reviewed and modified. Finally, the latest measure is the CII – Carbon Intensity Indicator, which is applicable since January 2023. Regarding the design of the vessel, the most effective regulation is the newly enforced EEXI which addresses to existing vessels through improvements of their technical means and modifications to speed. All the above are part of a general plan of the IMO, which is called emission pricing and is responsible for calculating the damage that these emissions cause (damage to crops, health care costs from heat waves and droughts, loss of property from flooding and sea level rise etc). After the calculations, these emissions are tied to their sources*(DNV Forecast 2023 edition).*

Although IMO is the main regulatory body, governments and committees globally must cooperate to eliminate GHG emissions in shipping. The European Union has already acted through a plan for the "inclusion of the maritime emissions in the EU ETS – Emissions Trading System". Since the 1st of January 2018, the European Union obliges all vessels over 5000 GT carrying cargo or passenger and operating within the EEA – European Economic Area to calculate and report their CO_2 emissions*(EU ETS 2018)*. The union aims to reduce the GHG emissions from ships by 2% until 2025, 14.5% until 2035 and 80% until 2050, using 2020 as a baseline. Beginning from the 1st of January 2024, the EU ETS will include the emissions of all vessels above 5000 GT, which create the 90% of the volume within the industry, entering the European ports, regardless of their flag. For vessels entering or exiting Europe from or to another continent, 50% of the emissions will be included and the remaining will be processed as the third country wishes. For vessels sailing between two ports inside the European continent, the whole number of emissions will be included in the calculation. Except of CO_2, other harmful gases like CH_4 and NO_X will be included in the calculations by 2026. The emissions will be inserted into the system and their compliance with the limits set by the EU will be examined. These limits will be gradually reduced to achieve the best possible outcomes. In this way the shipping enterprises will be pushed against more eco - friendly technologies and fuels, while at the same time the gap between the price of the traditional and alternative fuels will be bridged. In real time situation, each shipping company will have to buy and deliver their allowance for each ton of emissions, based on EU ETS. For the transition in the new regulation to be smoother, the shipping companies are obliged to hand in only a percentage of their total emissions, beginning from 40% until 2025, 70% until 2026 and 70% from 2027 and then. The above data will be regularly examined, and the requirements will be modified base on the IMO regulations*(EU ETS, 2023).*

Apart from the regulations for the emissions, as these are set, the EU has set since July 2021, a new basket of measures called “Fit for 55” package. This basket includes:

- A fuel EU maritime regulation which sets a cap at the GHG emissions produced by marine fuels, while at the same time urges to the use of zero emission technological means while the vessel is berthed. In this way the use of renewable and low carbon marine fuels is enhanced
- A revision of the directions which are set and concern the electricity sources in ports, both maritime and inland

- A revision of the directions set and concern the renewable supply sources within the EU. Through these revised directions, the need of renewable sources of energy is in transportation underlined and goals for their use are set.
- A revision of the taxation policy of each energy product within the EU

Through the implementation of this basket of measures the EU is trying to create barriers, such as the Energy Efficiency regulations and the use of alternative eco-friendly fuels to eliminate the Greenhouse Gases emission within the industry.

2.7.4. GHG emissions and the different scenarios

During the third IMO GHG Study in 2014, it was calculated that Greenhouse Gases deriving from Shipping can increase at an extend from 50% to 250% until 2050 compared to the year 2012, when the GHG emissions from shipping were the 2.2% of the CO2 emissions deriving from human activities. Some years later in 2020 another GHG study showed us that the emissions produced from shipping were approximately 2.89% of the total emissions from human activity and was estimated to be increased at an extend from 90% to 130% by 2050. All the above estimations can be turned into facts if more intensive use of IMO Ship Fuel Oil Consumption Database – IMO DCS are used in the short-term future*(IMO, 2023).*

2.7.4.1.Aim of the strategy

The IMO GHG 2023 strategy has 3 main objectives which will help the organization fulfill its commitment. The first of them is to include and build upon already existing international agreements like the Paris Agreement and the United Nations 2030 Agenda for Sustainable Goals Development, the 13th part of this agenda is to "Take urgent action to combat climate change and its impacts". In this way the contribution of IMO in the effort made to reduce the GHG emissions will be further reinforced. The second objective concerns the identification of the measures and actions which should be taken in the shipping sector. At the same time the impact of these actions on the states and the shipping globally should be taken into consideration, without underestimating and downgrading the critical role of international shipping. At the top of the priorities is always the development of global trade and transportations. To achieve the above-mentioned goals, new incentives for the development and application of advanced technological means and processes should be given. In this way more and more states and enterprises will be move towards alternative fuels, energy efficiency and routing optimization. the monitoring of GHG emissions is also of great importance. Through the application of monitoring systems and emission tracking technologies, clear outcomes can be made regarding the future course of the GHG emissions and in this way proceed to their limitation and elimination, achieving IMO's strategy (IMO, 2023).

2.7.4.2.Levels of ambition, timelines and guiding principles

Through reviews and changes as these are described later, the IMO 2023 GHG Strategy, indicates clear levels of ambition for the whole shipping industry. Emphasis is given mainly in the technological means and development. Different kinds of innovation will lead to low GHG emissions, close to or even total zero. New technologies, fuels and other energy sources will gradually lead into achieving the overall level of ambition if the above are applied in the global shipping industry. These levels of ambition and milestones should take into consideration all parts of the GHG life cycle as it is described in the LCA – Guidelines on life cycle GHG intensity of marine fuels, developed by the IMO. The objective of course will be the same, reducing GHG emissions in the shipping cycle but with great care given in order to avoid transferring these emissions from the shipping to another field of industry.

In total there are 4 levels of ambition:

• The improvement of the ship's efficiency as a tool for reduction of the vessel's carbon intensity

• Decrease of the vessel's carbon intensity in the industry globally

o The goal is to decrease the CO_2 emissions by at least 40% by the year 2030, in comparison to 2008

• Use of technologies, fuels and other sources of energy which lead to zero or near to zero Greenhouse Gases emissions o The use of sources of energy which will emit extremely low or close to zero GHG emission, should represent a 5% to 10% of the energy used in the shipping industry by the year 2030

- The emissions of GHG to reach the bottom

o The reduction of Greenhouse Gases emissions in shipping to almost zero levels by 2050. As part of the Paris Agreement and taking into consideration various circumstances these emissions should be eliminated as soon as possible in order to achieve long term temperature level goals

2.7.4.3.Checkpoints

The goal of zero GHG emissions in the shipping industry is divided in two time periods, using as milestone the year of 2008. The first time period is 2030. Researchers hope that by that time the GHG gases emitted by vessels globally will drop down by 20% or even more hopefully 30%. The second and even more long-term goal is to drop the emissions further and more specifically by 70% to 80% in the best-case scenario by 2040, using 2008 again as a milestone.

2.7.4.4.Guiding Principles

The principles which lead this strategy are roughly the same with the ones that the already existing strategies comply. As first and basic principle, all participants in the shipping industry must respect and comply with the principals of MARPOL and IMO as imposed by their conventions, without making any discrimination or being treated unequally. All the members have responsibilities but these responsibilities not same for each of them. This depends to their capabilities as well as national conditions which are described in the UNFCCC, the Kyoto Protocol and the Paris Agreement. Every ship of every flag is required to abide by the regulations and force the required measures as imposed, while at the same time monitor the effective and correct application of these regulations. Smaller and undeveloped countries should also be taken in consideration. The impact of these regulations in LDCs – Least Developed Countries and SIDS Small Island Developing States, should not be bypassed. These countries are characterized by specific peculiarities and needs as described in the Revised Strategic Plan for the Organization (resolution A.1149(32) and should always be taken into consideration. The above-mentioned principles must always be met but always based on evidence-based decision making combined with preventive measure as stated in resolution MEPC.67(37) (IMO, 2023; UNCTAD, 2023).

2.7.4.5.Candidate short, mid and long term GHG reduction measures with possible timelines and impacts on states

The candidates of the IMO GHG 2023 are not subject only to obligations but to certain timelines in terms of consistency too. More specifically, if the short-term reduction measures are concerned, they should have been agreed and finalized by the committee between 2018 and 2023, as advised by appendix 1. In terms of the midterm measures, these should be agreed and finalized by 2025 at the latest. Although these measures are coming into bundles, they do not have a common date in which they should come into force. Each measure can be applied individually, and its results are monitored individually too. There also other categories of midterm measures which should be finalized and agreed between 2023 and 2030. The dates in which these measures will begin to be applicable differentiates from case to case and the same applies to the date that the first results from the application of the measures will start to be visible. In terms of the short term GHG reduction measures, owners and operators will have to comply with regulations of MARPOL Annex VI 25.3 and 28.11. Under this view, a technical and operational analysis based on specific targets including measures to reduce carbon intensity must be completed and delivered by January 1, 2026. This analysis is otherwise called "short-term GHG reduction measures" (IMO, 2023).

Basket of candidate mid-term GHG reduction measures In line with the timelines as these are imposed in the Strategy and Work Plan, a bundle of measures targeting for the reduction of Greenhouse Gases emitted from vessels must be composed, handed in and applied. This bundle should consist of:

- Technical elements clearly stated marine fuel qualifications aiming to the GHG carbon intensity reduction.

- Economic elements, based on a specific methods and mechanisms of marine GHG emission pricing

To proceed to the finalization of the measures, different criteria and their impact in terms of the financial sector should be examined. In order these mid-term GHG reduction measures to be considered successful and proceed to an alteration of the energy sources used in shipping, a strong motivation factor should exist. At the same time this transition should be fair and in equal shares for all the participants (Carlton, 2023).

2.7.4.6.Other candidate mid-term GHG reduction measures

Except of the basic basket which the candidates owe to prepare and comply with, there more concurrent activities to be done and actions to be taken in order to reduces the GHG emitted from vessels. They are part of the policy of the organization and their main goal is to keep the states properly informed and give them access in efficient data and information. To achieve the above, the administration should provide for up to dated and accessible data in regular basis, using the IMO DCS and other sources like studies conducted. Interaction is also very important; the shipowners and operators should be able to receive efficient feedback regarding the past measures applied and their success but also regarding current projects. In this way they will be able to trace and compare results and monitor their success, but at the same time learning from mistakes made in the past and decide upon the best available practices. If more practical aspects are concerned, IMO should further expand the LCA – Life Cycle Assessment guidelines. The safety should also not be left out, the organization should create a regulatory framework under which the safety of the practices and the transition to policies reducing the GHG emissions is assessed. This framework should continuously expand and being enriched. Incentives should also be generously offered in order new members to be attracted and start switching their policy. The ships although are not the only source of GHG. In order to reduce these emissions, ports should be well equipped and prepared in order to support this effort. More specifically, ports must be able to supply vessels onshore or shoreside with energy deriving from eco-friendly and renewable sources. In addition, their infrastructures should support the provision of zero or near to zero GHG fuels. Finally, the supply chain should also be improved in the same way (IMO, 2023; Carlton, 2023).

Impacts on States The impact from the implication of these regulations should also be carefully examined before proceeding with the implementation of regulations and measures as imposed from the “Revised procedure for assessing impacts on States of candidate measures”. Great care should be given to the LDCs – Least Developed Countries and SIDS – Small Island Developing States. The criteria under which the regulations will be examined as suitable or not are the below:

- Geographic remoteness of and connectivity to main markets
- Cargo value and type
- Transport dependency
- Transport costs
- Food security
- Disaster response
- Cost – effectiveness
- Socio – economic progress and development

After the assessment of both the positive and the negative impact of a measure, the measure can be finally implied. After the application of the measure, the responsible committees should continue to monitor the results to proceed to any change or adjustment (IMO, 2023).

2.7.4.7.Capacity build, Technical Cooperation, Supportive Actions, Research and development

As it is clearly understood, developing countries, including SIDs and LDCs have needs in terms of technical cooperation and increase of their capacity. This is why in many cases, when it comes to application of GHG emission reduction measures, there countries face problems. For this reason, the IMO is tactically assessing the progress in these regions and can provide financial support through the Voluntary Multi – Donor trust fund which is described later. Through this support, all these areas are able to comply with the regulations as these are implied during the Committee and the ISWG – GHG –Intersessional Working Group on Reduction of GHG Emissions.

During the application of these regulations although, IMO is responsible to ensure that the transition will be smooth, fair for all the members and that any country will be neglected. The MEPC is also liable to secure that while the strategy is being implemented, clear rules and safety nets are set in all the fields of its application including technologies, fuels, energy sources and humans. Finally, shipping activity cannot be performed without the human factor. For this exacts reason the crew and all the participants must be properly trained and provided with efficient guidance (IMO, 2023; UNCTAD, 2023).

All the above mentioned cannot be supported by the organization itself only. Strategic allies should be found to contribute to this effort. This can be achieved via partnerships and alliances both in financial and informational level. Using the resolution MEPC.229 (65) "Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships" which will be described later, the members are now able to exchange information and technological methods to achieve increase of capacity. The success of the aforementioned is being tactically examined through the ITCP – Integrated Technical Cooperation Program and the IMO GHG TC-Trust Fund. In case necessary, a revised policy in regard with financial and capacity issues will be created*(IMO, 2023; UNCTAD, 2023).*

The organization has also scheduled its committees for the next 5 years up to 2028 (MEPC 88). During these conferences, various issues will be discussed and examined. The first and most important of them will be the training of all respective crew members to help achieve the IMO GHG Strategy. Moreover, new research and development activities regarding technological and energy issues will be launched. These activities are striving for vessel's energy efficiency and introduction of low or even zero GHG emissions. The exchange of information and the financial between the member states will also be discussed. Finally, more research must be carried out in order to achieve fuel efficiency deriving from alternative sources, especially in the developing countries, LDCs and SIDS. The overall strategy of the organization will be reviewed every 5 years*(IMO, 2023; UNCTAD, 2023).*

2.7.4.8.Previous work imposed by the IMO for the elimination of GHG from shipping

IMO has created several resolutions in order to reduce the emissions produced by Shipping.

- MEPC 62 (July 2011) – endorsed by resolution MEPC.203 (62). It is an introduction of measures both technical EEDI and operational SEEMP aiming at the best possible energy efficiency of the vessels. It is based on Inclusion of regulations on energy efficiency for ships by MARPOL Annex VI (NKK, 2023)

- MEPC 65 (May 2013) – adopted by resolution MEPC.229 (65). It is a technical guide for the member states to enhance cooperation between them and help to shift into more eco-friendly technologies emphasizing in developing countries. It is based on the Promotion of technical co-operation and transfer of technology relating to the improvement of energy efficiency of ships ("ANNEX 4 RESOLUTION MEPC.229(65) Adopted on 17 May 2013 PROMOTION OF ...")

- MEPC 67 (October 2014) – activated the third IMO GHG Study in 2014. Research proved that the GHG emissions from shipping in 2012 constituted the 2.2% of CO2 emissions produced by human activity and that this number could raise from 50% to 250% by 2050.

- MEPC 70 (October 2016) – endorsed by MEPC.278 (70). A set of changes to MARPOL Annex VI, initiating new systems for monitoring and reporting the fuel oil consumption of vessels and collecting data. The resolution also adopted the Road map for developing a comprehensive IMO strategy on reduction of GHG emissions from ships. The above applies to all ships from 5000 GT and above. In other words, to the 85% of the GHG production from shipping globally. These vessels are obliged to collect efficient data regarding all types of fuel that they consume, combined with other types of data regarding their transport work.

- MEPC 72 (April 2018) – adopted by resolution MEPC.304 (72). An expression of the initial IMO Initial IMO Strategy on Reduction of GHG Emissions from Ships. The resolution sets clear goals for the reduction of GHG emitted by shipping activity the soonest possible. The strategy is constantly under review and subject to constant changes.

- MEPC 73 (October 2018) – approval of a corrective plan known as the Program of follow – up actions of the Initial IMO Strategy. It's basic function is to enhance planning by setting clear timelines for the achievement of the IMO strategy

- MEPC 74 (May 2019) – approval of MEPC.1/Circ 855 "Procedure for assessing the impacts on States of candidate measures; adopted resolution". At the same time another resolution MEPC.323(74) on "Inviting Member States to encourage voluntary cooperation between the port and shipping sectors to contribute to reducing GHG emissions from ships". ("2023 IMO Strategy on Reduction of GHG Emissions from Ships") The second resolution is a revision of MEPC 79 and led to the establishment of voluntary multi – members fund "GHG TC-Trust Fund" aiming at the provision of technical and economic support with a parallel capacity development. In this way the cooperation between member states will be enhanced and the strategy of IMO for the elimination of GHG emissions will be further achieved.

- MEPC 75 (November 2020) – endorsed resolution on "Encouraging Member States to develop and submit voluntary National Action Plans to address GHG emissions from ships". It is basically a revision based on resolution of MEPC 79, which approved the fourth IMO GHG Study in 2020 and brought changes to the MARPOL Annex VI. Its cause is to basically empower the EEDI requirements for many different types of ships.

- MEPC 76 (June 2021) – adopted by resolution MEPC. 328 (76), introduced changes in MARPOL Annex VI through a GHG reduction measure basket. This basket consists of three short term measures, the EEXI – Energy Efficiency eXisting Shipping Index, the CII – Carbon Intensity Indicator and an improved SEEMP – Ship Energy Efficiency Management Plan. Consists of seven instructions aiming to support the EEXI and CII regulations. As described by the IMO it is a "Work plan to progress development of mid- and long-term GHG reduction measures in line with the Initial IMO Strategy on Reduction of GHG Emissions from Ships and its Program of follow-up actions". ("IMO's work to cut GHG emissions from ships")

- MEPC 77 (November 2021) – another revision of the original IMO strategy for the elimination of the GHG emission from the shipping industry, in order to further empower the initiatives to achieve the strategy. The committee also adopted the resolution MEPC.342 (77) on “Protecting the Arctic from shipping Black Carbon emissions recognizing that Black Carbon was a potent short-lived contributor to climate warming”. (“Protecting the Arctic from Shipping Black Carbon Emissions”)

• MEPC 78 (June 2022) – ten more technical instructions added in order to support the application and achieve the short-term goals as these imposed by the GHG emission strategy

• Council 128 (November 2022) – essentially blinded the creation of the Multi Donor Fund, paying special attention to the participation of developing countries and especially SIDS and LDCs. The roles, responsibilities, operations, tenure and obligations, in accordance with any specific legislative requirements will be clearly set out and agreed by the 130th council.

• MEPC 79 (December 2022) – an additional revision of MARPOL Annex VI regarding the data collection systems for fuel oil consumption, this time in relation to EEXI and CII regulations. A “Revised procedure for assessing the impacts on States of candidate measures” (MEPC.1/Circ.885/Rev.1) was also approved. Finally, two more resolutions of MEPC 79 (366 and 367) were endorsed aiming at “Invitation to Member States to encourage voluntary cooperation between the port and the shipping sectors to contribute to reducing GHG emissions from ships and Encouragement of Member States to develop and submit voluntary National Action Plans (NAPs) to address GHG emissions from ships”.

• MEPC 80 (July 2023) – the last Committee of the organization under which the MEPC.376 (80) was adopted pointing out clear instructions for the life cycle of Greenhouse Gases intensity of marine fuels – LCA guidelines. During MEPC 80 the impact of short and midterm measures was also examined. Finally, the last resolution of MEPC.377 (80) of the IMO regarding GHG emissions was adopted(IMO, 2023; UNCTAD, 2023).

2.7.4.9.Other relevant initiatives of IMO regarding supporting the reduction of GHG emissions from ships

The action of the IMO although is not limited in the above Committees only, more actions are being taken to achieve the GHG emissions reduction policy. The ITCP – Integrated Technical Cooperation Program, is striving for the support of governments with limited technical expertise and limited access to resources and funds so that they can operate safely within the global shipping industry. For one more time the focal point of this program is to reduce the GHG emitted from vessels. Within the last year, a niche program has been launched by the International Maritime Organization named "Reducing Atmospheric Emissions from Ships and Effective Implementation of MARPOL Annex VI and the Initial IMO GHG Strategy" , striving for the support of the member states in order to achieve their goals regarding the organization's GHG strategy. This program aims to improve energy efficiency measures and reduce the mentioned emissions not only for the period that the vessel is underway but also when it is onshore – shoreside. All the above-mentioned strategies and policies cannot be achieved without financial contribution, this is why IMO has created the voluntary multi – donor trust fund – GHG TC – Trust fund. The fund is drawing capital from the members of the IMO, from United Nations' agencies and other organizations who support the GHG reduction strategy, on a voluntary framework. Through this fund, the organization attempts to provide, except of financial support, technical collaboration and capacity growth in order to achieve the original goals of the IMO Strategy for the elimination of GHG from shipping (IMO, 2023).

Another action taken to support the LDCs, the SIDS and all the rest developing countries is the MTCC GMN – Global Maritime Technologies Cooperation Centers Network. A net of value of approximately 11 million (2016 – 2022) which consists of 5 centers, MTCC Asia in China, MTCC Pacific in Fiji, MTCC Africa in Kenya, MTCC Latin America in Panama and MTCC Caribbean in Trinidad and Tobago. For the time being, the five centers are cooperating on a Phase II GMN, a recent venture which aims at the revitalizing of the fleet owned by these areas in order to achieve the general policy of the IMO for the Greenhouse Gases reduction, while at the same time enhancing their development. Another program launched in the last four years is the Green Voyage 2050 (2019 – 2023) supported exclusively by Norway. With a worth of approximately 7.1 million USD, the project initiates countries to start calculating their national maritime emissions and develop proper strategies and NAPs – National Action Plans, later these calculations processed to achieve the goals of MARPOL Annex VI. At this point it is important to mention that these goals should be turned into laws for the participating countries. Simultaneously, the members must consider and begin the application low or even zero carbon emission projects both on board but also onboard and shoreside. This part of the plan is expected to come to an end by December 2023 but it's impact should affect the future development of NAPs and other relevant projects. Korea is also contributing at the implementation of the IMO GHG strategy by funding the GHG – Smart Program. A project of 2.5 million USD worth, which launched at 2020 and is expected to be completed by 2025. Its goals are relevant to other programs with the main one being the growth of capacity in LDCs and SIDS. It consists of online training courses on annual basis, on field training visits and independent training for each candidate. The project also gives the chance to its participants to claim a scholarship from the WMU – World Maritime University (Bazari, 2023; IMO, 2023)).

To achieve its goal, the organization also has to think the indirect ways in which the GHG reduction strategy is affected, one of them is the fouling of the vessels. In this field, two projects have already get started and running. The first is the GloFouling Partnerships with a worth of approximately 7 million USD, launched in 2018 and expected to conclude in 2025. In cooperation with UNDP – United Nations Development Program and GEF – Global Environmental Facility the program strives to enhance biofouling management and restrict the invasion of non-indigenous species to foreign habitats. The project acts supplementally to the application of the IMO 2011 plan "Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species". The project has also composed in 2022 research called "Analyzing the Impact of Marine Biofouling on the Energy Efficiency of Ships and the GHG Abatement Potential of Biofouling Management Measures". Norway has been involved in Biofouling projects too. In 2022 the TEST Biofouling – Transfer of Environmentally Sound Technologies was launched. The value of the project is approximately 4 million USD and is expected to come to an end by 2025. It focuses mainly on supporting the developing countries elaborate new technological means and methods of Biofouling management. In this way the migration of invasive species and its destructive consequences will be limited (UNCTAD, 2023).

Saudi Arabia is also contributing to the completion of the IMO's goals regarding the reduction of GHG emissions, by creating the IMO CARES – Coordinated Actions to Reduce Emissions from Shipping. A foundation worth of approximately 1.5 million USD already began to operate since 2022 and will be completed by 2024. The foundation's main objective is to bring the North and the South economies together to discover, develop and exchange technological means so that the IMO's Strategy is achieved. The Foundation also provides financial support especially in developing countries is ordered to achieve a gentle transition into the emerging low or zero emission world of shipping, with the contribution of MTCC Network. Another project implemented with the support of Korea is the FFT – Future Fuels and Technology Low – and Zero – carbon project. This alliance worth of 1.2 million USD reinforces the aims of the IMO regarding the Greenhouse Gases policy by delivering analytical tools, used to assist during the conferences of the Marine Environment Protection Committee. The outstanding position of Norway in global shipping can be noticed for one more time through the country's contribution in environmental issues. This time through the IMO-UNEP-Norway Innovation Forum. A venture launched in 2020, with a value of approximately 650 thousand USD. A pioneer project through which the technological innovation is being promoted, the ultimate aim of the forum is to create a worldwide forum through which the best ideas, methods and means will be exchanged between nation in order to achieve low or even zero emission shipping industry. The assemblies are held on the WMD IMO World Maritime Day, with a great success (IMO, 2023).

The financial part is also of great importance, except of the GHG TC – voluntary multi-donor trust fund, the IMO-EBRD-World Bank has created the FIN – SMART – Financing Sustainable Maritime Transport Roundtable. An enterprise which links the member states of the IMO with banks, stakeholders, banks and other financial organizations in order to assess the sustainability of investing in decarbonization of the shipping industry. Of course, the developing countries, LDSs and SIDS are also given great care and emerging opportunities of investing in these countries are examined (Bazari, 2023b).

Finally comes the NextGen – Green and Efficient Navigation portal. It was firstly operated in September 2021 by the MPA – Maritime and Port Authority of Singapore. The portal is another podium which helps all members of the shipping chain to communicate effective information and methods in the field of decarbonization of the industry. The current project of the forum is a trial of new routes used in the Asia – Pacific area aiming at the reduction of the Greenhouse Gases emissions(IMO, 2023).

2.8.Energy Efficiency and Carbon Intensity regulations

2.8.1. EEDI - Energy Efficiency Design Index

As part of the effort for the reduction of GHG in shipping, IMO has created a new amendment of MARPOL Annex VI, the EEDI. This new regulation is basically providing a standard for the newbuilding vessels and ensures that they are complying with standard levels of efficiency, achieving in this way lower emissions. It is basically a figurative between the newbuildings and the y existing ship built in 2010 and onwards*(DNV)*.The regulation is applicable to almost all types of vessels but with different impact to each one, for example the reduction factor is smaller for general cargo vessels, reefers, and smaller ships, approximately 15%. The only types of vessels which are exempted from the EEDI are the Gas Turbine vessels, the Diesel – Electric Drive (not the cruise passenger and the LNG carriers) and the Offshore. The regulations are constantly examined thus the companies must ensure that they follow the most up to date regulations. For the calculation of EEDI as well as all the above regulations, the emissions, the capacity, and the speed are taken into consideration and calculated with the below formula:

$$\frac{(\prod_{j=1}^{M} f_j)(\sum_{i=1}^{nME} P_{ME(i)}.C_{FME(i)}.SFC_{ME(i)}) + (P_{AE}.C_{FAE}.SFC^{*}_{AE}) + ((\prod_{j=1}^{M} f_j.\sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)}.P_{AEeff(i)})C_{FAE}.SFC_{AE}) - (\sum_{i=1}^{neff} f_{eff(i)}.P_{eff(i)}.C_{FME}.SFC_{ME})}{f_i.Capacity.V_{ref}.f_w}$$

Where:

<u>Engine Power</u>

Peff(i): Main engine power reduction due to individual technologies for mechanical energy efficiency

PAEff(i): Auxiliary engine power reduction due to individual technologies for electrical energy efficiency

PPTI(i): 75% of rated power consumption of shaft motor

PAE: Combined installed power of auxiliary engines

PME(i): Individual power of main engines

Ship design parameters

Vref: Ship Speed at reference conditions

Capacity: DWT for bulk carriers and tankers. A percentage of it for containers ships and GT for passenger ships

Specific fuel consumption (SFC)

SFCME: Fuel use per unit of engine power for the main engine

SFCAE: Fuel use per unit of engine power for the auxiliary engine

SFCAE*: Fuel use per unit of engine power for the auxiliary engine (adjusted for shaft generators)

SFCME (i): Main engine (individual)

Correction and adjustment factors (F)

Feff(i): Availability factor of individual energy efficiency technologies

Fj: Correction factor for ship-specific design elements, e.g., ice-classed ships which require extra weight for thicker hulls

Fw: Coefficient indicating the decrease in ship speed due to weather and environmental conditions.

Fi: Capacity adjustment factor for any technical /regulatory limitation on capacity

Fc: Cubic capacity correction

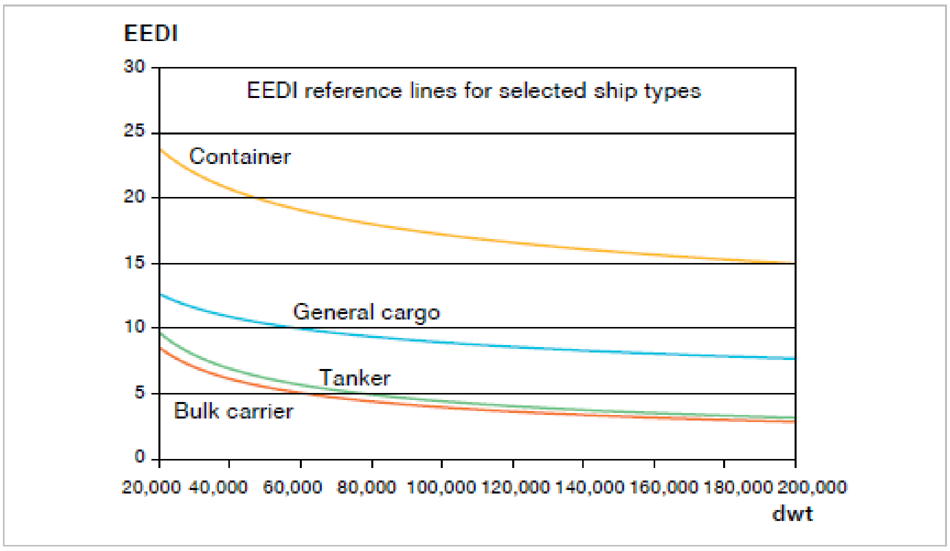
FL: Correction factor to compensate deadweight losses through cargo-related equipment like cranes, RoRo ramps, etc.

Reference line value = $a \times b^{-c}$, where a and c are baseline parameters and b is the maximum deadweight. In the case of Container Carriers 70% DWT is applied

The compared values are the attained EEDI and the required one. The attained must always be smaller by the required and is calculated as per below:

Attained EEDI = $\frac{CO2}{Transport\ work}$

Required EEDI = $(1 - \frac{X}{100}) \times$ Reference line value



Graphic 8 -EEDI Reference line for specific ship types*(Class NK, 2021)*

Ship type defined in regulation 2		a	b	c
2.25	Bulk carrier	961.79	DWT of the ship	0.477
2.26	Gas carrier	1120.00	DWT of the ship	0.456
2.27	Tanker	1218.80	DWT of the ship	0.488
2.28	Container ship	174.22	DWT of the ship	0.201
2.29	General cargo ship	107.48	DWT of the ship	0.216
2.30	Refrigerated cargo carrier	227.01	DWT of the ship	0.244
2.31	Combination carrier	1219.00	DWT of the ship	0.488
2.33	Ro-ro cargo ship (vehicle carrier)	$(DWT/GT)^{-0.7} \cdot 780.36$ where DWT/GT<0.3 1812.63 where DWT/GT≥0.3	DWT of the ship	0.471
2.34	Ro-ro cargo ship	1405.15	DWT of the ship	0.498
2.35	Ro-ro passenger ship	752.16	DWT of the ship	0.381
2.38	LNG carrier	2253.7	DWT of the ship	0.474
2.39	Cruise passenger ship having non-conventional propulsion	170.84	GT of the ship	0.214

Table 4 - Parameters for the calculation of EEDI based on ship type,*(Class NK, 2021)*

There are many ways in which the EEDI can be achieved, other more complex and some more simple which mainly concern speed and power. The first and simplest way is to decrease the speed. Even a small decrease in the speed can greatly affect EEDI, as the speed is proportional to power 3 or even 4 times. As a result, considering that the vessel sails with 20 knots, a small increase of 1 knot can cause only 5% increase of speed but the increase in the EEDI can be even 25%. Accordingly, and if we decrease the speed even by just a little, a much bigger decrease will be caused to power and as a result to the EEDI. There are also technical ways in which we can decrease the speed and concern mainly the propeller system, for example Pre – Swirl Fins, Wake Equal Duct, Kappel Design, Hub Cap Fins, Rudder Bulb, Post Swirl Fins and Efficiency Rudder. Other more expensive solutions involve a switch to alternative types of fuels like LNG and Methanol that produce less CO2 emissions. The fuel consumption can be reduced, using shaft generators on the main engine to produce electric energy as well as heat recovery systems that can save a energy. In some cases, even the change of the engine from 4 to 2 stroke can be considered. Finally, another important factor which affects the EEDI, is the capacity increase. By increasing the capacity but at the same time keep the same displacement, the lightweight of the ship is reduced and as a result the EEDI (Basic Principles of Propulsion, Man Power Solutions, 2023).

2.9.SEEMP – Ship Energy Efficiency Management Plan

Another part of the amendments made in the MARPOL Annex VI is the SEEMP. Effective since 2013 is a set of plans in different stages aiming to reduce the GHG emissions by improving the efficiency of the vessel. The main goal of this plan is to enable shipowners and operates to get involved with new technologies and methods to achieve improved efficiency and on later stages to control, monitor and improve this efficiency. The SEEMP consists of three stages (DNV, 2023; IMO, 2023),

- Stage 1 – Ship management plan to improve energy efficiency – applies to all vessels above 400 GT
- Part 2 – Ship fuel oil consumption data collection plan – applies to ships over 5000 GT and concerns Data Collection
- Part 3 – Ship operational carbon intensity plan – applies to all ships subject to CII like cargo ships, Ro – Ro, Ro – Pax, and cruise ships over 5000 GT

All three parts have common goals with other described regulations like EEDI, EEXI, CII etc as they are part of a greater plan regarding ship’s efficiency,

- Speed optimization
- Weather routing

- Hull monitoring and maintenance
- Installation of heat recovery systems

At the same time, they are generally divided in 4 stages.

- Goal
- Planning and implementation of measures
- Monitoring
- Self – evaluation and improvement

2.10. Energy Efficiency Operating Indicator

The EEOI – Energy Efficiency Operating Indicator (Baltic Exchange, January 2022) is an index, created to calculate and monitor the performance of a vessel during a specific voyage. Through the last few years although EEOI is being applied to calculate the performance of a whole fleet and its activities. An index which categorizes the vessels based on their DWT and operates as a preliminary measure by the SSC – Sea Cargo Charter in order to achieve compliance with the IMO regulations for the reduction of the GHG emissions from shipping. The EEOI can be affected by several different factors, such as the amount or cargo, the fuel consumption, alterations in speed but also from technical and maintenance factors like hull cleaning or installation of energy saving devices*(Wartsila, 2023).*

The formula used for the calculation of EEOI is the below:

$$EEOI = \frac{\sum_j (FC_j \times C_{Fj})}{m_{cargo} \times D}$$

FC_j: carbon emissions during the voyage, calculated for the whole voyage both in ballast and loaded.

J: the type of fuel

C_{FJ}: the CO_2 conversion factor for the fuel

$M_{cargo:}$ the mass of cargo carried.

D: the laden distance in miles

2.11. The EEXI and CII regulations

On June 17, 2021, the International Maritime Organization (IMO) approved amendments to MARPOL Annex VI during MEPC 76, building upon changes drafted at MEPC 75 in November 2020. These updates include new regulations 23 and 25, which introduce the Energy Efficiency Existing Ship Index (EEXI) and require ship operators to demonstrate operational carbon intensity reduction through the Carbon Intensity Indicator (CII). These amendments will go into effect on November 1, 2022, and the course covers the most recent changes made at MEPC 78. Since November 1st , 2022, new corrections were made to the International Convention of the Prevention of Pollution from Ships – MARPOL Annex VI. Incorporated under the initial strategy of the IMO regarding the reduction of GHG (Green House Gases) Emissions implemented since 2018. These changes in both technical and operational aspects are basically demanding the improvement of the vessel's energy efficiency in the nearby future leading into reduction of the GHG emissions. All the above have been mandatory since 1st February 2023, all the shipping enterprises with vessels over 400 tones are obliged to monitor and calculate the EEXI (Energy Efficiency eXisting Ship Index) which has been assigned to them. They must also measure their energy efficiency and collect sufficient data in order to create and file their annual operational CII (Carbon Intensity Indicator) report and CII rating. The aim of these regulations is to connect the GHG emissions with the amount of cargo carried over the distance travelled. In this way carbon intensity can be reduced up to 40% by 2030 compared to the intensities in 2008, the year which was used as milestone. These regulations are being followed worldwide, they are part of the Annex VI of the MARPOL and were adopted for the first time in 1997. Since this time many changes have been made and accepted under the tacit acceptance process. Since November 2022, MARPOL Annex VI includes 105 parties, in other words the 96.81% of the world merchant shipping by tonnage.

2.12. EEXI – Energy Efficiency Existing Ship Index

The regulation applies to vessels with a weight over 400 gross tones. For each vessel different values are set depending on its types and size category. This is the attained EEXI *(Ship Energy Efficiency Helmepa, 2023)*and it should always be lower than the required EEXI so that the ship complies with the minimum energy efficiency standard. The attained EEXI is basically the energy efficiency compared to a base set since 2008. The attained EEXI as described above will be compared to the EEXI which has been set as a baseline, this required EEXI derives from a percentage relative to the EEDI (Energy Efficiency Design Index) (Bahtić,2021).

The EEXI can be calculated as per below:

$$\frac{(\prod_{j=1}^{M} f_j)(\sum_{i=1}^{nME} P_{ME(i)}.C_{FME(i)}.SFC_{ME(i)}) + (P_{AE}.C_{FAE}.SFC^{*}_{AE}) + ((\prod_{j=1}^{M} f_j.\sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)}.P_{AEeff(i)})C_{FAE}.SFC_{AE}) - (\sum_{i=1}^{neff} f_{eff(i)}.P_{eff(i)}.C_{FME}.SFC_{ME})}{f_i.Capacity.V_{ref}.f_w}$$

Parameters used in the above formula:

PME: the power of the main engine or engines

SFCMESFCAE : Fuel oil consumption of main and auxiliary engines

CFME, CFAE :Conversion factors – fuel to CO2 mass

Capacity: Deadweight or Gross Tones depending on the type of the vessel

Vref: Reference ship speed related to Power of main engines.

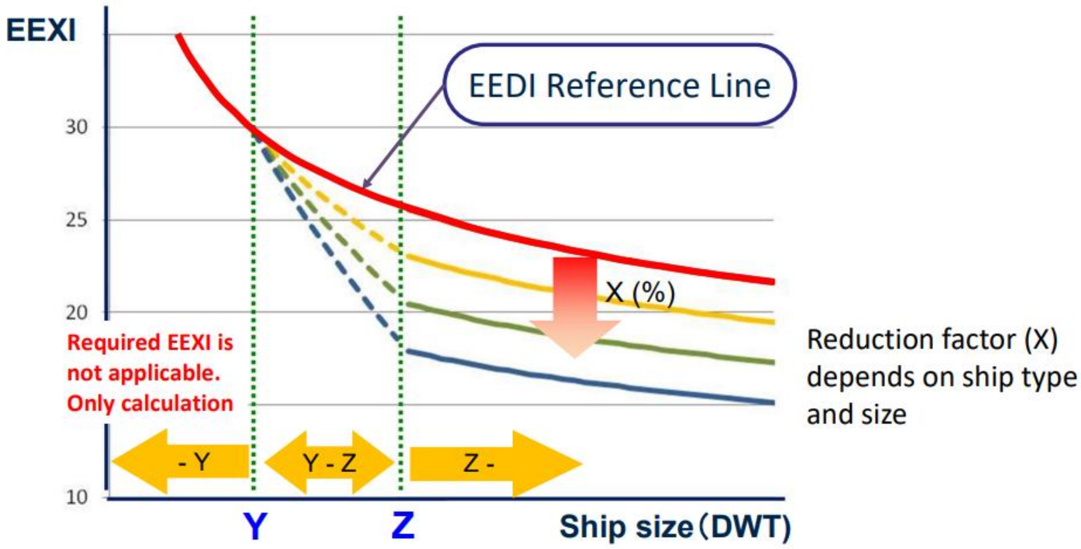
Fj: Correction factors, depends on the type of the ship

P(AE)eff: Power of innovative energy efficiency technology.

The compared values are the attained EEXI *(Class NK, December 2021)*and the required one. The attained must always be smaller by the required and is calculated as per below:

Attained EEXI: $\frac{CO2}{Transport\ work}$

Required EEXI = $(1 - \frac{X}{100})$ ×EEDI Reference line value



Graphic 9 - EEXI reference line*(ClassNK,2021)*

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

Table 5–Parameters of the calculation of the EEXI per vessel type, based on the reference line of the EEDI *(ClassNK,2021)*

Even though the EEXI regulation has been implied shortly, there are ways for almost all the types and ages of ships to meet her requirements. For the existing and usually older vessels there is the Shaft Power Limitation system which sets the limits for the maximum shaft power. Although, the most important in these cases is the Engine Power Limitation which adjusts the maximum engine power. Both methods are using technical means and are approved and verified by the IMO. For the existing and younger vessels there is another solution to comply with the Index and this can be the Fuel Change and the Energy Saving Devices. Finally, a third solution can be the Shipbuilding of new and efficient vessels *(NKK, 2021), (Basic Principle of Ship Propulsion – Man Power Solutions, 2023).*

Technical measure options	EEXI impact
Engine Power Limitation	High
Shaft Power Limitation	High
Fuel change (e.g. LNG)	Moderate
Main engine energy efficiency (e.g Rotors)	Moderate
Aux power installations (e.g. shaft gen, WHR)	Low
DWT increase	Low
Energy saving devices (e.g. ducts)	Low
…..	…..

Table 6 - Efficiency level of each method used to meet EEXI standards*(Ship Energy Efficiency 2023 – Chatzinikolaou,2023)*

All the above-mentioned means have different impact on the EEXI. The highest one derives from the Engine Power Limitation and the Shaft Power Limitation. Then comes the Fuel Change and the Main Engine Energy Efficiency and finally the lowest impact on the EEXI comes from the Auxiliary Power Installations, the Deadweight increase and the Energy Saving devices. To evaluate whether the measures applied were successful and the EEXI goals are met we must take into considerations many different aspects. Except of the impact on the EEXI we also consider the cost and the payback, the age of the ship and if the sailing speed if affordable for the operators and the shipping company*(Bahtić,2021)*.

Although the means to comply with the regulation seem to be purely technical, there are also operational measures which can achieve compliance. The vessel's operators in coordination with the rest of the departments can contribute to four main areas:

- Optimization of the vessel's performance

  - Great care of the hull and machinery parts must be taken. The engines must be running effectively, while the hull and the propeller must be regularly cleaned and coated to avoid marine growth which could cause high resistance and increase the fuel consumption. (Safety4Sea,2020)

  - The types of fuels and their management is also very important. High quality and low in Sulfur fuels should be provided. The fuels must be properly managed and avoid unnecessary consumption.

  - The equipment of the vessel must be carefully chosen. Energy efficient HVAC and lighting systems should be preferred, as well WHR systems which will supply the with the required energy (Sustainable Ships, 2023)

  - All the above must be regularly examined and inspected to ensure compliance and maintain the vessel's efficiency

- Route and Speed (Marine Digital, 2023)

  - The best possible route must be chosen, in order to avoid adverse weather conditions while unjustified deviations must be avoided. This can be achieved using voyage planning and weather prediction tools.

  - The optimum speed must be decided and applied for the vessel to achieve the desired efficiency but also stay persistent with the time limits of delivery

  - The loading of the vessel plays very critical role to the optimization of speed too. The cargo must be carefully stowed and trimmed in order to avoid any issues with the vessel's balance which could cause changes to the vessel's speed (Good maintenance on board ships, Class NK, 2017)

- Training of the crew (World Maritime Academy, 2023) o The recruitment process must be carefully contacted. Members with as much as possible skills, knowledge and experience on optimization must be chosen

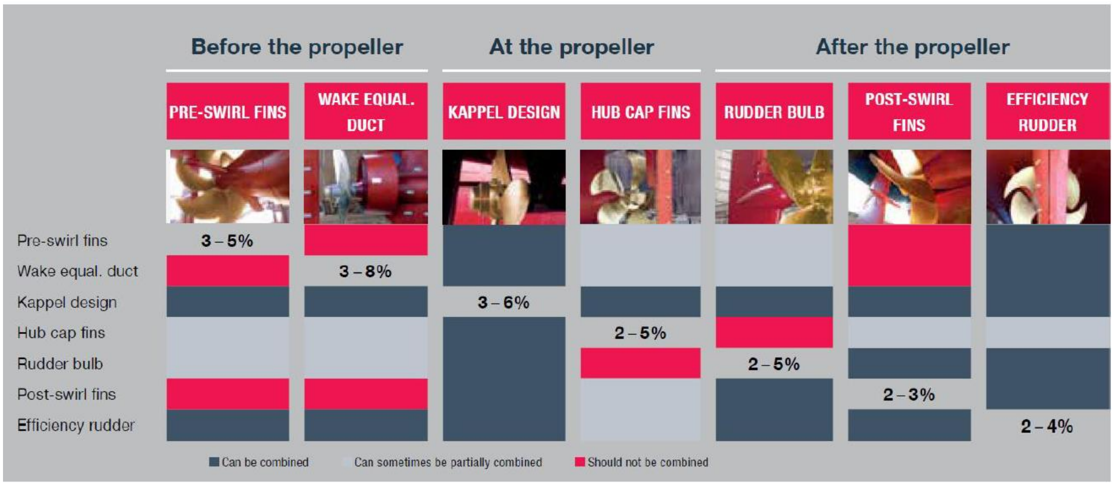
o The crew must be actively involved in the whole optimization process. They must be properly trained and familiar with the regulations and the practices.

o The crew must be encouraged to participate into new initiatives regarding the vessel's optimization and be able to communicate with each other or with higher officers in order to propose ideas, solutions or improvements.

Data collection and verification (The role of data in maximizing operational efficiency in shipping, Global maritime forum, 2023)

o High quality data collection systems must be constantly used in order to gather useful information like consumption, emissions and other performance data. A data driven business plan can lead into efficiency.

o The process can be much easier with the contribution of a classification society. Except of the verification, classification societies can help the enterprise remain up to dated and always comply with the regulations. At the same time new methods and tools can be suggested and offered.



Graphic 10 - Efficiency of energy saving devices*(Main means of Propulsion, Man Energy Systems)*

Except of the means relevant to the propeller as advised above, there are more technical means which can be used to achieve the best efficiency possible such as:

• Air Lubrication Systems: a mechanism, already used and for the reduction of the operational costs and the decrease of GHG emissions by even 10% respectively. An innovative technology used to create microbubbles around the flat bottom of the hull. In this way the resistance is reduced and improved efficiency is achieved. The air is basically released by ARUs – Air Release Units which create a layer of air beneath the vessel. A huge advantage of the described system is the fact that it is applicable under all weather conditions and does not have a negative impact on the way the vessel operates (Wartsila).

• Hull coatings: an additional mean of reduction of the hull's resistance. The roughest the hull is, the biggest the frictional resistance against the water and in this way the speed is directly affected. The vessel must increase speed or maintain higher speed levels in case of slow steaming. As a result the operational costs and the CO2 emissions of the ship is increased while at the same time the efficiency is decreased. For this exact reason shipowners should always renew the vessel's antifouling system every 5 years. As per research by GLOMEEP – Global Maritime Energy Efficiency Partnerships, the resistance can be decreased up to 8% which will occur to a reduction of consumption by 1% - 4% and increase efficiency.

• Bulbous Bow retrofit: the bulbous bow is a vital part of a vessel which helps the vessel increase its stability as it reduces the friction and in this way the whole body of the vessel is not affected by waves. Without the bow, the waves would cause constant changes at the vessel's speed, increasing in this way the consumption and the CO2 emissions while at the same time the efficiency would be severely decreased (Safety4Sea, 2020). The bow is essential for ships which maintain similar speeds at most of their voyages. In case the vessel must change its operational profile due to various reasons like the price of fuels or the market trends, the shipowner should take into severe consideration an adjustment of the ship's bow. It is proved that it could lead to a decrease of consumption by 3% - 5% (GreenVoyage 2050).

• Flettner Rotors: an innovative mean introduced the last few years. Consists of vertical cylinders placed on the deck of the vessel, with the use of the wind's force they rotate and create lift and propulsion power due to the Magnus Effect. It is a supplementary mean of propulsion and cannot be used to replace the main engine of a vessel. It also has to be mechanically controlled in order to achieve constant rotation and maneuverability (Marine Insights, 2015). It is suitable for vessels with plenty unused space on their decks to place the rotors, which are very sensitive to changes in the wind's power and direction. Finally, it is estimated that they can reduce the consumption by 3% - 15% depending on the type of vessel, the trading route, the size and the operational profile (GLOMEEP, 2020).

- Towing Kites: since the ancient years, the wind was the main mean of propulsion of vessels. Through the years of course it was replaced but the last few years it seems like it slowly coming to the front again through the towing kites. Another supplementary system used to replace a part of the engine's power thanks to it's towing power. It is estimated that it can reduce the main engine consumption from 1% to 5%, however its suitability is not the best possible (GLOMEEP, 2020). Results are better on vessels larger than 30 meters with operating speed of less than 16 knots. Moreover, kites can be used only at a percentage of 20% - 30% of the journey depending on the size of the vessel. At the same time an ambitious project called "Neonliner" using sails is being developed. The people responsible of this project claim that it can reduce the CO2 emissions even by 90%. (Neonline, 2022).

- Solar Power: a renewable source of energy which is being extensively used for years has now been implemented in shipping. Solar panels have been installed in vessels, mostly ones with efficient space on the deck like car carriers. Due to the big energy consumption of the motor vessels the solar panels can only work as a supplementary mean in this case and reduce the consumption of the auxiliary engine only by a small percentage of approximately 0.5% - 2%(GLOMEEP, 2020). In addition the panels have to be specially designed in order to cope with the adverse weather conditions of the open seas, while they cannot be productive through the whole duration of the journey.

- Waste Heat Recovery Systems: one of the most efficient ways to reduce the energy consumption and improve efficiency. These systems use the waste heat from the exhaust gases, engine cooling water and excess steam and turn it in electrical or thermal energy (GLOMEEP, 2020). There are three types of WHRs, the first one is called Heat to Heat system and uses the heat emitted by the exhaust gases in order to warm equipment on board and most commonly bunker fuels. The second one is heat to electricity, where the gases from the exhaust systems are used to generate electricity through a turbine. This electricity is then used in the auxiliary engines of the vessel or in other parts of it like the accommodation. The last and most uncommon type of WHR is the Heat to Cold where the gases are heat from the gases is transformed into cold via a thermos acoustic device and the energy extracted will be used in Heating, Ventilation and Air Conditioning (Sustainable Ships, 2023). In general, these systems can reduce the energy consumption of the main engine by 3% - 8% and reduce the fuel consumption by even 15%.

• Alternative fuels: except of the wind propulsion and the solar power, there are other more tangible sources of energy which can act in addition or completely replace oil. The most popular alternative fuels for the time being are LNG, Methanol, Biogas, Hydrogen and Battery/Hybrid. , at the time being there are 11 vessels using Methanol, 19 vessels using LPG, 396 using Battery (Hybrid), 923 vessels using LNG and the rest of them (approximately 98.8%) are still using conventional fuels (DNV Forecast, 2022). The main advantage of them is the lower emissions of both carbon but also SO2 and NOX, this is not only beneficial to the environment but also reduces the maintenance costs of the vessel due to replacement of spare parts. In addition, their resources are plentiful in comparison with classic fuel oil and some of them like hydrogen can be produced by renewable sources (Update on Potential of Biofuels for Shipping, 2023). In the above ways efficiency is achieved, and the vessel can comply with the environmental regulations. The process to retrofit existing vessels for using alternative fuels is extremely expensive. In addition, many ports and terminals are not well equipped to cover the supply and demand of the ships with alternative fuels (Challenges and opportunities for alternative fuels in the maritime sector,2021).

• EPL and SHaPoLi: probably the most effective ways of achieving the vessel's efficiency. They both act as limitation measures but in different parts of a vessel. More specifically, the first one limits the power produce by the engine, while the second limits the power transmitted from the shaft to the propellers. (Hellenic Shipping News, 2022)

o The EPL – Engine Power Limitation is a mechanism which limits the maximum engine power produced by a marine engine. It applies in both mechanically and electronically controlled engines. In the first case a mechanical stop screw sealed by a wire or a similar device with a prefixed limit is locking the fuel index and ensures that the EPL cannot by overtaken unless the captain commands so. In the second case the process is similar, the fuel index is locked electronically or sometimes a direct limitation of the power in the engine's control system is applied (MEPC 76, June 2021).

- The SHaPoLi – Shaft Power Limitation consists of three main parts, the sensors which record the torque, and the rotational power transmitted to the propellers, a data recording and processing device which is responsible for collecting the data required for the calculation and a control unit which calculates the collected data and limits the power transmitted to the propellers. The system includes and amplifier and an analogue to the digital converter too (MEPC 76, June 2021).

Finally, except of the above described operational and technical means, the market also affects the effort of the industry to comply with the new environmental regulations through different measures and initiatives. The most popular one which will be soon applied by the EU – ETS is the Carbon Pricing (Market – based measures for greenhouse gas emissions from maritime transport, EU 2019). The enterprises are required to buy carbon allowances and pay taxes for the Carbon Dioxide that they emit. The funds gathered will be offered for research and development of the energy efficiency in shipping. Incentives is also a proven solution, through the ESI – Environmental Ship Index. The vessels with the most efficient performance are offered financial incentives or discounts in services required during their stay in ports. The incentives can derive from both the private and the public sector. Governments can offer financial subvention to urge shipping enterprises to the use of alternative fuels and eco – friendly technologies (Final LCA IMO Subm on Climate Finance, UNAP, 2011). Moreover, banks and financial organizations can play a crucial role in the optimization of the vessel's efficiency, by offering low interest loans and ways of funding exclusively for investments in shipping efficiency. Private shipping funds can also enhance this effort by financing programs designed to improve efficiency. The compliance with the regulations for shipping efficiency can also be boosted using environmental contracts, where the compliance with the EEXI will be assessed and rewards will be offered. Additionally, like the Carbon Pricing programs are the Carbon Offset ones, where the shipowners can buy carbon credits which will substitute the number of emissions which was not reduced through the Efficiency Optimization measures. The Carbon Pricing and Offset programs accompanied by an emission trading systems which will allow enterprises to buy and sell emission allowances. Ultimately, new classifications can be introduced in order to make existing vessels as compliant with the regulations as possible, but also lead to the construction of more eco-friendly vessels. Some of the above have already been put in to action as per below (Guidelines for EEXI , IMO 2019).

- International Fund for GHG emissions from ships (GHG Fund) (Cyprus, Denmark, the Marshall Islands, Nigeria and IPTA, MEPC (60/4/8)
- LIS – Leveraged Incentive Scheme, Japan (MEPC 60/4/37)
- Port State Levy, Jamaica, (MEPC 60/4/40)
- SECT – Ship Efficiency and Credit Trading, United Sates (MEPC 60/4/12)
- VES – Vessel Efficiency System (VES), World Shipping Council (MEPC 60/4/39)
- ETS – Global Emissions Trading System ETS for international shipping, United Kingdom (MEPC 60/4/26)
- ETS – Emissions Trading System for International Shipping, France (MEPC 60/4/41)
- Market-Based Instruments: a penalty on trade and development, Bahamas (MEPC 60/4/10)
- RM – Rebate Mechanism for a market-based instrument for international shipping, IUCN (MEPC 60/4/55)

2.13. CII – Carbon Intensity Indicator

This category of regulation is basically a rating system developed and implied by the IMO under MARPOL Annex VI, it has come to effect together with EEXI in January 2023. This measure concerns all type of vessels above 5000 Gross Tones, sailing in international waters, including passenger ships. The Carbon Intensity Indicator (CII) is a tool used to measure the amount of carbon dioxide emitted by a ship during its operation. "The CII determines the annual reduction factor needed to ensure continuous improvement of a ship's operational carbon intensity within a specific rating level. *(“EEXI and CII - ship carbon intensity and rating system – IMO, 2023”)*The actual annual operational CII *(Basic Principle of Ship Propulsion – Man Power Solutions, 2023)* achieved must be documented and verified against the required annual operational CII. This enables the operational carbon intensity rating to be determined. *(ABS, 2023)*

In the case of the CII different formulas can be used depending on the type of the vessel. For the most common known types of vessels like Bulk carriers, Tankers, Container ships, Gas carriers, LNG carriers, General cargo ships, Refrigerated cargo carrier, Combination carriers the below formula is used:

$$\text{CII} = \frac{\sum_j C_{Fj} \cdot \left\{FC_j - \left(FC_{voyage\,,j} + TF_j + (0.75 - 0.03y_i) \cdot \left(FC_{electrical\,,j} + FC_{boiler\,,j} + FC_{others,j}\right)\right)\right\}}{f_i \cdot f_m \cdot f_c \cdot f_{iVSE} \cdot Capacity \cdot (D_t - D_x)}$$

Although for other types of vessels like cruise passenger ships, Ro-ro cargo ships (vehicle carriers), Ro-ro cargo ships, Ro-ro passenger ships the above formula can be modified and look like the below:

Parameters used in the above formula:

Σj: Fuel type

CFJ: Fuel mess to CO2 mass conversion factor

FCj: Total miss of consumed fuel type

FCvoyage: voyage correction

TFJ: STS/shuttle correction

Yi: year

FCelectrical: consumption for electric power, consumption for boiler, consumption for others

FI: capacity correction factor for ice class ships

Fm: factor for ice classed ships

Fc: cubic capacity correction for chemical tankers

FIvse: correction factor for specific voluntary structural enhancement, applicable only to self-unloading bulk carriers

Capacity: DWT – GT

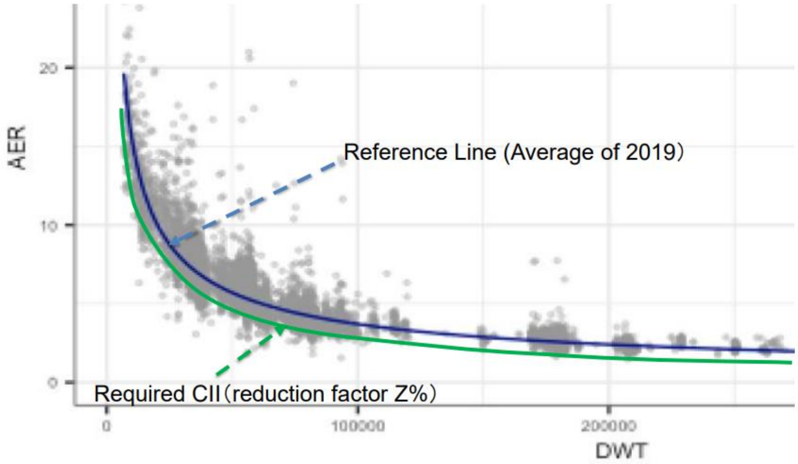
(D1 – D2): Distance IMO DCS – distance voyage correction

Reference line value: $aCapacity$-C

The compared values are the attained CII (Class NK, December 2021) and the required one. The attained must always be smaller by the required and is calculated as per below:

Attained CII: $\frac{CO2}{Transport\ work}$

Required EEXI = $\frac{100-z}{100}$ × CII Reference line value



Graphic 11 - CII reference line*(ClassNK, 2021)*

Ship type		capacity	a	c
Bulk Carrier	DWT ≥ 279,000	279,000	4745	0.622
	DWT < 279,000	DWT	4745	0.622
Gas Carrier	DWT ≥ 65,000	DWT	14405E+7	2.071
	DWT < 65,000	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	5119	0.622
LNG Carrier	DWT ≥ 100,000	DWT	9.827	0
	100,000 > DWT ≥ 65,000	DWT	14479E+10	2.673
	DWT < 65,000	65,000	14479E+10	2.673
Ro-ro cargo ship (VC)	GT ≥ 57,700	57,700	3627	0.590
	57,700 > GT ≥ 30,000	GT	3627	0.590
	GT < 30,000	GT	330	0.329
Ro-ro cargo ship		GT	1967	0.485
Ro-ro passenger ship	Ro-ro passenger ship	GT	2023	0.460
	High-speed craft	GT	4196	0.460
Cruise passenger ship		GT	930	0.383

Table 7 - Parameters of the calculation of the CII per vessel type *(ClassNK, 2021)*

With the use of the above calculations, the carbon intensity will be categorized in A, B, C, D and E categories which mean major superior, minor superior, moderate, minor inferior, or inferior performance level respectively. The ship's compliance with energy efficiency regulations and policies will be documented in a Statement of Compliance, which will be further detailed in the ship's Ship Energy Efficiency Management Plan (SEEMP). In case a vessel belongs to category D for 3 years in a row or for 1 year in category E is obliged to submit a plan which will declare corrective techniques and actions to rise to the scale. At the same time, all the involved parties such as the operators, the local authorities and the stakeholder are required to encourage through benefits so that the ship is rated to categories A or B.

As long as the means required to improve the CII of a vessel are concerned, they are similar to the one used in the Efficiency Index. The hull is one of the most important aspects, and the ship operators must take appropriate actions in order to ensure that it remains clean so as to reduce drag and resistance. Optimization in terms of speed and travelling route – distance is also crucial. There are also other means which are not connected to the power of the main engine, for example the replacement of conventional light bulbs with energy saving ones to reduce electrical power consumption. A big advantage would also be given to the vessels which would be able to cover their needs for electricity through auxiliary sources of energy like solar and wind.

3. METHODOLOGY

This diploma thesis is a result of an extended quantitative research. The data used is collected online from Surveys and reports created from organizations, shipping institutions and enterprises specializing in shipping technological means. At the same time literature survey is conducted wherever necessary. Moreover, tables, charts and graphs are extensively used. Although, the most important of all is the use of numerical methods and statistical analysis, through a specialized software which will be described later on. This software enabled us to create a broad picture of the true impact of the regulation in shipping operation. Beginning with the Literature review, the impact of the Greenhouse Gases is thoroughly analyzed, emphasizing on the GHG produced by shipping industry. Later, an extended analysis on the regulations and measures imposed by the IMO for the reduction of GHG emissions and especially the regulation imposed under MEPC as well as the EEXI and CII regulations is conducted. After the literature review comes the Case Study, where data from the noon reports and the technical files of the vessel are used. A noon report is a document developed onboard, on daily basis. It contains data such as the vessel's speed, daily weather conditions, location among other sand is used to present the changes in the vessel's speed and performance to achieve the required EEXI. The technical file of the vessel regarding the EEXI, is a report submitted to the classification society which contains data such as, the type of the main and auxiliary engines, the type of fuel used as well as the speed and many other data similar to the ones contained in the noon reports. The main difference with the noon report is the fact that the required and attained EEXI as well as speed and power curves are calculated and in this way the compliance of the vessel with the regulations is verified. The data used in this thesis are collected with the help of some well-intentioned colleagues who volunteered to share this info for the sake of this work. The analysis of these data is conducted with the help of a specialized software (owned by the MSc program) which calculates the best possible speed required per draught and assesses whether this speed is feasible for the specific ship. In case it is not, the percentage of speed which will have to be increased or decreased is also calculated. In the next phase of the essay, conclusions regarding the data which were analyzed are being made. The main conclusion is the extend in which the vessel must reduce its operating speed and how this will affect its operations. During the last phase of this

Diploma Thesis and the part of the discussion, by using the data provided from the analysis part and the whole essay, the possible impact of the EEXI in the supply chain, as well the Freight and the S&P market will be discussed.

4. DATA ANALYSIS – CASE STUDY

The impact of these newly – introduced regulations will be more clearly inferred using a real ship example. In this thesis the calculations and results shown are done using technical and operational data from an existing ship with the use of ShipFORCE software, developed by ShipReality Inc – The department of Maritime Studies owns an academic license. The main source of info derives from the noon reports of the vessel. These reports are issued on daily basis, for every sailing day of the vessel while port days are excluded, and they contain the below data:

- Vessel's name
- Voyage number
- The date and time that the report was issued
- The position of the vessel
- Average speed between the previous and the current noon report
- The propeller Slip, the total number of revolutions of the propeller recorder between the previous and the current noon report
- Average RPM, Revolutions of the propulsion engines Per Minute
- Wind Direction and Wind Force
- General Sea and Swell condition
- Distance to next Port of Call
- ETA – Estimated Time of Arrival
- ROB – Remaining on Board, a calculation of the amount of Fuel Oil, Lubricants and Water on board the vessel

Vital for the completion of this case study was the use of the EEXI technical file of the vessel. This file contains data relevant to speed but also technical aspects like the type of the main and auxiliary engines and their consumption. Through this data, the attained and required EEXI is calculated and in this way the compliance with the regulations is examined. The main data contained in this report are the below:

- DWT – Dead Weight Tonnage or GT – Gross Tonnage of the vessel
- MCR – Rated Installed Power of the engines

- The Ship Speed
- Type of fuel
- SFC – Specific Fuel Consumption of the main and auxiliary engines
- Description of the Energy Saving Equipment
- Calculated value of the Attained EEXI
- The estimated and the approved speed power curve
- Ship type
- Classification of the ship

All the above-mentioned data are combined and inserted into an innovative software powered by ShipReality Inc. The MSc program owns a license of this software. The above mentioned data from the Noon Reports and the EEXI Technical file were inserted into the system and after the completion of the calculations the below outcome data is produced:

- The current – required EEXI
- The attained EEXI
- The marginal Engine – Shaft Power Limitation – EPL/SHaPoLi
- The new maximum speed based on the EPL
- A report of the EEXI calculation, based on the vessel's parameters
- The EEXI technical file

All the above can be contacted in less than 2 hours, while at the same time there are additional capabilities offered to the user of the software, which are also presented in the upcoming case study. More specifically the software can carry out an EPL feasibility study and calculate the maximum attainable speed based on different draught conditions, after the application of the EPL. The software also creates different speed/draught profiles based on speed and draught range, while it also evaluates the feasibility of the EPL based on draught and speed. Except of the EPL, the application performs feasibility studies regarding the Energy Efficiency Technologies used, categorizing these technologies into A – B or C classification.

To understand the real effect of this new regulation to the shipping industry, academic research is not enough. An analysis of the environmental impact of shipping, the harmful greenhouse gases and their damaging impact on the environment but also the correctives actions against this type of pollution is essential. Nevertheless, the most important to create a broad picture of the effect of this newly admitted regulation to the operation of the vessel and the shipping industry as a whole, is a case study similar to the one which will be presented further on.

4. 1. Introduction

The EEXI Technical Report of Vessel Unipi test has been developed following the guidelines adopted in the following MEPCs:

1. RES. MEPC.350(78) - 2022 Guidelines on the method of calculation of the Attained Energy

Efficiency Existing Ship Index (EEXI)

2. RES. MEPC.351(78) - 2022 Guidelines on survey and certification of the Attained Energy

Efficiency Existing Ship Index (EEXI)

3. RES. MEPC.335(76) - 2021 Guidelines on the shaft / engine power limitation system to

comply with the EEXI requirements and use of a power reserve

4.2. Vessel Data

Vessel Name	Papei test
Vessel Type	Tanker
IMO Number	2324324
Hull Number	
Length Between Perpendiculars	136.00 [m]
Breadth, moulded	22.60 [m]
Depth, main deck, moulded	12.50 [m]
Summer Load Draught, moulded	9.20 [m]
Deadweight at Summer (Scantling) Draught	17567.0 [ton]

Table 8 - Vessel Characteristics

Number of Main Engines: 1

Main Engine #1	
Manufacturer	a
Type	a
Maximum Continuous Rating	5920.00 [kW]
Rotational Speed at MCR	173.0 [RPM]
Specific Fuel Consumption @ 75% (SFC)	190.00 [g/kWh]
CO2 Conversion Factor	3.114 [t/t]
Number of Sets	1

Table 9 - Main Engine Characteristics

Number of Auxiliary Engines

Auxiliary Engine #1	
Manufacturer	a
Type	a
Maximum Continuous Rating	800.00 [kW]
Rotational Speed at MCR	900.0 [RPM]
Specific Fuel Consumption @ 50% (SFC)	201.70 [g/kWh]
CO2 Conversion Factor	3.206 [t/t]
Number of Sets	3

Table 10 - Auxiliary Engine Characteristics

4.3 Calculations of EEXI Parameters

4.3.1. Auxiliary Engine Power Calculations - P(AE)

For ships for which the total propulsion power

$$\left(\sum MCR_{ME(i)} + \frac{\sum P_{PTI(i)}}{0.75}\right)$$

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) = 5920.00 kW, therefore, P(AE) = 296.00 kW.

4.3.2. Main Engine Power Calculations - 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:

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

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

P(AE) = 296.00 kW. Therefore, final ΣP(PTO) = 0.00 kW.

Finally, ΣP(ME) = 4440.00 kW.

Note: The ship speed in the frame of the present calculation (Vref) should correspond to the above calculated value (here: ΣP(ME) = 4440.00 kW).

4.3.3. Certified specific fuel consumption

From the NOx Technical File / Shop Tests documents of the vessel, Specific Fuel Oil Consumption of the Main Engines SFC(ME) is taken as 190.00 g/kWh.

From the NOx Technical File / Shop Tests document of the vessel, Specific Fuel Oil Consumption of the Auxiliary Engines SFC(AE) is taken as 201.70 g/kWh.

4. 3.4. Conversion factor between fuel consumption and CO2 emission CF

The Conversion Factor of the Main Engines CF(ME) is taken as 3.114 t-CO2/t-Fuel.

The Conversion Factor of the Auxiliary Engines CF(AE) is taken as 3.206 t-CO2/t-Fuel.

4.3.5. Capacity

For Tankers, Deadweight should be used as Capacity. Therefore, the Capacity of the vessel is 17567.0 tn [Full Load (Summer Draught)].

4.3.6. Coefficients

4.3.6.1. FJ: Ship specific design elements

For Tankers, fj = 1.000.

4.3.6.2. FW: Factor for speed reduction at sea

No specific weather conditions apply to the present ship. Therefore, fw = 1.000. 3.6.3. fi.

4.3.6.3. Capacity factor for technical/regulatory limitation on capacity

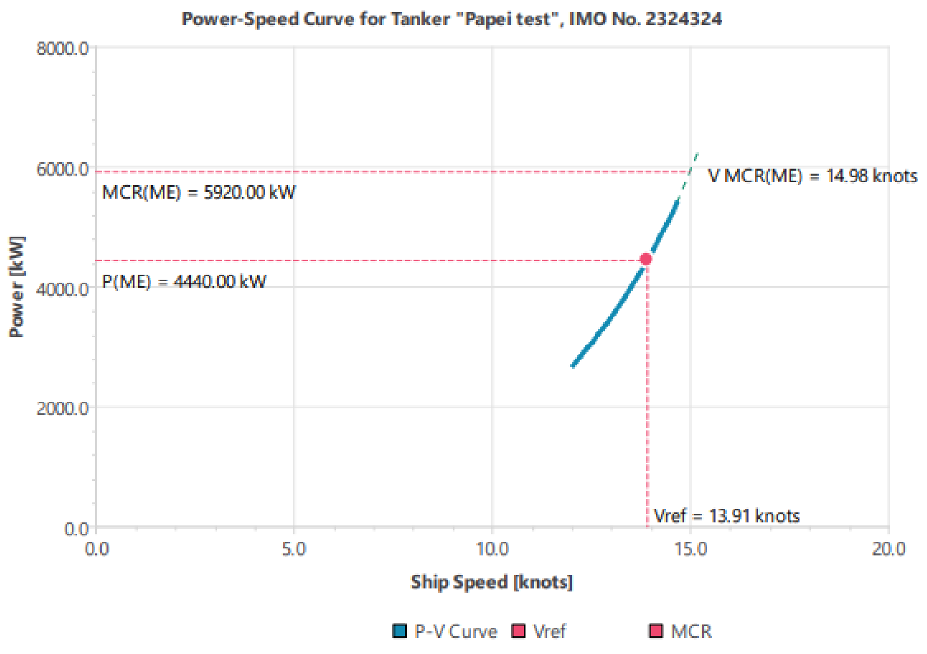
The present ship does not have Ice Class Notation. Ship specific voluntary structural enhancement(VSE) and common structural rules (CSR) do not apply to this ship. Therefore, fi = 1.000.

4.3.6.4. FC: Cubic capacity correction factor

For Tankers, fc = 1.000.

4.3.7. Reference Ship Speed

Vref 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) = 4440.00 kW.



Graphic 12 - Power-Speed Curve of Vessel Unipi test at Scantling Draught. Calculation of Vref.

Here, Vref is calculated equal to 13.91 knots.

4.4 Calculation of Current and Required EEXI

4. 4.1. Calculation of Current EEXI

The current ship Energy Efficiency Existing Ship Index (EEXI) is a measure of energy efficiency (g-CO2/ton.mile), and is calculated by the following formula:

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

$$= \frac{1 \times (4440.00 \times 3.114 \times 190.00) + (296.00 \times 3.206 \times 201.70) + 0 - 0}{1 \times 1 \times 1 \times 17567.0 \times 1 \times 13.91 \times 1}$$

= 11.53 g-CO2/ton.mile.

Summary of values calculated/reported above:

Parameter	Value
ΣP(ME)	4440.00 [kW]
SFC(ME)	190.00 [g/kWh]
CF(ME)	3.114 [t-CO2/t-Fuel]
P(AE)	296.00 [kW]
SFC(AE)	201.70 [g/kWh]
CF(AE)	3.206 [t-CO2/t-Fuel]
Capacity	17567.0 [ton]
Coefficient fj	1.000 [-]
Coefficient fi	1.000 [-]
Coefficient fc	1.000 [-]
Coefficient fl	1.000 [-]
Coefficient fw	1.000 [-]
Coefficient fm	1.000 [-]
Vref	13.91 [knots]

Table 11 - Calculated values

The Current EEXI of the vessel is 11.53 g-CO2/ton.mile

4.4.2. Calculation of Required EEXI

According to MARPOL Annex VI / Reg.24, the EEDI reference line value shall be as follows:

Ship Type	a	b	c
Tanker	1218.8	17567.0	0.488

Table 12 - EEDI Reference line value

EEDI Reference line value = a x b^(-c) = 1218.8 x 17567.0^(-0.488) = 10.34 (g-CO2/ton.mile)

4.4.3. Required EEXI

According to MARPOL Annex VI / Reg.25, the required EEXI value shall be as follows: Required EEXI = (1 - Y / 100) x EEDI Reference line value where Y is the reduction factor specified in Table 2 for the required EEXI compared to the EEDI reference line.

Ship Type	Deadweight	Reduction Factor
Tanker	17567.0	16.9588

Table 13 - Reduction factor (in percentage) for the EEXI relative to the EEDI reference line

Required EEXI = (1 - 16.9588 / 100) x 10.34 = 8.59 (g-CO2/ton.mile

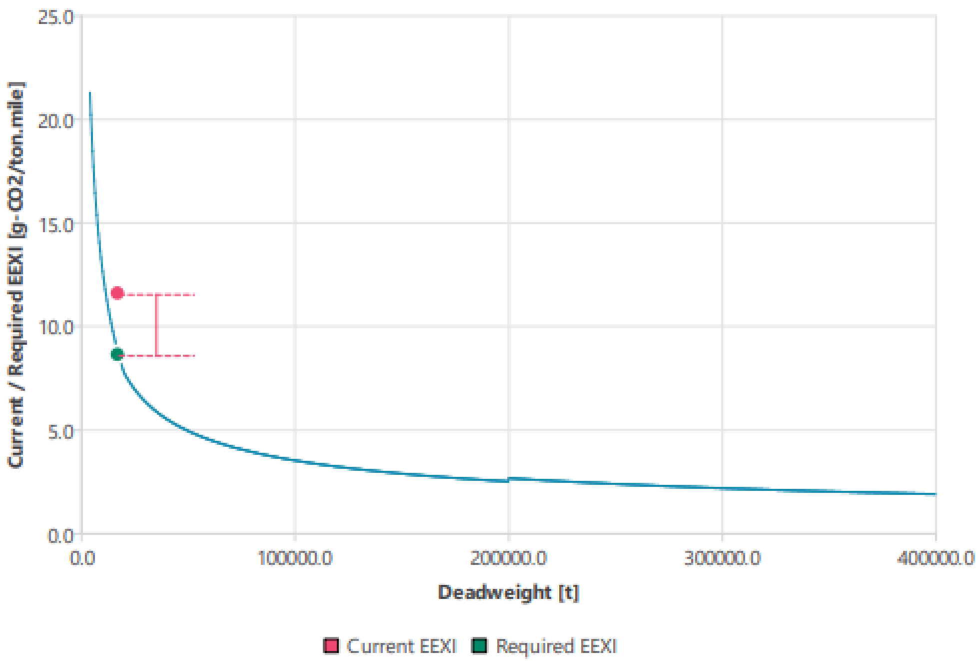
The Required EEXI of the vessel is 8.59 g-CO2/ton.mile.

4.5. EEXI Assessment

The Current EEXI of the vessel is 11.53 g-CO2/ton.mile.

The Required EEXI of the vessel is 8.59 g-CO2/ton.mile.

Vessel Unipi test does not meet the requirements of EEXI Regulation. A reduction to EEXI of 11.53 - 8.59 = 2.94 g-CO2/ton.mile is further required.



Graphic 13 - Current/Required EEXI for Vessel Unipi test

4.5. Overridable Mechanical Engine Power Limitation Calculations

4.5.1. "Suggested" Power Reduction

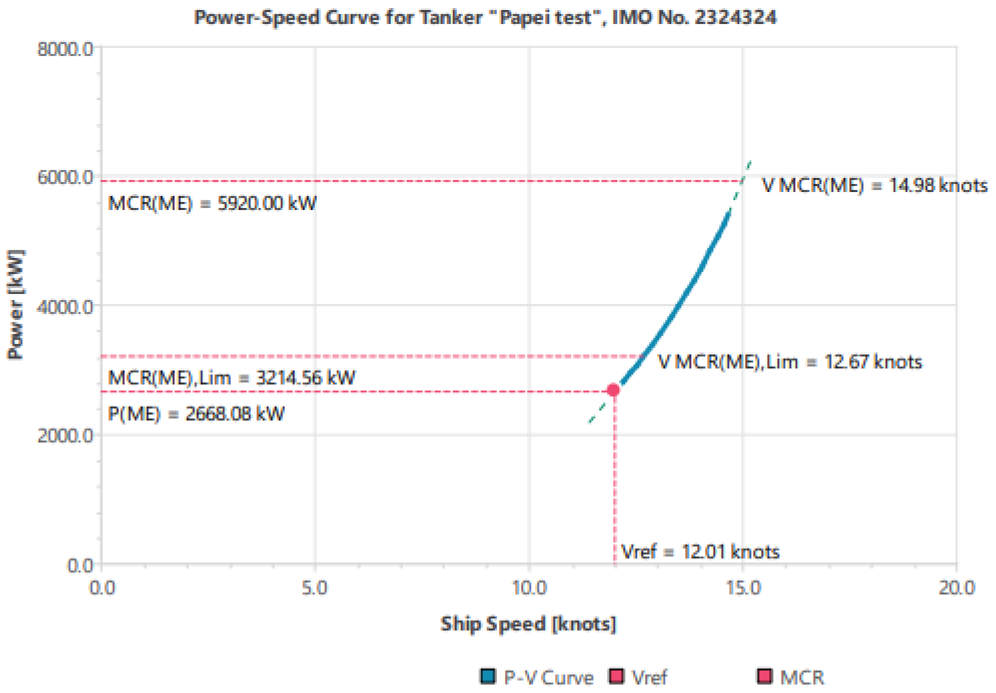
The "Suggested" Mechanical Engine Power Reduction of Vessel Unipi test is calculated equal to 45.7%, so as to meet the required reduction in EEXI.

4.5.2. Engine Speed after Power Limitation

Based on estimated P-n curve at scantling draught, the corresponding estimated value of propeller speed at MCR, Lim is n, appr=147.6 RPM. The estimated P-n curve at scantling draught can be described by the propeller law: P = c x n^3, where propeller speed at MCR, 173.0 RPM, has been adjusted by a factor of 3%, n=173.0/1.03=168.0 RPM, and corresponding power, 5920.00 kW, by a factor of 25%, P=5920.00/1.25=4736.00 kW. Therefore, the propeller curve at scantling draught is estimated as: P = 0.0009995 x n^3.

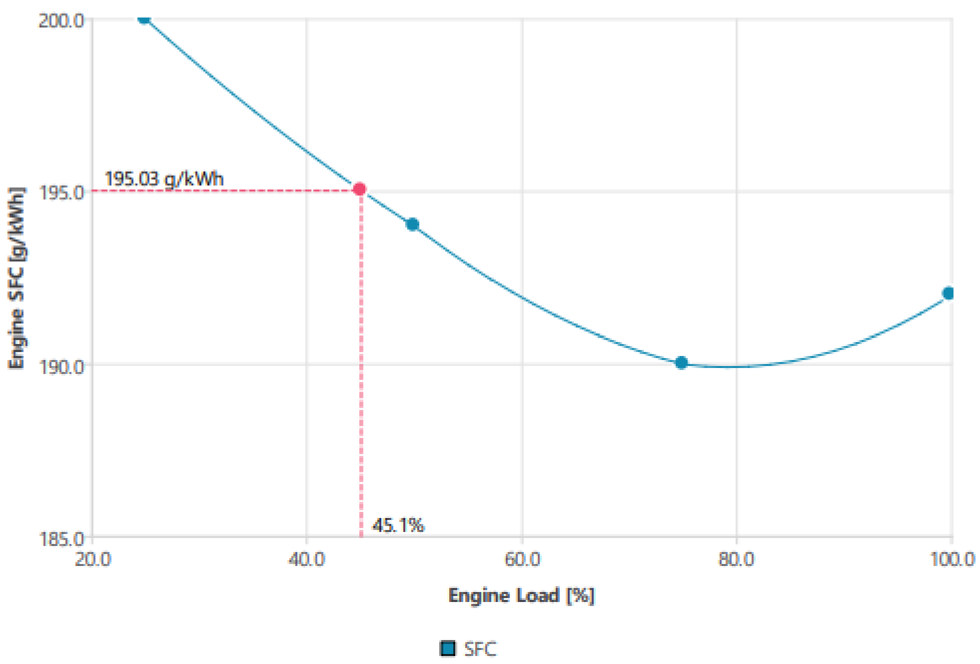
4.5.3. Reference Ship Speed

Vref 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) = 2668.08 kW.



Graphic 14 - Power-Speed Curve of Vessel Unipi test at Scantling Draught. Calculation of Vref.

Here, Vref is calculated equal to 12.01 knots. The maximum vessel speed with Overridable Mechanical EPL, at scantling draught condition, is calculated as: V MCR(ME),Lim = 12.67 knots.



Graphic 15 - Segmented Second Order Interpolation for calculating Main Engine SFC at P(ME) for vessel.

4.5.4. Calculation of "Suggested" Attained EEXI value

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

$$= \frac{1 \times (2668.08 \times 3.114 \times 195.03) + (296.00 \times 3.206 \times 201.70) + 0 - 0}{1 \times 1 \times 1 \times 17567.0 \times 1 \times 12.01 \times 1}$$

= 8.59 g-CO2/ton.mile.

Summary of values calculated/reported above:

Parameter	Value
ΣMCR(ME)	5920.00 [kW]
ΣMCR(ME,Lim)	3214.56 [kW]
ΣP(ME)	2668.08 [kW]
SFC(ME)	195.03 [g/kWh]
CF(ME)	3.114 [t-CO2/t-Fuel]
P(AE)	296.00 [kW]
SFC(AE)	201.70 [g/kWh]
CF(AE)	3.206 [t-CO2/t-Fuel]
Capacity	17567.0 [ton]
Coefficient fj	1.000 [-]
Coefficient fi	1.000 [-]
Coefficient fc	1.000 [-]
Coefficient fl	1.000 [-]
Coefficient fw	1.000 [-]
Coefficient fm	1.000 [-]
Vref	12.01 [knots]

Table 14 - Calculated Values

The Required EEXI of the vessel is 8.59 g-CO2/ton.mile.

By application of Overridable Mechanical Engine Power Limitation (Mechanical EPL) of 45.70%, Vessel Unipi test meets the requirements of EEXI Regulation, with a margin of 8.59 - 8.59 = 0.00 g-CO2/ton.mile. No further actions are required.

4.5.5. Summary of Overridable Mechanical Engine Power Limitation Calculations

Speed Vref	Speed Vref,Lim	Speed Reduction
[knots]	[knots]	[%]
13.91	12.01	13.71

Table 15 - Speed Reduction

Number of Sets	MCR(ME)	MCR(ME),Lim	Power Reduction
	[kW]	[kW]	[%]
1	5920.00	3214.56	45.70

Table 16 - Power Reduction

Current EEXI	Suggested EEXI	Required EEXI
[g-CO2/ton.mile]	[g-CO2/ton.mile]	[g-CO2/ton.mile]
11.53	8.59	8.59

Table 17 - Current, Suggested and Required EEXI Values

4.6 EEXI Compliance through Energy Efficiency Technologies (EET)

According to MEPC.1/Circ.815, Energy Efficiency Existing Ship Index (EEXI) may also be improved through Energy Efficiency Technologies (EET) application.

Innovative energy efficiency technologies are allocated to category (A), (B) and (C), depending on their characteristics and effects to the EEDI formula. Furthermore, innovative energy efficiency technologies of category (B) and (C) are categorized to two sub-categories (category (B-1) and (B-2), and (C-1) and (C-2), respectively).

• Category (A) : Technologies that shift the power curve, which results in the change of combination of PME and Vref.

• Category (B): Technologies that reduce the propulsion power, PP, at Vref, but not generate electricity. The saved energy is counted as Peff.

- Category (B-1): Technologies which can be used at any time during the operation and thus the availability factor (feff) should be treated as 1.00.
- Category (B-2): Technologies which can be used at their full output only under limited condition. The setting of availability factor (feff) should be less than 1.00.

Category (C): Technologies that generate electricity. The saved energy is counted as PAEeff.

- Category (C-1): Technologies which can be used at any time during the operation and thus the availability factor (feff) should be treated as 1.00.

- Category (C-2): Technologies which can be used at their full output only under limited condition. The setting of availability factor (feff) should be less than 1.00.

4.6.1. Sensitivity Study for Vref

The table below provides the required speed (Vref) combined with Mechanical Engine Power Limitation (Mechanical EPL), in order to satisfy the EEXI Requirement as per MEPC 76. The calculated Vref for the different Mechanical EPL levels is also stated for reference. It is demonstrated that a total required Mechanical Engine Power Limitation (Mechanical Engine) of 38.52% is required in order to meet the EEXI regulation.

Vref for different Mechanical Engine Power Limitation [%]		
Mechanical Engine Power Limitation	Calculated Vref	Required Vref
[%]	[kn]	[kn]
0.0	13.91	18.67
9.8	13.91	18.65
17.0	13.58	17.31
24.2	13.24	16.00
31.3	12.87	14.67
38.5	12.45	13.35

Table 18 - Sensitivity Study for Vref

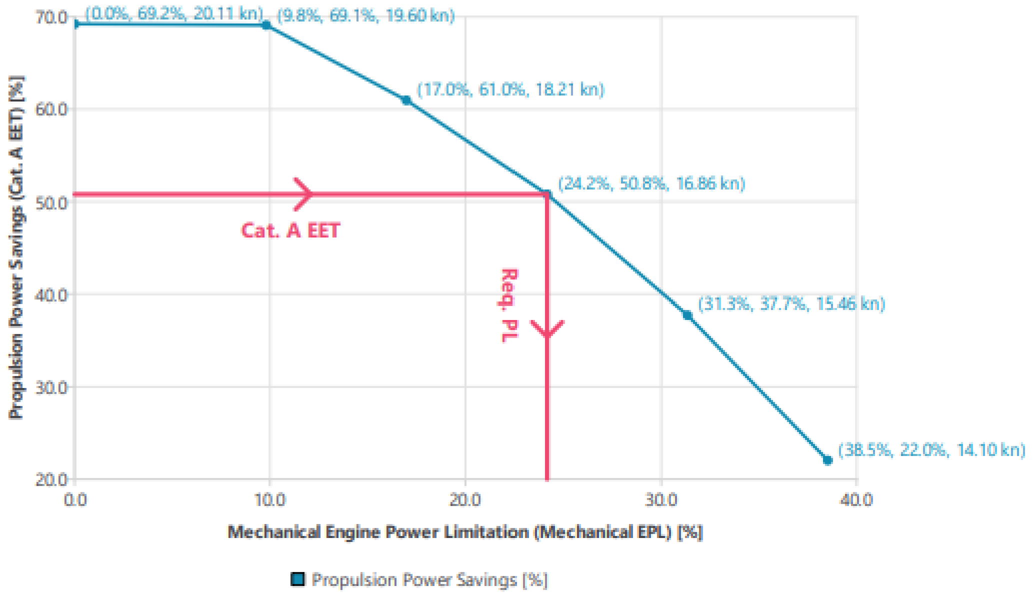
Category A Energy Efficiency Technologies provide propulsion power savings over the entire vessel speed range, by affecting the Power-Speed curves of the vessel. If Category A EET are adopted, the required Mechanical Engine Power Limitation (Mechanical EPL) of the vessel for satisfying the EEXI requirement can be reduced.

4.6.2. Application of Category A Energy Efficiency Technologies-Wide Mechanical EPL Range

The table below presents the required Mechanical EPL [%] in order to satisfy the EEXI requirement, as a function of the propulsion power savings [%] offered by Category A EET. The maximum attainable vessel speed at scantling draught for each case is also calculated and presented.

Propulsion power savings (Cat. A) and corresponding required Mechanical EPL			
Required Mechanical EPL	Propulsion Power Savings	Required Vref	Max. Speed @ Scantling
[%]	[%]	[knots]	Draught after Mechanical
0.0	69.2	18.67	20.11
9.8	69.1	18.65	19.60
17.0	61.0	17.31	18.21
24.2	50.8	16.00	16.86
31.3	37.7	14.67	15.46
38.5	22.0	13.35	14.10

Table 19 – Effect of Category A EET adoption on required Mechanical Engine Power Limitation



Graphic 16 - Effect of Category A EET adoption on required Mechanical Engine Power Limitation.

For example, if no EET is installed, the required Mechanical Engine Power Limitation to meet the EEXI regulation will be 38.5%, and the maximum speed of the vessel at scantling draught conditions will be 14.10 knots. On the other hand, if Category A EET is installed, offering propulsion power savings of 50.8%, the required Mechanical Engine Power Limitation will be 24.2%. The corresponding maximum speed of the vessel at scantling draught conditions will be 16.86 knots.

4.6.3. Application of Category B Energy Efficiency Technologies

A list of the most commonly adopted EET of Category A, combined with their propulsion power saving, is shown below:

• Low Friction Hull Coating (3-5%)

• Hull Form Optimization (3-5%)

• Hull Cleaning (3-5%)

• Bare Optimization (3-5%)

• Rudder Resistance (3-5%)

• Propeller Design (3-5%)

• Post Swirl Fins (2-3%)

• Rudder Bulb (3-5%)

• Kappel Propeller Winglet (3-5%)

• Propeller Boss Cap Fin (2-5%)

• Alpha High Thrust Nozzle (5-8%)

• Mewis Duct(3-6%)

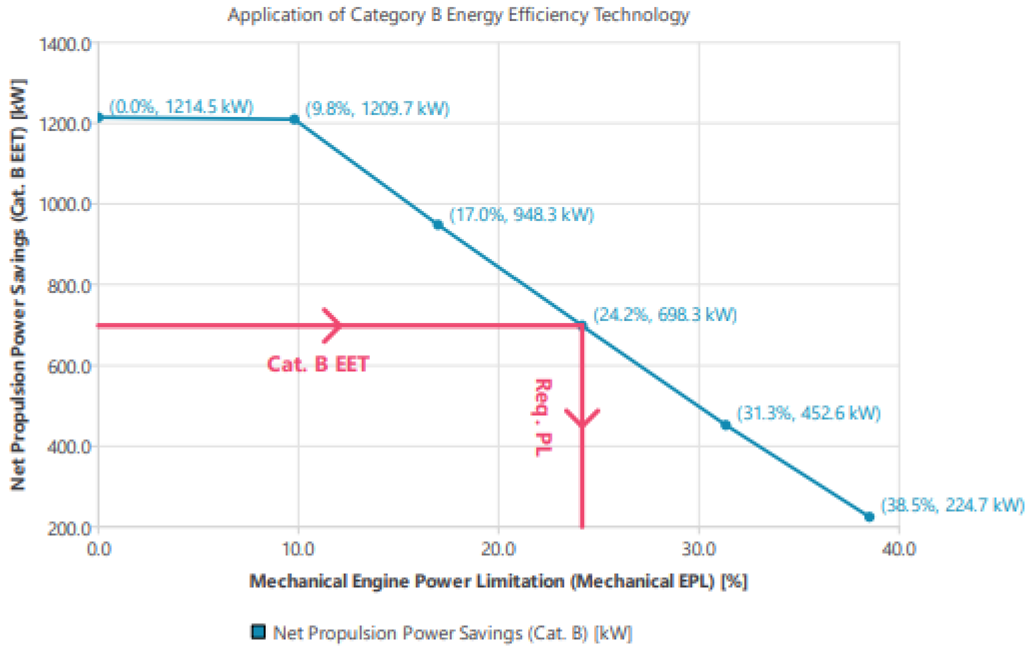
• Pre Swirl Fins (3-5%)

• Efficiency Rudders (2-4%)

For Category B EET, the table below provides the net propulsion power savings (i.e. Peff x feff as per IMO MEPC.1/Circ.815), combined with appropriate Mechanical EPL, in order to satisfy the EEXI requirement. The maximum attainable vessel speed at scantling draught for each case is also calculated and presented.

Net propulsion power savings (Cat. B) and corresponding required Mechanical EPL	
Required Mechanical EPL	Net Propulsion Power Savings
[%]	[kW]
0.0	1214.49
9.8	1209.69
17.0	948.27
24.2	698.29
31.3	452.56
38.5	224.73

Table 20 - Effect of Category B EET adoption on required Mechanical Engine Power Limitation



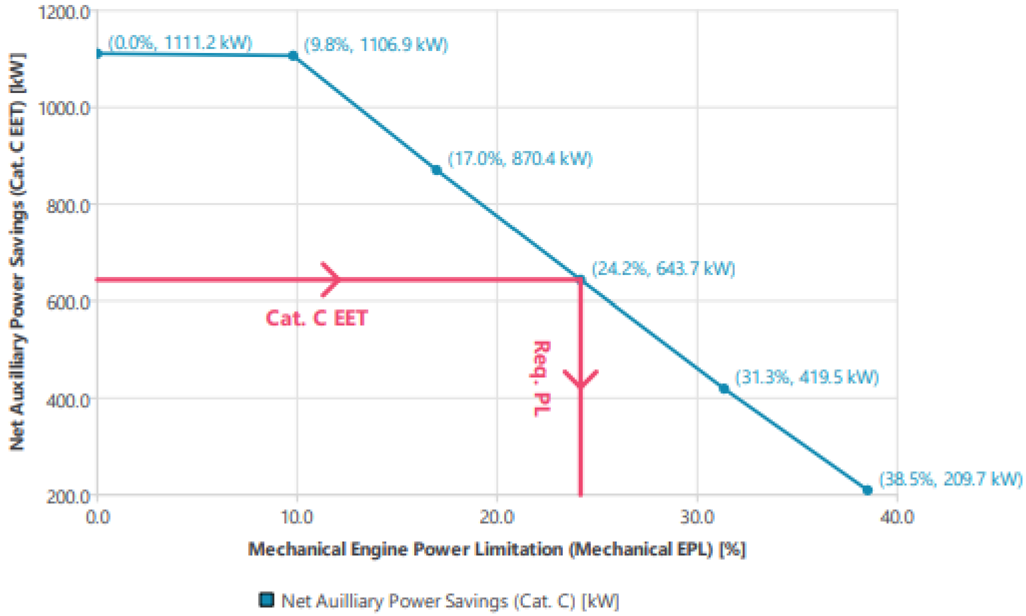
Graphic 17 - Effect of Category B EET adoption on required Mechanical Engine Power Limitation.

4.6.4. Application of Category C Energy Efficiency Technologies

For Category C EET, the table below provides the net auxiliary power savings (i.e. PAEeff x feff as per IMO MEPC.1/Circ.815), combined with appropriate Mechanical EPL, in order to satisfy the EEXI requirement. The maximum attainable vessel speed at scantling draught for each case is also calculated and presented.

Net auxilliary power savings (Cat. C) and corresponding required Mechanical EPL	
Required Mechanical EPL	Net Aux. Power Savings
[%]	[kW]
0.0	1111.21
9.8	1106.89
17.0	870.40
24.2	643.71
31.3	419.47
38.5	209.69

Table 21 - Effect of Category C EET adoption on required Mechanical Engine Power Limitation.



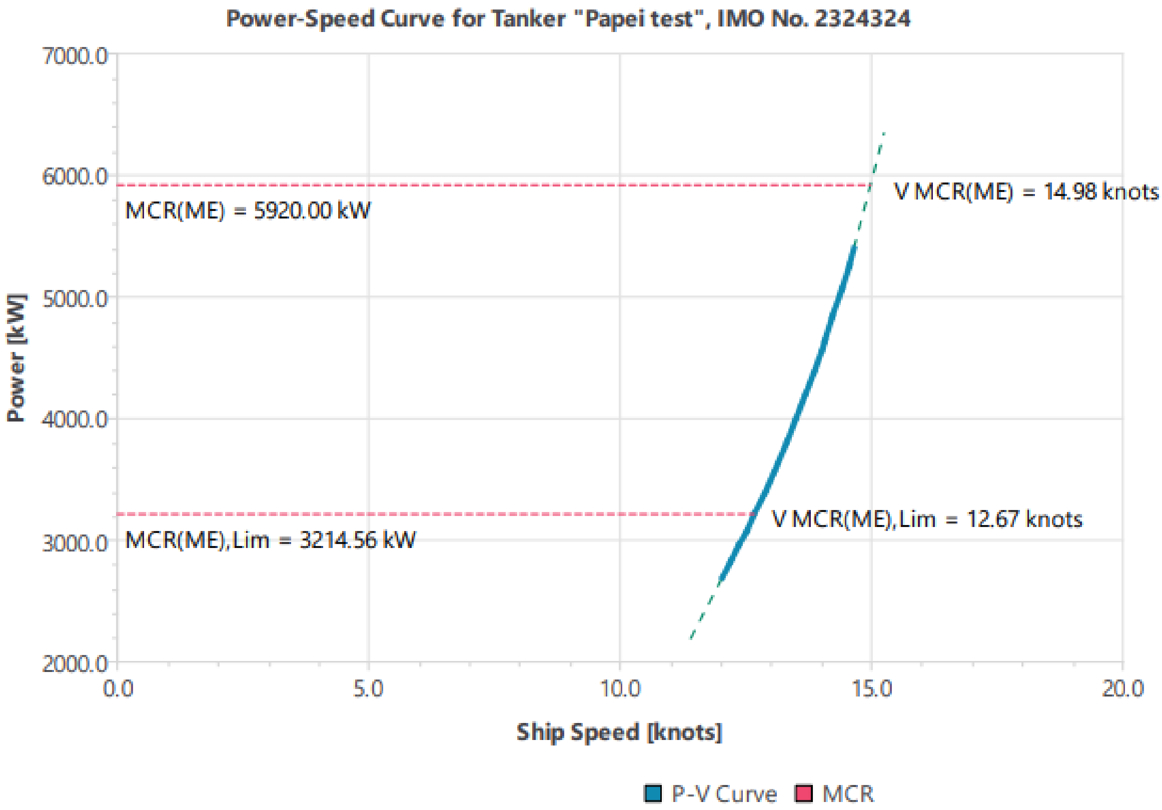
Graphic 18 - Effect of Category C EET adoption on required Mechanical Engine Power Limitation.

4.7 Ship Performance Calculations

4.7.1. Performance with Clean Hull / Calm Weather Conditions

The limited engine power MCR(ME),Lim is 3214.56 kW. Maximum ship speed at different draught conditions is calculated as follows:

At Scantling Draught, Vmax MCR(ME),Lim = 12.67 knots.



Graphic 19 - Power-Speed Curve of Vessel Unipi test at Scantling Draught. Calculation of Maximum Vessel Speed

The calculated values of Vmax, after Mechanical EPL at the different vessel draughts are presented below in Table 16.

Vmax MCR(ME),Lim
[knots]
Scantling Draught
12.67

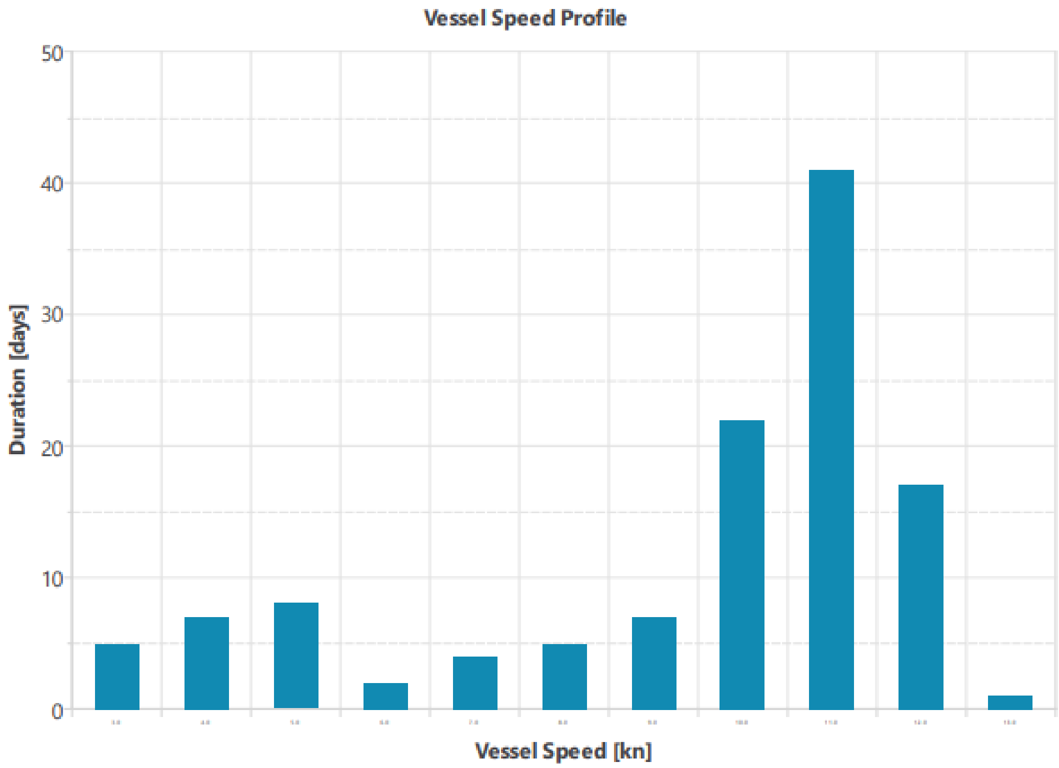
Table 22 - Mechanical Engine Power Limitation. Summary of Vessel Speed calculations.

Based on noon report data available for Vessel Unipi test, the vessel speed profile is presented below.

Number of noon reports: 120

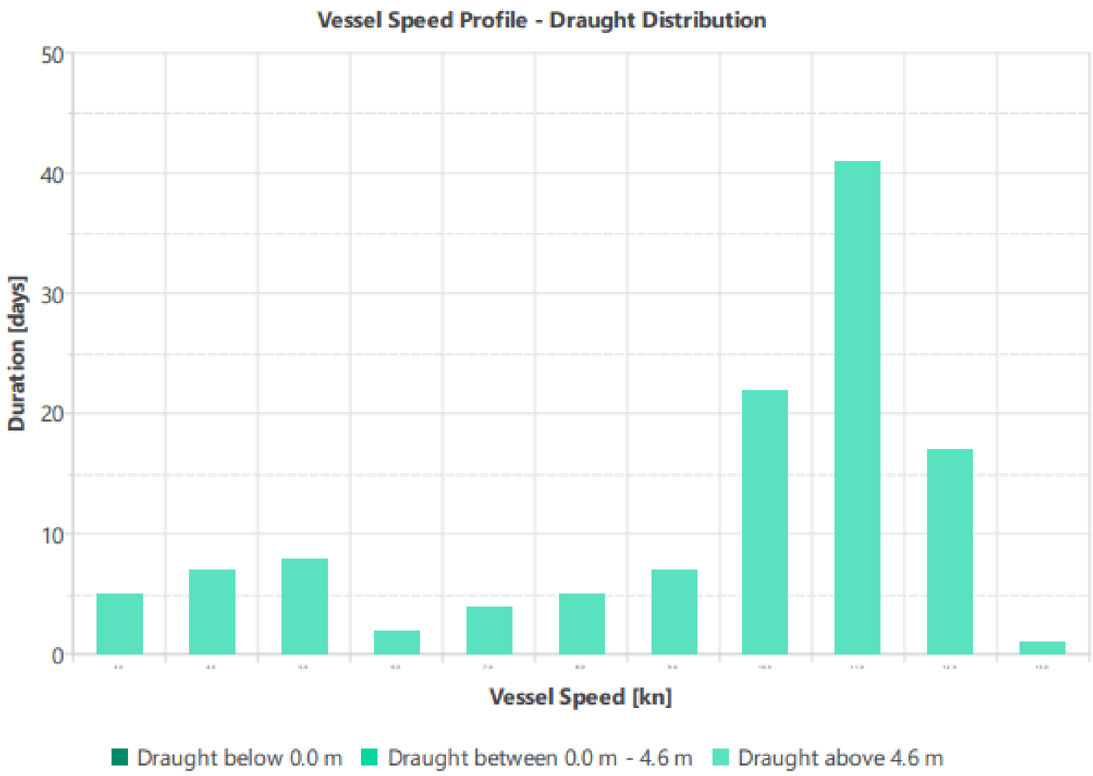
Minimum vessel speed: 2.5 knots (Range: 2.5 knots-3.5 knots)

Maximum vessel speed: 12.6 knots (Range: 12.5 knots-13.5 knots)



Graphic 20 - Speed profile of Vessel Unipi test.

The vessel speed profile based on existing noon data, and taking into account the actual vessel draughts, is presented in Graphic. 19.



Graphic 21 - Speed profile of Vessel Unipi test. Draught distribution per vessel speed.

Scantling Draught: 9.20

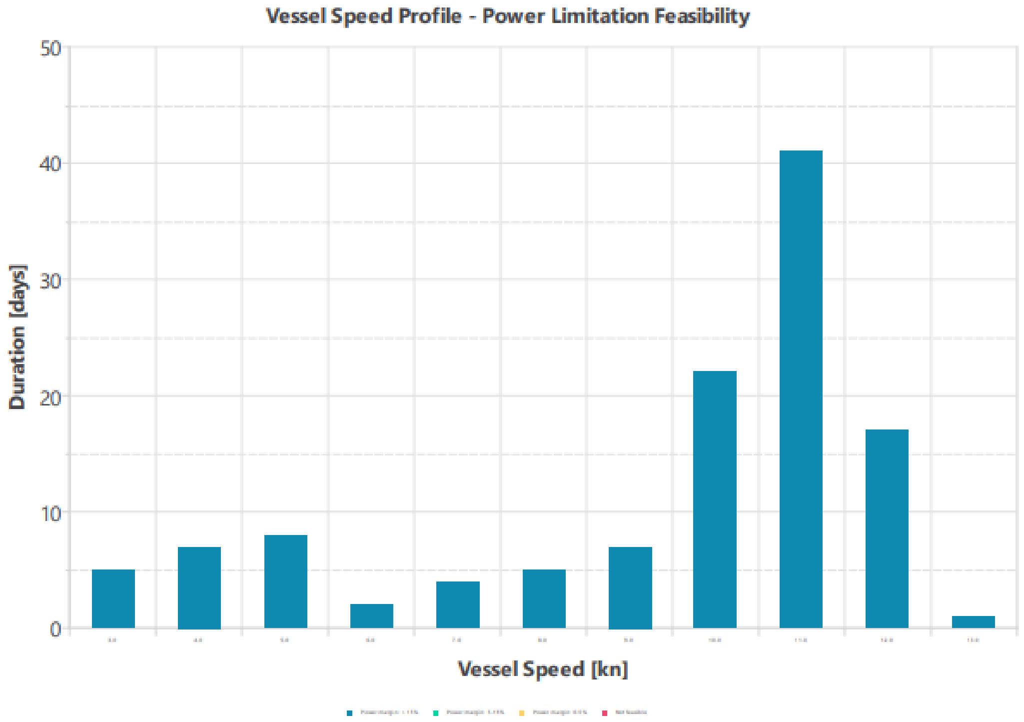
For each speed range, calculations are performed for estimating vessel performance with Mechanical EPL installed. The existing noon data are then distributed into four categories:

(1) Category "Not Feasible (NF)": Engine power after EPL not sufficient

(2) Category "Power Margin 0-5%": Engine after EPL provides power margin between 0-5%

(3) Category "Power Margin 5-15%": Engine after EPL provides power margin between 5-15%

(4) Category "Power Margin > 15%": Engine after EPL provides power margin greater than 15%



Graphic 22 - Speed profile of Vessel Unipi test. Mechanical EPL Feasibility.

Speed [knots]	Not Feasible	0-5%	5-15%	>15%	Summary
3.0	-	-	-	4.2%	4.2% (5)
4.0	-	-	-	5.9%	5.9% (7)
5.0	-	-	-	6.7%	6.7% (8)
6.0	-	-	-	1.7%	1.7% (2)
7.0	-	-	-	3.4%	3.4% (4)
8.0	-	-	-	4.2%	4.2% (5)
9.0	-	-	-	5.9%	5.9% (7)
10.0	-	-	-	18.5%	18.5% (22)
11.0	-	-	-	34.5%	34.5% (41)
12.0	-	-	-	14.3%	14.3% (17)
13.0	-	-	-	0.8%	0.8% (1)
Summary	0.0% (0)	0.0% (0)	0.0% (0)	100.0% (119)	100.0% (119)

Table 23 - Vessel Performance estimation (after Mechanical EPL installation) based on existing noon report data.

Statistics Summary

Total number of Valid Records: 119 Total number of Not Feasible Records: 0 (0.0%) Total number of Records with Power Margin in the range 0-5%: 0 (0.0%) Total number of Records with Power Margin in the range 5-15%: 0 (0.0%) Total number of Records with Power Margin above 15%: 119 (100.0%)

Vessel performance (after Mechanical EPL installation) per draught and speed is presented in the following table:

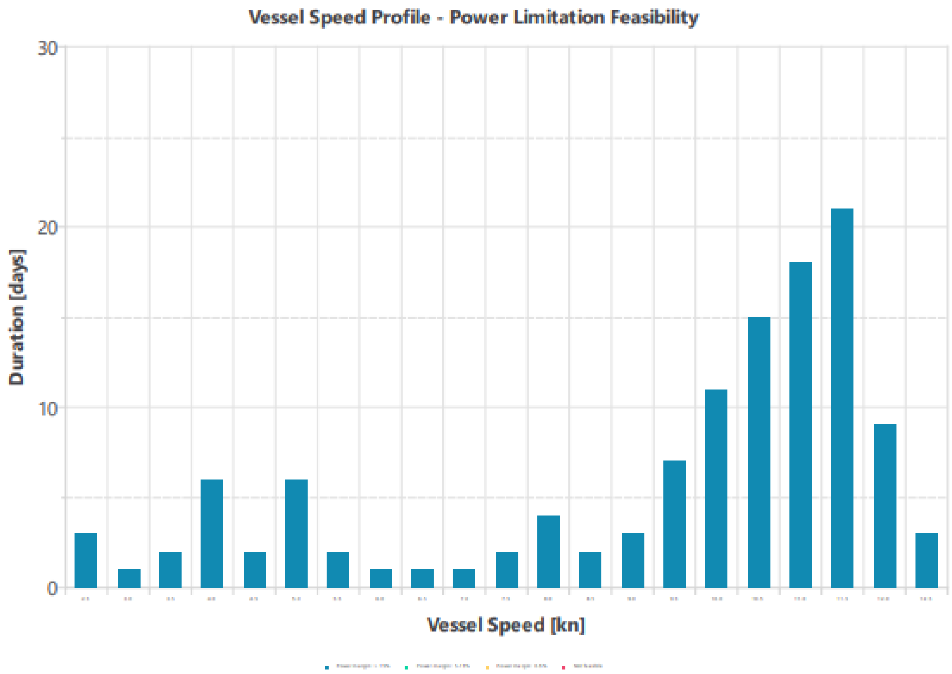
	3.0 kn	4.0 kn	5.0 kn	6.0 kn	7.0 kn	8.0 kn	9.0 kn	10.0 kn	11.0 kn	12.0 kn	13.0 kn	Tot.
9.0 m	4.2%	5.9%	6.7%	1.7%	3.4%	4.2%	5.9%	18.5%	34.5%	14.3%	0.8%	100.0%
Tot.	4.2%	5.9%	6.7%	1.7%	3.4%	4.2%	5.9%	18.5%	34.5%	14.3%	0.8%	100%

	3.0 kn	4.0 kn	5.0 kn	6.0 kn	7.0 kn	8.0 kn	9.0 kn	10.0 kn	11.0 kn	12.0 kn	13.0 kn	Tot.
9.0 m												100.0%
Tot.	4.2%	5.9%	6.7%	1.7%	3.4%	4.2%	5.9%	18.5%	34.5%	14.3%	0.8%	100%

■ Power margin: > 15% ■ Power margin: 5-15% ■ Power margin: 0-5% ■ Not feasible

Table 24 - Vessel Performance (after Mechanical EPL installation) per Draught and Speed.

Performance statistics (after Mechanical EPL installation) per draught and speed at higher vessel speeds are presented below:



Graphic 23 - Speed profile of Vessel Unipi test at high vessel speeds. Mechanical EPL Feasibility.

	2.5 kn	3.0 kn	3.5 kn	4.0 kn	4.5 kn	5.0 kn	5.5 kn	6.0 kn	6.5 kn	7.0 kn	7.5 kn	8.0 kn	8.5 kn	9.0 kn	9.5 kn	10.0 kn	10.5 kn	11.0 kn	11.5 kn	12.0 kn	12.5 kn	Tot.
9.0 m	2.5%	0.8%	1.7%	5.0%	1.7%	5.0%	1.7%	0.8%	0.8%	0.8%	1.7%	3.3%	1.7%	2.5%	5.8%	9.2%	12.5%	15.0%	17.5%	7.5%	2.5%	100.0%
Tot.	2.5%	0.8%	1.7%	5.0%	1.7%	5.0%	1.7%	0.8%	0.8%	0.8%	1.7%	3.3%	1.7%	2.5%	5.8%	9.2%	12.5%	15.0%	17.5%	7.5%	2.5%	100%

	2.5 kn	3.0 kn	3.5 kn	4.0 kn	4.5 kn	5.0 kn	5.5 kn	6.0 kn	6.5 kn	7.0 kn	7.5 kn	8.0 kn	8.5 kn	9.0 kn	9.5 kn	10.0 kn	10.5 kn	11.0 kn	11.5 kn	12.0 kn	12.5 kn	Tot.
9.0 m																						100.0%
Tot.	2.5%	0.8%	1.7%	5.0%	1.7%	5.0%	1.7%	0.8%	0.8%	0.8%	1.7%	3.3%	1.7%	2.5%	5.8%	9.2%	12.5%	15.0%	17.5%	7.5%	2.5%	100%

■ Power margin: > 15% ■ Power margin: 5-15% ■ Power margin: 0-5% ■ Not feasible

Table 25 - Vessel Performance (after Mechanical EPL installation) per Draught and Speed at high vessel speeds

4.7.2. Performance with Hull Fouling / Weather Power Margin

Based on noon report data available for Vessel Unipi test, and assuming power-speed curve data correspond to clean hull and calm weather conditions, performance statistics per draught and speed, for three different hull fouling and weather conditions (power demand increase of 0%, 5% and 10%, respectively) are presented below.

	3.0 kn	4.0 kn	5.0 kn	6.0 kn	7.0 kn	8.0 kn	9.0 kn	10.0 kn	11.0 kn	12.0 kn	13.0 kn	Tot.
9.0 m												100.0%
Tot.	4.2%	5.9%	6.7%	1.7%	3.4%	4.2%	5.9%	18.5%	34.5%	14.3%	0.8%	100%

	3.0 kn	4.0 kn	5.0 kn	6.0 kn	7.0 kn	8.0 kn	9.0 kn	10.0 kn	11.0 kn	12.0 kn	13.0 kn	Tot.
9.0 m												100.0%
Tot.	4.2%	5.9%	6.7%	1.7%	3.4%	4.2%	5.9%	18.5%	34.5%	14.3%	0.8%	100%

	3.0 kn	4.0 kn	5.0 kn	6.0 kn	7.0 kn	8.0 kn	9.0 kn	10.0 kn	11.0 kn	12.0 kn	13.0 kn	Tot.
9.0 m												100.0%
Tot.	4.2%	5.9%	6.7%	1.7%	3.4%	4.2%	5.9%	18.5%	34.5%	14.3%	0.8%	100%

■ Power margin: > 15% ■ Power margin: 5-15% ■ Power margin: 0-5% ■ Not feasible

Table 26 - Vessel Performance (after Mechanical EPL installation) per Draught and Speed, for different hull fouling / weather conditions corresponding to power demand increase of (a) 0% (Clean Hull/Calm weather), (b) 5%, and (c) 10%.

5. DISCUSSION

5.1. The impact of the EEXI on the operation of vessel Unipi

The above report is a live example of the impact of the EEXI on the operation and more specifically a tanker. At the beginning of the report, the characteristics of the vessel and its engines are cited. The next and very important step is the assessment of the EEXI. Based on its technical and operational characteristics, the vessel does not meet the EEXI requirements. The current EEXI is calculated as 11.53 g-CO $_2$/ton.mile while the required is 8.59 g-CO 2/ton.mile which means that the emissions should be reduced by 2.94 g-CO 2/ton.mile. to achieve compliance an EPL – Overridable Mechanical Engine Power Limitation of 45.7% must be applied. This EPL will also decrease the reference speed (V_{ref}) by the same percentage. The new main engine power will now be 3214.56 kw, 2705.44 kw less compared to the initial 5920 kw, which will finally lead to the desirable decrease of speed from 13.91 to 12.01 knots. After the application of the EPL, the maximum vessel speed at scanting draught will be reduced to 16.67 knots. Although, based on the noon reports, most of the recorded speeds vary between 10.5 to 11.5 knots and only the 2.5% of the speeds are over 12.5 knots, which would be close to or potentially exceed the new maximum speed after EPL. The proposed EPL of 45.7% appears to be a viable solution for EEXI compliance, with minimal impact on the vessel's current operational profile. Many recorded speeds fall well within the vessel's capabilities after EPL implementation. However, the small percentage of high-speed operations (above 12.5 knots) may no longer be possible. Except of the Engine Power Limitation there are also alternative or complement measures in order the vessel to comply with the EEXI. These measures are known as EETs – Energy Efficiency Technologies and are classified into three categories, Category A: Technologies that shift the power curve, which results in the change of combination of PME and Vref. As per the above analysis, no use of EETs entails 38.5% EPL and adjusts the maximum speed at 14.10 knots at scantling draught. In case EETs are used the required EPL is reduced to 24.2% and the maximum speed will be adjusted at 16.86 knots. The impact of the EETs is similar for the other two categories too. For Category B: Technologies that reduce the propulsion power, PP, at Vref, but not generate electricity. The saved energy is counted as Peff. In case these types of EETs are used, propulsion power savings of 698.29kW, the required Mechanical Engine Power Limitation will be 24.2%. Regarding the last category which is C, technologies that generate electricity. The saved energy is counted as PAEeff. if Category C EET is installed, offering propulsion power savings of 643.71kW, the required Mechanical EPL of the Main Engine(s) will be 24.2%. Implementing EETs could provide additional flexibility and potentially allow for a less severe EPL. This might be worth considering if the vessel occasionally requires higher speeds or if there are concerns about future operational needs. The last part of the analysis contains the Speed Profile of the vessel which was created using 120 noon reports. The vessel's speed according to the operating pattern extracted from the available noon reports ranges from 2.5 to 13.5 knots while the most common speeds are 10-11 and 11-12 knots. The maximum speed at scantling draught would be reduced to 12.67 knots after EPL implementation. These results are highly encouraging. Despite the significant 45.7% EPL, the vessel's typical operational profile remains well within the engine's capabilities. The high-power margins across all recorded operations suggest that the EPL can be implemented without major disruptions to current operations. The fact that even the highest recorded speeds (up to 13.5 knots) fall within the "Power margin > 15%" category indicates that the vessel should maintain good operational flexibility even after EPL implementation. However, it's worth noting that the absolute maximum speed will be reduced to 12.67 knots at scantling draught. In summary, through the findings of the above analysis, the EPL is the most viable solution so that the vessel complies with the EEXI regulations as it appeared to have the least possible impact on the vessel's operational profile.

5.2. Impact of the EEXI on the product Supply

The changes in speed deriving from the impact of the EEXI may not change the operational profile of the vessel so drastically in this case. Although in many more cases they could have a direct impact on the supply chain globally. The technological advance required to comply with them creates new expenses for the shipowners, while simultaneously the operational expenses are also increasing. The above leads to an unavoidable increase to the transportation expenses, making the products even more expensive *Review of Maritime Transport (United Nations Conference on Trade* *and Development, Geneva, 2023).*The retrofitting of an enterprise's fleet is also an unaffordable process which demands technological modification or even replacement of the whole fleet. In this case, the only way for the shipowners to bounce back is through high rates and as a result the increase in the products prices. The equivalence between supply and demand will also be disrupted. The non-compliance with the above mentioned measures can turn many vessels into non suitable for trading in specific routes or even non suitable at all. For this exact reason the demand will overcome the supply and will lead to increased prices but also severe delays in delivery times. These delays will gradually become a usual phenomenon in the supply chain and will affect the industry both on terms of cost but also in terms of management*(Decarbonization pathways for international maritime transport: A model-based policy impact assessment, Transportation Research Part D: Transport and Environment, 2022).* The stock of products will be constantly changing and the competitive advantage of many enterprises will be lost*(Disruptions and resilience in global container shipping and ports: the COVID-19 pandemic versus the 2008–2009 financial crisis,2022)* leading to lack of profitability. Furthermore, the EEXI will be almost mandatory to be included in the risk management assessment of each enterprise. Finally, the criteria for the selection of the suitable carrier will radically change. The most efficient ones will be preferred, and smaller enterprises will limited funds for operational improvements will be neglected*(Unintended Consequences Weekly Tanker Market Report, Gibson Shipbrokers, 2022).*The trading routes will also play a very important role, as many vessels will be no longer suitable to operate in specific areas of the world and will be driven out of the market*("Energy efficiency measures for compliance with EEXI requirements." Ocean Engineering,2022).*Even though these measures appear to have a controversial impact in shipping, the advantages of their adoption can be extremely beneficial for the achievement of the IMO's goals regarding the reduction of GHG emissions. Meanwhile, it is estimated that they will lead into gradual reduction of shipowners' the expenses and enhance competitiveness within the shipping industry.

5.3 Chain Impact of the EEXI on the Shipping Market

5.3.1.Freight market

As it is obvious in the above figures deriving from the analysis of the data collected from the vessel, reduction of speed is required for the vessel to comply with the EEXI regulation. This speed reduction may have additional consequences on the whole shipping chain. The first and more obvious part of the shipping chain which is being affected is the freight market or otherwise Chartering. The charterers are already being more selective regarding the choice of the vessels used to carry their freight, depending on their efficiency. Directly affected by the above are the charter rates*(Sailing on Solar: Could green ammonia decarbonise international shipping?" Environmental Innovation and Societal Transitions, 2022).* The vessels which are complying with the regulation seem to be more likeable to charterers, while at the same time shipowners whose fleet does not comply with the EEXI may be required to lower their demands in order to continue being competitive. In the opposite, shipowners with a modernized eco-friendly fleet can demand higher charter rates*(Does complying with energy efficiency regulations pay off in shipping? Transportation Research Part D: Transport and Environment,2023).* As it clearly understood, the modifications in speed can also lead into changes in the delivery time, since the vessel may be obliged to change her route and speed in order to comply with the regulation. As a result, delays with the delivery times which lead to great costs can occur. The operational costs of a vessel are also likely to be increased, as for the implementation of these regulations both technical and operational means have to be used*(Regulatory and contractual challenges in chartering energy-efficient ships." WMU Journal of Maritime Affairs,2023)*. Especially in time charter cases, the operational behavior of the vessel may change to worse, something which could cause further expenses to the owner during the evaluation process*(Sailing on Solar: Could green ammonia decarbonise international shipping?" Environmental Innovation and Societal Transitions, 2022)*. Moreover, in cases where technical means have to be replaced or improved to achieve efficiency, it has to be clearly stated which of the two contracting parties will undertake these expenses in order to avoid any dispute*(Decarbonization pathways for international maritime transport: A model-based policy impact assessment." Transportation Research Part D: Transport and Environment, 2022).* Finally, during the vessel's operations, daily reporting is required in order to achieve operational efficiency, so both parties should cooperate and not to skip this part.

5.3.2.The Sale and Purchase market

The implementation of the EEXI regulation may have different effect on the S& P market. Same as the freight market, anyone interested in expanding his fleet will take the compliance with the regulations in great consideration. Older and outdated vessels will not be so popular to buyers as they may not be able to comply with EEXI or this compliance costs an amount of money which makes them disadvantageous to buy. On the other hand, eco-friendly vessels will be more popular*(Review of Maritime Transport. United Nations Conference on Trade and Development, Geneva, 2023).* The changes in the regulations over the last few years will also affect the demolition market. Over the years more and more vessels which cannot comply with the regulation will be sold for scrap and in this way the market will be directly affected*(Does complying with energy efficiency regulations pay off in shipping? Transportation Research Part D: Transport and Environment,2022).* The S& P market is not affected only by Sales and Purchases as imposed by its name. investments are also a great part of this market. It is yet unknown if in the upcoming years shipowners will choose between modernizing their fleet by repairing and applying new technologies as per the efficiency standards or will choose to entirely replace the vessels which do not comply with these standards*(Integrated approach to vessel energy efficiency, 2023).* In case the majority chooses to proceed with the last option then the newbuildings market will be greatly affected*(Decarbonization of Maritime Transport: To Be or Not to Be?" Maritime Economics & Logistics,2023).*New orders will be constantly placed, and the shipyards' order books will be constantly full creating huge delays at the deliveries. These delays can turn the buyers to the secondhand market in order to cover their needs. These constant changes caused by the implication of the regulations will create great volatility in the S&P market and the conformity with the new measures will be from now on a very strong negotiation means for both sellers and buyers.

6. CONCLUSIONS

The EEXI – Energy Efficiency Ship Index in our days, consists a vital regulatory framework, which aims at the optimization of the energy efficiency of the vessels by reducing the GHG emissions and therefore eliminating the harmful impact of shipping. Through the above analysis of the regulations, it is clear that they will determine the future of maritime operations in a huge extend. The diploma thesis, skims through several factors concerning the EEXI, both operational such as the speed calculation but also functional, technical and regulatory. By examining the evolution of marine fuels and the actions taken by the International Maritime Organization (IMO) to combat pollution, the EEXI represents a significant step towards achieving sustainable shipping practices. The regulations set forth by the IMO, including MARPOL and the EEXI, demonstrate a concerted effort to curb emissions and promote energy efficiency in maritime operations. The most explanatory aspect described in this thesis is the way EEXI is calculated using parameters such as the fuel consumption of the main and the auxiliary engines, the vessel capacity and the technological means used to reduce the GHG emissions. The described calculations in association with the CII – Carbon Intensity Indicators create categories of vessels which underline the importance of compliance of each vessel with the environmental regulations and the standards imposed by them. This compliance as described in the above thesis will finally lead to a greener shipping industry. The inclusion of a real case study in the thesis has provided valuable insights into the practical application of the EEXI regulation. By analyzing data from vessel reports and technical files, the thesis has demonstrated how the EEXI impact ship operation, speed optimization, and compliance monitoring. The use of a specialized software for the data analysis and the EEXI calculations has facilitated a comprehensive understanding of the regulatory framework and its implications on vessel’s performance.

Through the investigation in this diploma thesis we can easily come to the outcome that the new environmental regulations led by the EEXI will highly affect the maritime operations in several ways, both operational but also technical. Stakeholders within the shipping industry are already trying to develop new technological and operational practices to meet the new environmental standards and reduce the impact of the industry on the environment. These practices mainly focus on the impact of the compliance with the regulations, as well as the elaboration of new practices, including the use of renewable sources of fuels in shipping.

In conclusion, the new environmental regulations and especially the EEXI constitute the dominant mean in order to achieve a more sustainable and environmentally friendly industry. Through their compliance to these regulations, the shipping companies will be able to reduce their carbon footprint and achieve environmental sustainability. The insights provided in this thesis shed light on the importance of energy efficiency in shipping and pave the way for a more sustainable future for the global shipping sector.

7. BIBLIOGRAPHY

Introduction to IMO (2023) International Maritime Organization. Available at: https://www.imo.org/en/About/Pages/Default.aspx (Accessed: 02 October 2024).

ABS (2023) . Available at: ww2.eagle.org

Alexopoulos, A. (2016) Environmental Management. Lecture Notes. Business College of Athens. Athens.

Bahtić, F. (2021) IMO defines new guidelines on EEXI and CII to support GHG measures. Offshore Energy [Online]. Available at: https://www.offshore-energy.biz/imo-defines-new-guidelines-on-eexi-and-cii-to-support-ghg-measures/

Baltic Exchange (2021) OTC FFA master agreement [Online]. Available at: https://www.balticexchange.com/content/dam/balticexchange/consumer/data-services-/documents-/other-useful-docs/Baltic%20Exchange%20OTC%20FFA%20Master%20Agreement%20Oct%202021.pdf

Baltic Exchange Consumer Main vessel types [Online]. Available at: https://www.balticexchange.com/en/who-we-are/guide-to-modern-shipping/main-vessel-types.html

Bazari, Z (2023) SQE and the upcoming environmental regulations. City, University of London Press. Bayes School. London.

Bazari, Z. (2023) Environmental Regulatory Management. City, University of London Press. London.

Carlton, J.S. (2023) Risk Management. City, University of London Press. London.

Cavalcante, I. (2020) Marine Diesel Engines Third Edition. Academia.edu [Online]. Available at: https://www.academia.edu/43585492/MARINE_DIESEL_ENGINES_THIRD_EDITION

Chrobak, U. (2022) The World's forgotten greenhouse gas. BBC Future [Online]. Available at: https://www.bbc.com/future/article/20210603-nitrous-oxide-the-worlds-forgotten-greenhouse-gas

ClassNK (no date) ClassNK No [Online]. Available at: https://www.classnk.or.jp/hp/pdf/activities/statutory/eedi/16_pr38rev4.pdf

Crown Oil (2023) Guide to bunker fuel [Online]. Available at: https://www.crownoil.co.uk/guides/bunker-fuel-guide

Denchak, M. (2023) Greenhouse effect 101. Be a Force for the Future [Online]. Available at: https://www.nrdc.org/stories/greenhouse-effect-101#gases (Accessed: 24 October 2023).

DNV (no date) Maritime forecast to 2050 [Online]. Available at: https://www.dnv.com/maritime/publications/maritime-forecast-2023/index.html

European Environment Agency (no date) Advanced search [Online]. Available at: https://www.eea.europa.eu/en/advanced-search?q=greenhouse+gases

Gibson Shipbrokers (2022) Unintended consequences [Online]. Available at: https://safety4sea.com/wp-content/uploads/2022/09/Gibson-Unintended-Consequences-2022_09.pdf

IMO (2023) [Online]. Available at: imo.org

IMO (no date) Fourth Greenhouse Gas Study 2020 [Online]. Available at: https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

IMO (no date) Guidance on reducing underwater noise from commercial shipping [Online]. Available at: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/833%20Guidance%20on%20reducing%20underwater%20noise%20from%20commercial%20shipping,.pdf

IMO (no date) IMO's response to current environmental challenges [Online]. Available at: https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/IMO%20and%20the%20Environment%202011.pdf

International Maritime Organization (2018) Ship emissions toolkit [Online]. Available at: https://greenvoyage2050.imo.org/wp-content/uploads/2021/01/SHIP-EMISSIONS-TOOLKIT-GUIDE-NO.3-DEVELOPMENT-OF-A-NATIONAL-SHIP-EMISSIONS-REDUCTION-STRATEGY.pdf

International Maritime Organization (no date) Ballast Water Management [Online]. Available at: https://www.imo.org/en/OurWork/Environment/Pages/BallastWaterManagement.aspx

International Maritime Organization (no date) EEXI and CII - ship carbon intensity and rating system [Online]. Available at: https://www.imo.org/en/MediaCentre/HotTopics/Pages/EEXI-CII-FAQ.aspx

International Maritime Organization (no date) IMO 2020 - cleaner shipping for Cleaner Air [Online]. Available at: https://www.imo.org/en/MediaCentre/PressBriefings/Pages/34-IMO-2020-sulphur-limit-.aspx

International Maritime Organization (no date) Imo2020 fuel oil sulphur limit - cleaner air, Healthier Planet [Online]. Available at: https://www.imo.org/en/MediaCentre/PressBriefings/pages/02-IMO-2020.aspx

International Maritime Organization (no date) Sulphur Oxides (sox) and particulate matter (PM) – regulation 14 [Online]. Available at: https://www.imo.org/en/OurWork/Environment/Pages/Sulphur-oxides-(SOx)-%E2%80%93-Regulation-14.aspx

MAN Energy Solutions (no date) Basic principles of ship propulsion [Online]. Available at: man-es.com

MOL Mitsui O.S.K. Lines (no date) History and transition of Marine Fuel [Online]. Available at: https://www.mol-service.com/blog/transition-in-ships-fuel

NASA (no date) What is the greenhouse effect? [Online]. Available at: https://climate.nasa.gov/faq/19/what-is-the-greenhouse-effect/

Nippon KaijiKyokai (no date) CII Carbon Intensity Indicator [Online]. Available at: https://www.classnk.or.jp/hp/pdf/activities/statutory/seemp/CII_en.pdf

Oiltanking (no date) Marine Gasoil (MGO) [Online]. Available at: https://www.oiltanking.com/en/news-info/glossary/marine-gasoil-mgo.html

Queensland Government (2023) Sulfur dioxide [Online]. Available at: https://www.qld.gov.au/environment/management/monitoring/air/air-pollution/pollutants/sulfur-dioxide

Sofiev, M. et al. (2018) Cleaner fuels for ships provide public health benefits with climate tradeoffs. Nature News [Online]. Available at: https://www.nature.com/articles/s41467-017-02774-9

UNCTAD (2023) [Online]. Available at: unctad.org

US EPA (2023) Climate Change [Online]. Available at: https://www.epa.gov/climate-change

Wartsila (no date) Energy efficiency operating indicator 'EEOI' [Online]. Available at: https://www.wartsila.com/encyclopedia/term/energy-efficiency-operating-indicator-eeoi

Wartsila (no date) Exhaust gas emissions from ships [Online]. Available at: https://www.wartsila.com/encyclopedia/term/exhaust-gas-emissions-from-ships

IMO (July 2011) RESOLUTION 203 (62) – AMENDMENTS TO THE ANNEX OF THE PROTOCOL OF 1997 TO AMEND THE INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS. MEPC 62.

IMO (May 2013) RESOLUTION 229 (65) – AMENDMENTS TO THE 2012 GUIDELINES ON SURVEY AND CERTIFICATION OF THE ENERGY EFFICIENCY DESIGN INDEX (EEDI). MEPC 65.

IMO (October 2014) RESOLUTION 232 (67) – AMENDMENTS TO THE 2013 INTERIM GUIDELINES FOR DETERMINING MINIMUM PROPULSION POWER TO MAINTAIN THE MANOEUVRABILITY OF SHIPS IN ADVERSE CONDITIONS. MEPC 67.

IMO (October 2016) RESOLUTION 278 (70) – AMENDMENTS TO THE ANNEX OF THE PROTOCOL OF 1997 TO AMEND THE INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS. MEPC 70.

IMO (April 2018) RESOLUTION 304 (72) – INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS. MEPC 72.

IMO (October 2018) RESOLUTION 309 (73) - AMENDMENTS TO THE 2014 GUIDELINES ON SURVEY AND CERTIFICATION OF THE ENERGY EFFICIENCY DESIGN INDEX. MEPC 73.

IMO (May 2019) RESOLUTION 323 (74) – INVITATION TO MEMBER STATES TO ENCOURAGE VOLUNTARY COOPERATION BETWEEN THE PORT AND

SHIPPING SECTORS TO CONTRIBUTE TO REDUCING GHG EMISSIONS FROM SHIPS. MEPC 74.

IMO (November 2020) RESOLUTION 203 (75) – AMENDMENTS TO THE MARPOL ANNEX VI PROCEDURES FOR SAMPLING AND VERIFICATION OF THE SULPHUR CONTENT OF FUEL OIL AND ENERGY EFFICIENCY DESIGN INDEX. MEPC 75.

IMO (June 2021) RESOLUTION 328 (76) – AMENDMENTS TO THE ANNEX OF THE PROTOCOL OF 1997 TO AMEND THE INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS. MEPC 76.

IMO (November 2021) RESOLUTION 342 (77) – PROTECTING THE ARCTIC FROM SHIPPING BLACK CARBON EMISSIONS. MEPC 77.

IMO (June 2022) RESOLUTION 342 (62) – AMENDMENTS TO MARPOL ANNEX VI AND THE NOX TECHNICAL CODE. MEPC 78.

IMO (November 2022) COUNCIL 128.

IMO (December 2022) RESOLUTION 366 and 367 (79) – ENCOURAGEMENT OF MEMBER STATES TO DEVELOP AND SUBMIT VOLUNTARY NATIONAL ACTION PLANS TO ADDRESS GHG EMISSIONS FROM SHIPS. MEPC 79.

IMO (July 2023) RESOLUTION 376 (80) – 2023 IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS. MEPC 80.

Maritime Economics (2009) , 3rd Edition. Available at: https://logistics.nankai.edu.cn/2016/0625/c5252a44004/page.htm

Manshani, S. (2023) Emissions services and our CII module: New TNM service launch, tnmservices. Available at: https://tnmservices.com/emissions-services-and-our-cii-module/

Mallouppas, G. and Yfantis, E.Ar. (2021) Decarbonization in shipping industry: A review of Research, technology development, and innovation proposals, MDPI. Available at: https://www.mdpi.com/2077-1312/9/4/415

Limiting engine power to reduce CO2 emissions from existing ships (2021). Available at: https://www.researchgate.net/publication/339337153_Limiting_engine_power_to_reduce_CO2_emissions_from_existing_ships

Reducing emissions from the shipping sector Climate Action. Available at: https://climate.ec.europa.eu/eu-action/transport/reducing-emissions-shipping-sector_en

Review of Maritime Transport 2023 - UNCTAD. Available at: https://unctad.org/system/files/official-document/rmt2023_en.pdf

This is how on-board carbon capture (OCC) works (2023) PierNext. Available at: https://piernext.portdebarcelona.cat/en/technology/capturing-carbon-on-board/

Air lubrication system - wärtsiläWartsila.com. Available at: https://www.wartsila.com/marine/products/propulsors-and-gears/energy-saving-technology/air-lubrication-system

Coatings become a critical component in the battle against emissions Riviera. Available at: https://www.rivieramm.com/news-content-hub/news-content-hub/coatings-become-a-critical-component-in-the-battle-against-emissions-75898

Hull coating. Available at: https://glomeep.imo.org/technology/hull-coating/

Do you know what the Bulbous Bow is for? (2023) SAFETY4SEA. Available at: https://safety4sea.com/cm-do-you-know-what-the-bulbous-bow-is-for/

Flettner rotors. Available at: https://glomeep.imo.org/technology/flettner-rotors/

Hellenic shipping news.. (2022) EEXI: Achieving Vessel Compliance, Hellenic Shipping News Worldwide. Available at:

https://www.hellenicshippingnews.com/eexi-achieving-vessel-compliance/ https://help.fleetmon.com/en/articles/4170886-what-is-a-noon-report.

Energy efficiency existing ship index (EEXI) technical file Marine Topics. Available at: https://www.marinetopics.com/articles-desktop-en/energy-

ShipFORCE, Ship Reality (2023). Available at: https://www.shipreality.com/products/ship-force

Cuong, T.N. et al. (2023) Seaport profit analysis and efficient management strategies under stochastic disruptions - Maritime Economics & Logistics, SpringerLink. Available at: https://link.springer.com/article/10.1057/s41278-023-00271-z.

Ančić, I., Vladimir, N., & Cho, D. S. (2022): "Energy efficiency measures for compliance with EEXI requirements." Ocean Engineering

Hellenic shipping news.. (2022) Gibson Tanker Report – unintended consequences, Hellenic Shipping News Worldwide. Available at: https://www.hellenicshippingnews.com/pective-gibson-tanker-report-unintended-consequences/.

Halim, R.A. et al. (2018) Decarbonization pathways for International Maritime Transport: A model-based Policy Impact Assessment, MDPI. Available at: https://www.mdpi.com/2071-1050/10/7/2243.

Adland, R., Alger, H., Banyte, J., & Jia, H (2023) "Does complying with energy efficiency regulations pay off in shipping?" Transportation Research Part D: Transport and Environment, Available at: https://www.researchgate.net/publication/310593821_Does_fuel_efficiency_pay_Empirical_evidence_from_the_drybulk_timecharter_market_revisited

Rehmatulla, N., Calleya, J., & Smith, T. (2022). sailing on solar - could green ammonia decarbonise international shipping? Available at:

https://www.researchgate.net/publication/332845713_Sailing_on_Solar_-_Could_green_ammonia_decarbonise_international_shipping.

Schinas, Metzger, D. (2023) Market-based measures and their impact on green shipping technologies - WMU Journal of Maritime Affairs, SpringerLink. Available at: https://link.springer.com/article/10.1007/s13437-021-00258-8 .

Review of Maritime Transport 2023 (2023) UNCTAD. Available at: https://unctad.org/publication/review-maritime-transport-2023.

Integrated approach to Vessel Energy Efficiency (2022) . Available at: https://www.researchgate.net/publication/284234611_Integrated_approach_to_vessel_energy_efficiency.

Psaraftis, H.N. (2022) Decarbonization of maritime transport: To be or not to be? - maritime economics & logistics, SpringerLink. Available at: https://link.springer.com/article/10.1057/s41278-018-0098-8.

Disruptions and Resilience in Global Container Shipping and ports: The covid-19 pandemic versus the 2008–2009 financial crisis (2022). Available at: https://www.researchgate.net/publication/348229195_Disruptions_and_resilience_in_global_container_shipping_and_ports_the_COVID-19_pandemic_versus_the_2008-2009_financial_crisis (Accessed: 02 October 2024).