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**SCHOOL OF INDUSTRY AND SHIPPING**

**DEPARTMENT OF MARITIME STUDIES**

**MSc Sustainability and Quality in Marine Industry**

# SHIP ENERGY EFFICIENCY – THE IMPACT IN SHIP DESIGN AND SHIP OPERATION OF THE NEW AMENDMENTS TO MARPOL VI

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Thesis

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# ABSTRACT

This thesis, titled "Ship Energy Efficiency: The Impact of New Amendments to Marpol VI on Ship Design and Operation," was conducted as part of the obligations in the postgraduate program MSc in Sustainability & Quality in the Marine Industry at the Department of Maritime Studies, University of Piraeus. The research was carried out under the supervision of Assistant Professor Stefanos Chatzinikolaou.

The objective of the thesis is to study ways to improve the practical implementation of the new imposed EEXI and CII indices, at the ship level. Achieving this goal is possible by evaluating the influence of the available solutions for energy efficiency on the vessel's operational profile when integrated with widely applied solutions such as the engine power limitation and the speed reduction.

Energy production from fossil fuels is a significant source of greenhouse gas (GHG) emissions, which contribute to climate change. The international shipping sector is one of the largest emitters of GHG emissions, accounting less than 3% of manmade GHG emissions (IMO, 2020).

The International Maritime Organization (IMO) has recently introduced a new regulatory framework under MARPOL VI, to gradually decrease the GHG emissions from international shipping. This includes setting limits on the carbon intensity of ships and encouraging the retrofitting of existing ships with energy-efficiency solutions.

The reduction of harmful emissions from the marine industry is a complex issue and requires a multi-faceted approach that includes regulatory frameworks, technological advancements, rethinking of operational patterns, and industry collaboration. The implementation of measures such as the EEXI and CII are important steps towards reducing GHG emissions from the shipping sector and mitigating the impact of climate change.

Reducing the ship's speed is a frequently used option to reduce fuel consumption and GHG emissions, since the required propulsive power increases significantly with speed. In this thesis we examine the widely applied technical solution of reducing the available propulsive power, through an engine power limitation (EPL) or Shaft Power Limitation (ShaPoLi) in combination with other technical and operational measures, with the purpose to meet the goal-based standard imposed by the EEXI regulation. Furthermore, the speed adjustment is considered as an operational solution to meet the requirements of the CII regulation.

The case study phase utilizes two cargo ships of different sizes and types. Documentation from the shipping company was collected for these ships regarding the design parameters (i.e. general particulars, propulsion, auxiliaries) which are used to calculate the EEXI, and operational parameters (transport work information per year from noon reports), which are needed for the CII calculations. Calculations of the attained EEXI and CII were performed per ship using the ShipFORCE commercial software which is available in the Department of Maritime Studies in an academic license. Calculations were performed for different levels of engine power limitation, ranging from no limitation to significant reduction of the available propulsive power. The analysis demonstrated the significant impact of EPL to meet the EEXI requirements.

In another step of the analysis, the gap between the attained and required EEXI and CII levels is assessed for the case study ships, and the effectiveness of different technical and operational measures to reduce this gap are evaluated.

The most effective technical and operational measures for the practical implementation of the EEXI and CII regulations in the short term are highlighted (i.e. speed reduction, EPL) and their impact in vessel's efficiency is commented. The operational speed reduction might be an effective and low-cost strategy to comply with the CII regulation but it has limited effect when a more drastic energy efficiency improvement is required.

Overall, this work aspires to provide valuable insights into the potential of engine power limitation and speed reduction as means of meeting regulatory requirements for emissions reduction in shipping and identify effective strategies for achieving these goals while maintaining vessel efficiency and profitability.

Keywords: Carbon Intensity Indicator (CII), Energy Efficiency Existing Index (EEXI), Engine Power Limitation (EPL), Shaft Power Limitation (ShaPoLi).

# ABSTRACT IN GREEK

Η παρούσα διπλωματική εργασία εκπονήθηκε στο πλαίσιο των υποχρεώσεων του μεταπτυχιακού προγράμματος σπουδών MSc στη Βιωσιμότητα & Ποιότητα στη Ναυτιλιακή Βιομηχανία στο τμήμα Ναυτιλιακών Σπουδών του Πανεπιστημίου Πειραιώς, υπό την επίβλεψη του Επ. Καθηγητή κ. Στέφανου Χατζηνικολάου.

Ο σκοπός της ανάλυσης είναι να βελτιωθεί η πρακτική εφαρμογή των νέων δεικτών EEXI και CII, σε επίπεδο πλοίου. Η επίτευξη αυτού του στόχου είναι δυνατή με την αξιολόγηση της επίδρασης των τεχνολογιών ενεργειακής απόδοσης στο λειτουργικό προφίλ ενός πλοίου όταν συνδυάζονται με την μείωση ισχύος της κύριας μηχανής του πλοίου (EPL) και τον περιορισμό της ταχύτητας, εάν απαιτείται.

Η παραγωγή ενέργειας από ορυκτά καύσιμα αποτελεί σημαντική πηγή εκπομπής αερίων του θερμοκηπίου, που συμβάλλουν στην κλιματική αλλαγή. Ο τομέας της ναυτιλίας εκπέμπει λιγότερο από 3% των παγκόσμιων ανθρωπογενών εκπομπών.

Ο Διεθνής Ναυτιλιακός Οργανισμός (IMO) έχει αναπτύξει ένα νέο πλαίσιο κανονισμών ενταγμένων έκτο παράρτημα της MARPOL (MARPOL VI), για τη μείωση των εκπομπών του παγκόσμιου στόλου. Αυτό περιλαμβάνει τον καθορισμό των ορίων στην ένταση του άνθρακα από τα πλοία και την εισαγωγή ενός Δείκτη Υπάρχοντος Αποδοτικότητας Πλοίων (EEXI) για την ενθάρρυνση μετατροπών στα υπάρχοντα πλοία με ενεργειακά αποδοτικές τεχνολογίες.

Η μείωση των επιβλαβών εκπομπών από τη ναυτιλιακή βιομηχανία αποτελεί ένα πολύπλοκο ζήτημα που απαιτεί μια πολυεπίπεδη προσέγγιση που περιλαμβάνει κανονιστικά πλαίσια, τεχνολογική πρόοδο, έρευνα και ανάπτυξη, και συνεργασίες εντός της βιομηχανίας. Η εφαρμογή μέτρων όπως το EEXI και το CII είναι σημαντικά βήματα προς τη μείωση των εκπομπών, από τον ναυτιλιακό τομέα και τη μείωση των επιπτώσεων της κλιματικής αλλαγής.

Η μείωση της ταχύτητας του πλοίου είναι μια συνηθισμένη στρατηγική για τη μείωση της κατανάλωσης καυσίμου και των εκπομπών του, καθώς η ισχύς που απαιτείται για την κίνηση ενός πλοίου αυξάνεται σημαντικά με την ταχύτητά του. Σκοπός αυτής της διατριβής είναι να εξετάσει το δυναμικό μείωσης της ταχύτητας του πλοίου μέσω του EPL και του συνδυασμού του με άλλα

τεχνικά και λειτουργικά μέτρα για την επίτευξη του Δείκτη Υπάρχοντος Αποδοτικότητας Πλοίων (EEXI) και των επιπτώσεών του στον Δείκτη Υπάρχοντος Άνθρακα (CII).

Η μελέτη ξεκινά με την επιλογή δύο πλοίων διαφορετικών μεγεθών και τύπων και την ανάλυση των τρεχουσών τους τιμών EEXI και CII. Υπολογισμοί των τιμών EEXI και CII πραγματοποιούνται για κάθε πλοίο σε διάφορα επίπεδα περιορισμού ισχύος μηχανής και ταχύτητας. Η σχετική μελέτη δείχνει το δυνητικό αντίκτυπο του EPL και της μείωσης της ταχύτητας στην επίτευξη των απαιτούμενων τιμών EEXI και CII.

Στη συνέχεια, υπολογίζεται το χάσμα μεταξύ των επιτευχθέντων και απαιτούμενων επιπέδων EEXI και CII, προκειμένου να αξιολογηθεί η αποτελεσματικότητα των διαφόρων τεχνικών και λειτουργικών μέτρων για τη μείωση αυτού του χάσματος.

Στο τελικό στάδιο, εξάγονται συμπεράσματα βασισμένα στα ευρήματα της ανάλυσης και προτείνονται ιδέες για μελλοντικές μελέτες στην περιοχή. Τα αποτελεσματικά τεχνικά και λειτουργικά μέτρα για τη μείωση των εκπομπών και της κατανάλωσης καυσίμου ενός πλοίου σχολιάζονται, και τονίζεται η σημαντικότητα των αποφάσεων σε επίπεδο λειτουργίας πλοίου, λαμβάνοντας υπόψη τον πιθανό αντίκτυπο της μείωσης της ταχύτητας στην αποδοτικότητα και τις λειτουργικές δαπάνες του πλοίου.

Συνολικά, η μελέτη φιλοδοξεί να προσφέρει  σχετικά με το δυναμικό περιορισμού ισχύος των κινητήρων και την μείωση της ταχύτητας ως μέσα για την επίτευξη των κανονιστικών απαιτήσεων για τη μείωση των εκπομπών στη ναυτιλία και θα εντοπίσει αποτελεσματικές στρατηγικές για την επίτευξη αυτών των στόχων διατηρώντας παράλληλα την αποδοτικότητα και την κερδοφορία του πλοίου.

Λέξεις-κλειδιά: Δείκτης Εκπομπής Διοξειδίου του Άνθρακα (CII), Δείκτης Ενεργειακής Απόδοσης Υφιστάμενων Σκαφών (EEXI), Περιορισμός Ικανότητας Ισχύος Κινητήρα (EPL), Περιορισμός Ικανότητας Ισχύος Άξονα (ShaPoLi).

# CHAPTER 1: INTRODUCTION

Air emissions have serious environmental impacts on local and global scale, and the use of fossil fuels is a significant contributor to this problem. The shipping industry, despite being one of the most energy-efficient modes of transportation, still contributes to the problem. (EC, 2023)

Ships typically run on heavy fuel oil, which is a type of fuel that contains high levels of sulfur and other pollutants. When these fuels are burned in internal combustion engines, they release harmful air emissions such as sulfur oxides, nitrogen oxides, particulate matter, and carbon dioxide into the air. These emissions have a range of negative impacts on human health and the environment, including respiratory and cardiovascular problems, acid rain, and climate change. (ClearSeas, 2023)

The International Maritime Organization (IMO), which is the main regulatory body for the global shipping industry, has taken steps to address this issue. IMO has already introduced regulations to limit the sulfur content in the marine fuels and has set targets for reducing GHG emissions from the shipping sector. However, much more needs to be done from the shipping industry becomes in order the sector to reach future targets and become more sustainable and environmentally friendly (IMO, 2019a).

There are efforts to explore alternative fuels for ships, such as biofuels, hydrogen, and electric power. (EMSA, 2023) However, these alternatives are still in early stages of development, with significant challenges still need to be addressed before they can be widely adopted within the shipping industry.

Overall, reducing air emissions from the international shipping industry is a complex and challenging problem, which needs to be addressed in different levels with various solutions at the operational, technical, and market-based perspective.

To address these emissions, regulatory frameworks have been developed and are continuously being developed to calculate, control, and minimize the industry's impact on the environment. For example, IMO has implemented regulations such as the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) to improve the energy efficiency of ships and reduce their GHG emissions. (DNV, 2023).

Additionally, the IMO has set targets to reduce the shipping industry's GHG emissions by at least 50% by 2050 compared to 2008 levels, with a goal of achieving zero emissions during the second half of the century. (IMO, 2019a). This target is a part of the IMO's Initial GHG Strategy, which also includes a commitment to reduce the carbon intensity of shipping by at least 40% by 2030.

Overall, there is a growing recognition of the need to address the shipping industry's impact on the environment, and regulatory frameworks are being developed to help the reduction of the GHG emission.

# CHAPTER 2: ENVIRONMENTAL CONCERNS

## 2.1 GREENHOUSE GAS EMISSIONS

Greenhouse gases such as carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), and fluorinated gases (such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride) trap heat in the Earth's atmosphere and contribute to climate change. Of these greenhouse gases, carbon dioxide is the most abundant and is primarily emitted by burning fossil fuels for electricity generation, transportation, and other human activities. Methane is also a potent greenhouse gas and is emitted from sources such as livestock and natural gas production. Nitrous oxide is emitted from sources such as fertilizers and industrial processes.

Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O) and Fluorinated Gases are the most crucial GHGs. Below a small overview is presented:

- Carbon Dioxide (CO2): Carbon dioxide is a greenhouse gas because it absorbs infrared radiation and traps heat in the Earth's atmosphere, contributing to global warming and climate change. The combustion of fossil fuels for energy, transportation, and other human activities is the primary source of carbon dioxide emissions. Deforestation and other land use changes also contribute to carbon dioxide emissions by reducing the amount of vegetation that can absorb and store carbon. Reducing carbon dioxide emissions and increasing carbon sequestration through measures such as reforestation and carbon capture and storage is critical to addressing climate change.

- Methane (CH4): Methane is a potent greenhouse gas that is emitted from various sources, including livestock farming, landfills, and fossil fuel production. In the energy industry, methane is emitted during the production, processing, and transportation of oil, natural gas, and coal. Methane emissions from the energy industry are estimated to account for around one-third of all anthropogenic methane emissions worldwide. Other significant sources of methane emissions include agricultural practices such as livestock farming and rice cultivation, as well as natural sources such as wetlands and termites. (EC, 2023)

- Nitrous Oxide ($N_2O$): is a greenhouse gas primarily emitted from agricultural practices such as the use of nitrogen-based fertilizers and manure management. When these fertilizers and manure are applied to soil, they can break down and release nitrous oxide into the atmosphere. Nitrous oxide is also emitted from the burning of fossil fuels and from industrial processes such as the production of nitric acid. However, the majority of nitrous oxide emissions are related to agricultural practices. Nitrous oxide is a potent greenhouse gas, with a global warming potential that is over 273 times greater than that of carbon dioxide. (EPA, 2024a) Reducing nitrous oxide emissions is an important part of mitigating climate change, and measures such as improving agricultural practices to reduce fertilizer use and improving manure management can help to achieve this goal. Additionally, using renewable energy sources and improving energy efficiency can reduce nitrous oxide emissions from fossil fuel combustion. (EPA, 2024b)
- Fluorinated gases: Include chlorofluocarbons, hydro chlorofluorocarbons, and hydro fluorocarbons. These are fluorinated gases that are potent greenhouse gases with high global warming potentials. They are not naturally occurring gases, but are instead manufactured chemicals that have been used for a variety of industrial and commercial purposes. (EPA, 2024b)

Numerous human activities increase the amount of greenhouse gases in the atmosphere, which absorb more and more heat and cause global warming.

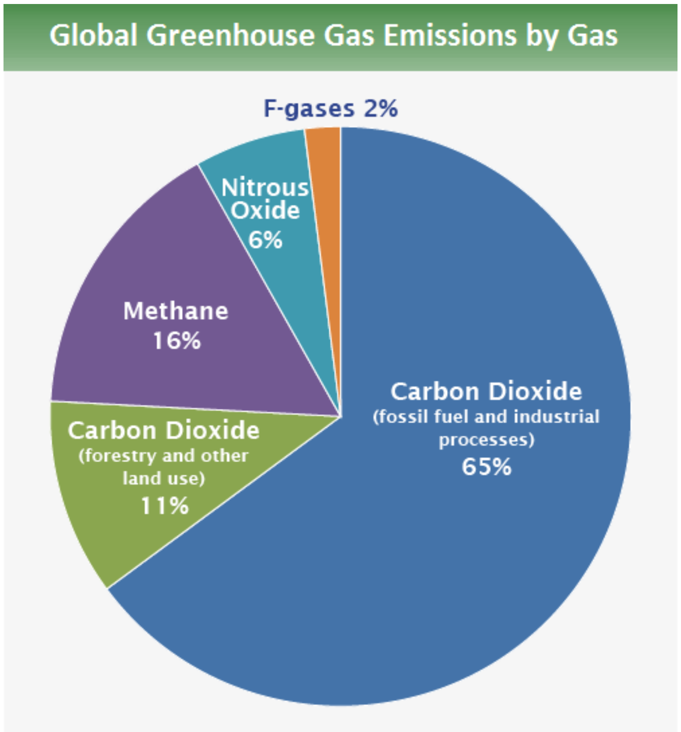



*Figure 1: Global Greenhouse Gas Emissions by Gas (Wikipedia, 2019)*

## <u>CO2 emissions from fossil fuels:</u>

The growth of global CO2 emissions from the mid-18th century up to 2023 is show in Fig.2.

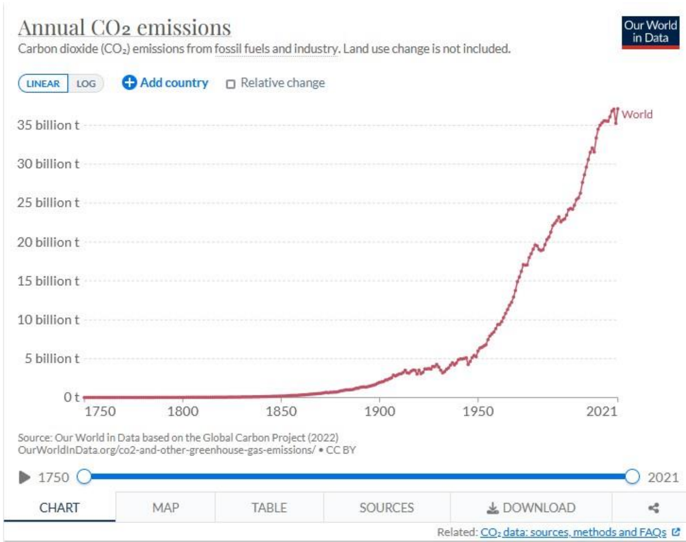



*Figure 2:Annual CO2 emissions (Roser et.al, 2023)*

CO2 emissions were quite low before the Industrial Revolution. In year1950 the world emitted 6 billion tonnes of CO2, while in 1990 22 billion tonnes and in 2021emitted 34 billion tonnes in total. (Roser et.al, 2023)

CO2 emissions cause the temperature increase of the planet and are shown in the below graph (Roser et.al, 2023).

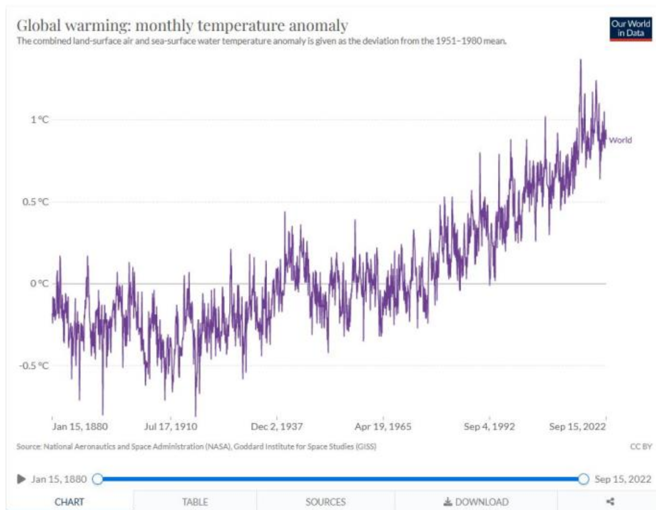



*Figure 3:Global warming: monthly temperature anomaly (Roser et.al, 2023)*

# CHAPTER 3: GREENHOUSE EFFECT

The greenhouse effect is a natural process that helps to regulate the Earth's temperature and make it suitable for life as we know it. It is caused by certain gases in the atmosphere, such as carbon dioxide, water vapor, and methane, which trap heat from the sun and keep it close to the Earth's surface. Without the greenhouse effect, the Earth would be much colder and less hospitable to life. However, human activities, particularly the burning of fossil fuels, have significantly increased the levels of greenhouse gases in the atmosphere. This, in turn, has led to an enhanced greenhouse effect, causing global temperatures to rise and resulting in climate change. The increase in global temperatures has numerous effects, including melting of polar ice caps, rising sea levels, more frequent and severe weather events, and changes in the distribution of plant and animal species. To mitigate the effects of climate change, it is important to reduce greenhouse gas emissions through actions such as increasing the use of renewable energy sources, improving energy efficiency, and implementing policies that promote sustainable practices. (EPA, 2023)

As reported by Environmental Protection Agency, EPA (EPA, 2021), the main sources of greenhouse gas emissions in the United States are the following:

**Transportation:** Globally, transportation is responsible for about 14% of greenhouse gas emissions. The burning of fossil fuels for transportation, primarily gasoline and diesel, is a significant contributor to greenhouse gas emissions. The transportation sector is heavily reliant on petroleum-based fuels, which are produced by refining crude oil. When these fuels are burned, they release carbon dioxide (CO2) and other greenhouse gases into the atmosphere, contributing to climate change.

**Electricity production:** According to the International Energy Agency (IEA), electricity and heat production account for approximately 42% of global CO2 emissions, making it the largest sector contributing to greenhouse gas emissions. Fossil fuels such as coal, natural gas, and oil are the primary sources of electricity generation worldwide, accounting for approximately 64% of the world's electricity generation in 2020. The remaining electricity generation comes from renewable sources such as wind, solar, and hydropower. The transition to cleaner and more sustainable energy sources is crucial in reducing greenhouse gas emissions and mitigating the impact of climate change.

**Industry:** The industrial sector is a significant contributor to greenhouse gas emissions. The primary source of emissions from industry is the combustion of fossil fuels for energy generation, such as in manufacturing processes, transportation of goods, and other industrial activities. Additionally, many industrial processes involve chemical reactions that emit greenhouse gases, including carbon dioxide, methane, and nitrous oxide, during the production of goods from raw materials. Some examples of industries with high emissions include cement production, steel manufacturing, and chemical production. Reducing emissions from industry will require a combination of energy efficiency improvements, the deployment of low-carbon technologies, and the transition to renewable energy sources. Additionally, increasing the use of circular economy practices, such as recycling and reusing materials, can also help reduce emissions from industry.

**Commercial and Residential:** Fossil fuel combustion for heating and cooling buildings, as well as the use of appliances and equipment that rely on electricity generated from fossil fuels, contribute significantly to greenhouse gas emissions from homes and businesses. The use of certain items, such as refrigerants and foam insulation, also contributes to emissions due to their high global warming potential. Additionally, waste management practices, including landfilling and incineration of waste, contribute to greenhouse gas emissions from businesses and households. These emissions primarily come from the decomposition of organic waste in landfills and the combustion of waste in incinerators. Implementing energy-efficient practices, such as upgrading building insulation, using energy-efficient appliances, and reducing waste production, can help reduce greenhouse gas emissions from homes and businesses. Additionally, transitioning to renewable energy sources, such as solar or wind power, can further reduce emissions.

**Agriculture:** Greenhouse gas emissions from agriculture derive from livestock such as cows, agricultural soils, and rice production.

**Land Use and Forestry:** Land regions, such as forests, grasslands, and wetlands, have the potential to act as both sources and sinks of greenhouse gas emissions. When plants grow, they absorb carbon dioxide from the atmosphere through photosynthesis and store it in their biomass and in the soil. This process of carbon sequestration can help mitigate climate change by removing carbon dioxide from the atmosphere. However, when land is disturbed, such as through deforestation or soil degradation, it can release carbon dioxide and other greenhouse gases into the atmosphere.

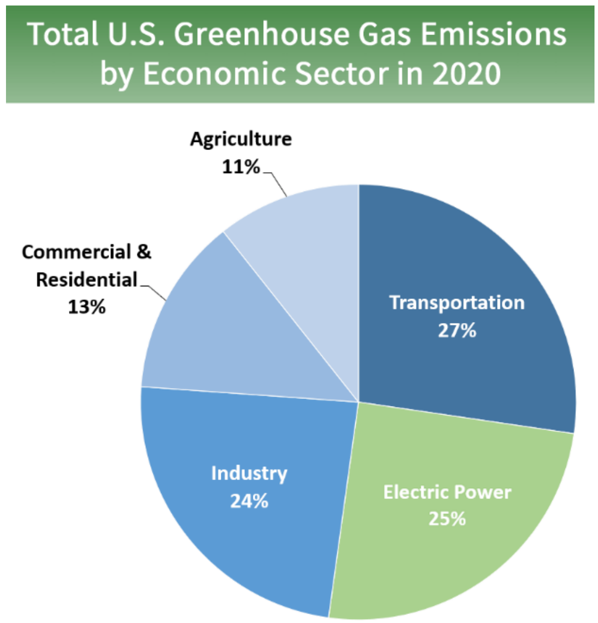



*Figure 4:Total U.S emissions in 2020=5,981 Million Metric Tons of CO2 equivalent. (EPA) (EPA, 2023)*

# CHAPTER 4: CO2 EMISSIONS FROM SHIPPING

Shipping is crucial for global trade and is responsible for transporting over 80% of the world's goods. However, it is also a significant source of GHG, accounting for approximately 3% of the related emissions. According to the latest IMO Greenhouse Gas Study, the majority of these emissions come from international shipping, which accounts for nearly 87% of all annual CO2 emissions from ships. Without any mitigation efforts, the shipping industry's emissions are projected to increase significantly and could account for 10-13% of all emissions within a few decades. To address the issue, IMO is continuously introducing measures to control emissions from the maritime industry. (UNCTAD, 2023)

One of the current strategies is to promote the use of cleaner fuels such as liquefied natural gas (LNG), which produces fewer emissions than traditional marine fuels like heavy fuel oil. While LNG is a cleaner fuel compared to traditional marine fuels, it still emits greenhouse gases, including carbon dioxide. Therefore, the shipping industry is exploring alternative low-carbon fuels to further reduce emissions. (Enazi et.al, 2021)

Green methane, also known as biomethane or renewable natural gas, is a promising alternative to LNG. It is produced from organic waste, such as agricultural and food waste, and can be used as a drop-in replacement for natural gas. Green methane has the potential to significantly reduce greenhouse gas emissions from the shipping industry since it can be produced from renewable sources. (wikipedia, 2024)

Another potential substitute for fossil fuels containing carbon is ammonia. Ammonia is a carbon-free fuel that can be produced using renewable energy sources, such as wind and solar. It has the potential to be a highly effective option for decarbonizing the shipping industry, as it does not emit any greenhouse gases during combustion. However, ammonia is a hazardous substance, and caution must be taken to prevent leaks, which can be harmful and offensive. (Dincer and Chehade, 2021)

In addition to green methane and ammonia, other low-carbon fuel options for the shipping industry include hydrogen, biofuels, and electric propulsion. The development and adoption of these alternative fuels are essential in achieving the shipping industry's emissions reduction targets and mitigating the impact of climate change. (King, 2022)

Black carbon (BC) is a significant contributor to the climate impact of shipping, representing 7% of total shipping $CO_2$-eq emissions on a 100-year timescale and 21% of $CO_2$-eq emissions on a 20-year timescale. BC is a short-lived climate pollutant, which means that reducing BC emissions from ships would immediately reduce shipping's climate impacts. (Olmer et.al, 2017)

However, BC has been largely ignored as a climate pollutant from ships until recently. The missing inventory of BC emissions from ships should be considered when evaluating the climate impacts of shipping. In recent years, there has been growing recognition of the importance of reducing BC emissions from shipping, and several initiatives and regulations have been developed to address this issue. These include measures to reduce emissions from marine engines and exhaust gas cleaning systems, as well as the use of cleaner fuels such as LNG, green methane, and ammonia. (Olmer. et. al, 2017)

## 4.1 The new regulatory framework for the reduction of GHG in the context of MARPOL VI

The MARPOL Annex VI came into force by IMO in September 1997 to address air pollution from ships. The primary objective is to remove significant air pollutants from the atmosphere, including sulfur oxides (SOx), nitrogen oxides (NOx), and greenhouse gas (GHG) emissions that contribute to the greenhouse effect and climate change. Revisions to the Annex VI came into force on May 19, 2005, to set limits on the maximum sulfur content of marine fuels used on board ships. A revised version of Annex VI, with stricter limitations on emissions, was adopted in October 2008 and came into force on July 1, 2010. The revised Annex VI includes further reductions in sulfur oxide and nitrogen oxide emissions and introduces a mandatory energy efficiency design index for new ships. (Barreiro. et.al, 2022)


*Figure 5: MARPOL Annexes (Barreiro. et.al, 2022)*

The regulations set forth in Annex VI have had a significant impact on the shipping industry, as ship owners and operators have had to invest in new technologies and fuels to comply with the new emission limits. The implementation of Annex VI has led to a reduction in emissions from the shipping industry, improving air quality and reducing the sector's contribution to climate change. (Barreiro. et.al, 2022)

The IMO and the United Nations Framework Convention on Climate Change (UNFCCC) have cooperated to initiate a study on the calculation and reduction of greenhouse gas (GHG) emissions from shipping. The study aims to collect data on fuel consumption and CO2 emissions from ships and develop methods for calculating and reporting emissions from the sector. (IMO, 2023)

The study is part of the IMO's efforts to reduce GHG emissions from the shipping sector, which is responsible for a significant proportion of global emissions. The study is also aligned with the objectives of the UNFCCC and the Paris Agreement, which aim to limit global warming to well below 2 degrees Celsius above pre-industrial levels.

The study provides important information on the extent of emissions from shipping and the potential for reducing these emissions through technological and operational measures. It will also contribute to the development of policies and regulations to address shipping emissions and support the transition to a low-carbon economy. (IMO, 2023)

Kyoto protocol was adopted on December 11, 1997, and entered into force on February 16, 2005. The protocol requires participating countries, known as Parties, to set binding emission reduction targets for greenhouse gases such as carbon dioxide, methane, and nitrous oxide (UNFCCC). The targets are set based on the country's level of development and contribution to global emissions. The protocol also allows for flexibility in achieving these targets, such as through emissions trading and the use of clean development mechanisms. (UN, 2023)

IMO introduced further amendments to the Annex VI which is part of the International Convention for the Prevention of Pollution from Ships (MARPOL) to address the contribution of ships to global carbon emissions. The Annex VI now includes operational and technical requirements aimed at reducing greenhouse gas (GHG) emissions from ships.

The operational requirements focus on improving the energy efficiency of ships and promoting the use of alternative energy sources. Ships are required to implement a Ship Energy Efficiency Management Plan (SEEMP) to improve their energy efficiency, and measures such as optimizing speed and route planning, improving maintenance, and reducing engine loads can be taken to achieve this goal.

The technical requirements include the use of new technologies to reduce GHG emissions, such as the use of energy-saving devices, waste heat recovery systems, and alternative fuels like liquefied natural gas (LNG). Additionally, the Annex VI sets limits on the sulfur content of marine fuels and requires the use of low-sulfur fuels or alternative compliance methods like exhaust gas cleaning systems (scrubbers).

Overall, the Annex VI aims to improve the energy efficiency of ships and promote the use of alternative energy sources.

Ship Energy Efficiency Management Plan Part I adopted on or after 1st of January 2013 and applies to ships of 400GT and above. In addition to that, amendments incorporated in 2016 by resolution MEPC.282 (70) to collect and report their fuel oil consumption data to the Administration or a Recognized Organization. These amendments apply to ships of 5,000 GT and above and urges ship owners to use new technologies and practices for the optimization of vessel’s performance. Further amendments were adopted in Resolution MEPC.328(76) with the introduction of the CII rating from the 1st of January 2023 on the annual fuel consumption of each vessel. (IMO, 2021)

The Energy Efficiency Operational Indicator (EEOI) is an index proposed for the monitoring of the ship's fuel efficiency and for measuring the amount of $CO_2$ emissions per unit of transport work. However, the EEOI can be affected by various external factors that can influence the ship's performance, such as weather conditions, the type of cargo being carried, the ship's route, and more. Therefore, it's important to use the EEOI in conjunction with other monitoring tools and to consider the context and external factors that may impact the results. (Tran and Anh, 2017)

The application of EEDI (Energy Efficiency Design Index) for new ships as a primary $CO_2$ emission goal-based standard is crucial in terms of technical performance. The index promotes the use of less polluting equipment and engines. EEXI was initially applied for the following ship types: tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers and combination carriers. In 2014 the Marine Environmental Protection Committee (MEPC) of IMO, adopted amendments to the EEDI regulation and extended the scope of EEDI to: LNG carriers, ro-ro cargo ships (vehicle carriers), ro-ro cargo ships; ro-ro passenger ships and cruise passenger ships having non-conventional propulsion. (IMO, 2022)

The EEDI is a performance-based mechanism that allows technologies to follow a specific ship design. While the EEDI is set at a certain level per ship type and ship size, designers and builders may come up with inexpensive solutions to make ships compliant. The EEDI offers a precise numerical value for a particular ship design. *The ship is considered more energy efficient when the EEDI is kept low (below the benchmark)*. The formula, which is based on the technical specifications of a particular ship, can be used to compute the EEDI. The first phase's $CO_2$ reduction level (in grams of $CO_2$ per tonne mile) is set at 10%, and it will adjust every five years in response to new technological advancements. (Strasser, 2021)

Both technical and operational standards, aspire to achieve increasing performance of existing ships as well as fuel savings and to promote the design of new more efficient vessels with higher efficiency and smaller environmental footprint.

## 4.2 IMO Strategy for the reduction of GHG from international shipping

The IMO GHG initial strategy is an important step towards reducing greenhouse gas emissions from the shipping industry, and it sets ambitious goals for reducing emissions by 40% by 2030 and

50% by 2050 compared to 2008 levels. The adoption of binding international energy efficiency standards and the addition of a new Chapter (Chapter 4) titled "Regulations on energy efficiency for ships" to MARPOL Annex VI are important measures to achieve these goals. (DNV, 2023)

The MEPC, or the Marine Environment Protection Committee, is the specialized unit of the International Maritime Organization (IMO) that is responsible for addressing marine environmental issues, including reducing greenhouse gas (GHG) emissions from ships. (IMO, 2023)

During its meetings, the MEPC discussed various submissions and proposals on how to progress the next stages of IMO's work to cut GHG emissions from ships, leading to the revision of the initial GHG strategy in 2023. As a result, the MEPC adopted a work plan to make progress with candidate mid- and long-term measures, which includes measures to incentivize the move away from fossil fuels utilizing low- and zero-carbon fuels to accomplish the decarbonization of global shipping.

This work plan is a concrete way forward for the IMO to address the urgent need to reduce GHG emissions from the shipping sector, which is responsible for less than 3% of global emissions. The adoption of this plan shows the commitment of the IMO and its member states to take action on climate change and work towards a sustainable future for the shipping industry. (IMO, 2020)

The IMO’s 2023 Revised GHG Strategy has three interlinked ambitions (DNV, 2023):

1. A reduction in carbon intensity of international shipping by at least 40 per cent by 2030 compared to 2008.
2. Uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to represent at least 5%, striving for 10%, of the energy used by 2030.
3. GHG emissions from international shipping to reach net zero by or around, i.e. close to, 2050.

The strategy also sets out indicative checkpoints for 2030 and 2040 (DNV, 2023)

- Checkpoint 1: to reduce the total annual GHG emissions from international shipping by at least 20%, striving for 30%, by 2030.
- Checkpoint 2: to reduce the total annual GHG emissions from international shipping by at least 70%, striving for 80%, by 2040.

To provide a regulatory framework to achieve the targets of the initial strategy, the IMO implemented the following measures as part of MARPOL (DNV, 2023)

- Energy Efficiency Design Index (EEDI): New ships must be built and designed to be more energy efficient.
- Ship Energy Efficiency Management Plan (SEEMP): A practical tool for helping shipowners manage their environmental performance and improve operational efficiency.
- Energy Efficiency Existing Ship Index (EEXI): Set to enter into force in 2023, EEXI applies many of the same design requirements as the EEDI, with some adaptations regarding limited access to design data.
- The Fuel Oil Consumption Data Collection System (DCS): Mandates annual reporting of CO2 emissions and other activity data and ship particulars for all ships above 5,000 GT.
- Carbon Intensity Indicator (CII) is a rating scheme (A-E) developed by the IMO to measure the annual performance of all ships above 5,000 GT in terms of CO2 per DWT and distance covered.

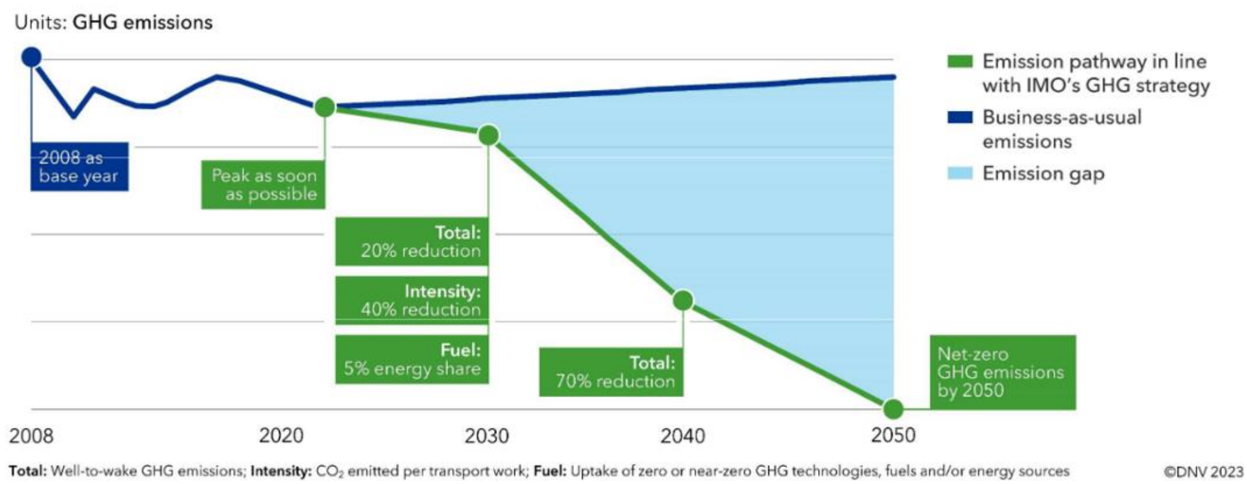



*Figure 6:Revised IMO's GHG strategy (DNV, 2023)*

To encourage the 40% reduction in the carbon intensity of all vessels by 2030, as compared to the 2008 baseline, ships must assess two metrics. First, they need to calculate their Attained EEXI to evaluate their energy efficiency. Second, they must determine their annual operational CII and its corresponding rating. Carbon intensity establishes a connection between greenhouse gas emissions and the quantity of cargo transported over the distance traveled.

The calculation of the EEXI and the establishment of the CII and rating will be mandatory. Accordingly, vessels will be given an energy efficiency rating of A, B, C, D, or E. (Tan. et.al, 2022)

Plans also will be established in order ships listed under category E or D to achieve category C or above. These amendments entered into force on 1st of November 2022. EEXI and CII certification will affect from the 1st of January 2023. Annual reporting will be completed in 2023 and rating will be given in 2024.

There are various initiatives and activities aimed at reducing GHG emissions from the shipping industry in the short-term, such as:

1. Research and development: There are ongoing efforts to develop new technologies, including alternative fuels, advanced propulsion systems, and energy-efficient designs, that can help reduce emissions from ships.
2. National action plans: Many countries have developed national action plans to reduce GHG emissions from shipping, which include measures such as incentives for the use of low-carbon fuels. Stricter emissions standards, and port-based measures to reduce emissions from ships.
3. Port activities: Many ports around the world are taking steps to reduce emissions from ships such as providing shore power and other infrastructure to support the use of alternative fuels.
4. Alternative fuels: The use of alternative fuels, such as liquefied natural gas (LNG), biofuels, and hydrogen, can help reduce GHG emissions from ships. Many shipping companies are already using these fuels, and there are ongoing efforts to develop new and more sustainable alternatives.
5. Technical and capacity-building activities: There are various technical and capacity-building activities aimed at helping shipping companies improve the energy efficiency of their ships, such as training programs, energy audits, and performance monitoring tools.

GHG strategy focuses on reducing harmful emissions, also known as *emissions trajectory*, using cleaner fuels to eliminate CO2, and increasing fuel economy.

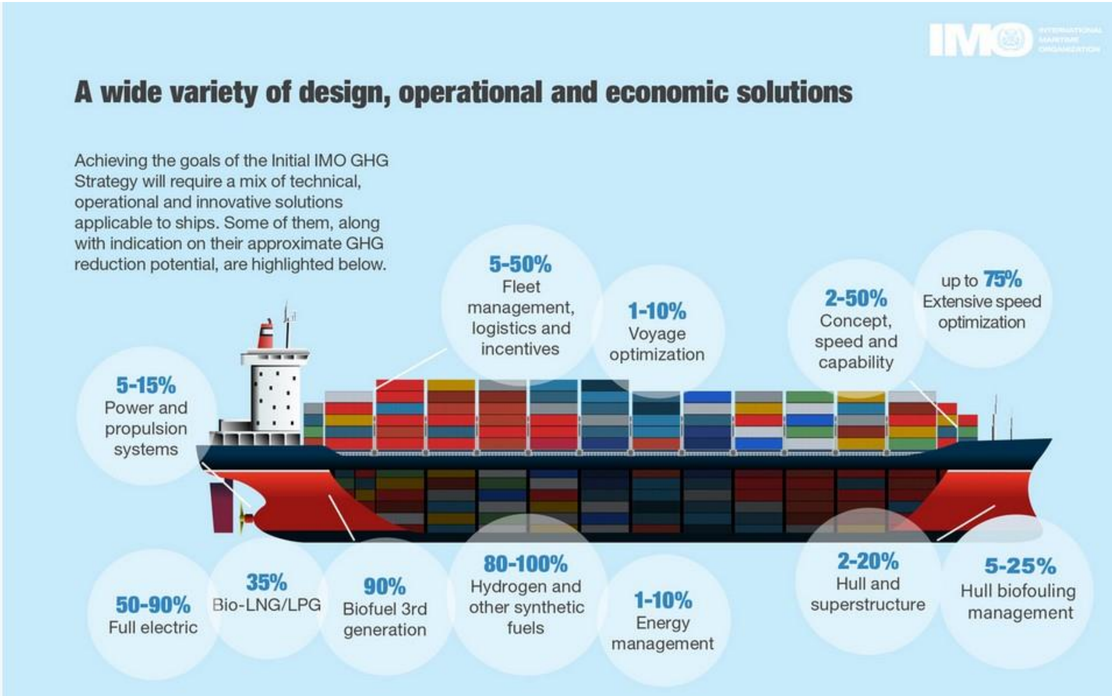



*Figure 7:Proposed solutions for energy efficiency (IMO, 2023)*

There are many measures that a ship can take to improve its environmental rating and reduce its impact on the environment. Some of the measures you mentioned are (IMO, 2023):

1. Hull cleaning: Fouling of the hull can increase drag and reduce the ship's efficiency. Regular hull cleaning can reduce the drag and improve the ship's performance.
2. Speed optimization: Reducing the speed of the ship can significantly reduce fuel consumption and emissions. This can be achieved by optimizing the ship's route, using weather routing services, and maintaining an appropriate trim and speed.
3. Installation of low-energy light bulbs: Replacing traditional incandescent light bulbs with LED bulbs can reduce energy consumption and greenhouse gas emissions.
4. Installation of solar/wind auxiliary power: Ships can install solar panels or wind turbines to generate renewable energy for their accommodation services, reducing their reliance on fossil fuels.

By implementing these measures, ships can reduce their environmental impact and improve their environmental rating, which can lead to benefits such as reduced operating costs, increased customer satisfaction, and improved reputation.

# CHAPTER 5: METHODOLOGY

The objective of this thesis is to perform an assessment, at the ship level, of selected and widely implemented technical and operational solutions for the improvement of vessel's energy efficiency and the reduction of GHG emissions derived from vessels, in the context of the recently enforced amendments to MARPOL VI.

For this assessment the study uses the performance of the ship against the key indicators such as EEXI, and CII, that regulate the vessel's energy efficiency. Compliance with the revised MARPOL VI regulation is mandatory for shipping companies, as they strive to meet the required targets for these indicators while simultaneously satisfying their commercial targets. These indicators represent short-term goal-based standards, outlined by the MEPC and compliance with these may be possible with different solutions (technical and operational).

However, due to the limited time given to ships to comply, there is evidence from the industry that certain solutions (such as the engine power limitation, and the speed adjustment/reduction) are in the short-term the widely preferred options from the ship operators. (Smith, 2022)

The investigation commences with a comprehensive exposition of the Energy Efficiency Existing Ship Index and Carbon Intensity Indicator regulations. Key technical ship parameters that significantly influence these calculations are meticulously identified, and the correlation between these indices and the tangible efficiency levels of vessels is presented.

The detailed presentation of EEXI and CII is presented in order to understand the level of information that needs to be retrieved at the ship level to perform an accurate calculation (as described in the specific guidance given from the MEPC documentation).

Two cargo ships were selected for the case study phase. Technical ship data and documentation (drawings, energy systems information, energy efficiency technologies, design parameters etc.) have been collected from the shipping company to develop the input file for the EEXI calculations.

Furthermore, the operational profile of the selected ships in the form of noon reports over the period of one year, were collected from the ship operator to perform the CII calculations. Examples of the data and the documentation used, can be found in Annex II of the thesis.

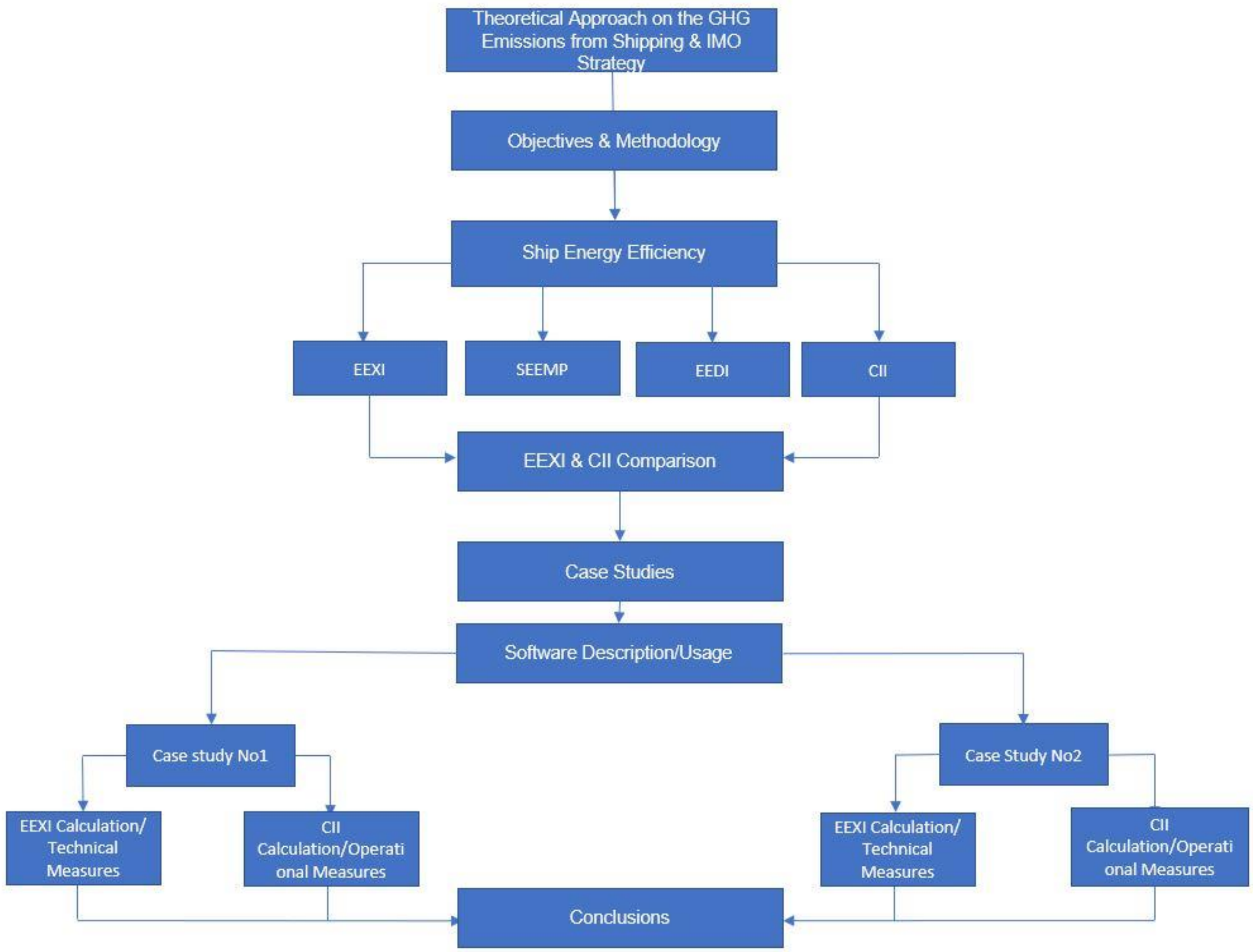
For the part of calculations, the study is using the ShipFORCE platform, a commercial software which is available (via an academic license) in the Department of Maritime Studies. An input file is first created to insert the vessel's technical data in the software. With selecting the EEXI module the first calculations are performed and the attained EEXI value for the case study ship derives. To satisfy the EEXI regulation, the ship should be able to meet the required EEXI value by implementing technical solution(s). Subsequently, the selection is made (i.e. EPL) and the recalculation is performed. Due to the structure of the EEXI index the measure that has the more drastic effect on the index is the Engine Power Limitation which corresponds to a speed reduction (by mean of a technical approach, often referred to as speed limit). The EPL was the measure that has been widely selected from ships to meet the EEXI requirement.

Subsequently, the study proceeds with the analysis on the attained and required CII values. The CII calculation takes in historical data from the ship operation, and is carried out for the current years and for the following years (as a projection) up to 2030. Relevant data are gathered in a normal reporting system daily in the form of noon reports which are emailed from the ship to the shore based technical staff of the shipping company. Noon reports were collected and fed the software to perform the calculations in the software. In cases where the attained CII surpassed the required value, a gradual speed reduction (from an operational perspective) was implemented to identify the impact on the CII over time.

Finally, the overall conclusions are outlined some overarching conclusions during the final stages of the thesis. The potential impact of speed reduction as a practical short-term solution to achieve regulatory compliance and enhance energy efficiency is a major insight of this thesis.

It is evident that ongoing endeavors to reduce greenhouse gas (GHG) emissions in the shipping sector will necessitate consideration of more radical measures to enhance vessel efficiency, such as exploring new fuels and alternative energy sources for onboard utilization.

The thesis methodology is presented below.



# CHAPTER 6: SHIP ENERGY EFFICIENCY

Enhancing energy efficiency in ship operation offers a dual solution: it reduces greenhouse gas (GHG) emissions while simultaneously enhancing ship performance. This improvement not only lessens the ship's environmental impact but also generates economic savings by optimizing fuel usage. Energy savings range from 25% up to 75% according to IMO (IMO, 2015). Over the last two decades, numerous efforts have been made to minimize both fuel consumption and pollution originating from international shipping (IMO, 2015). For this scope, IMO first introduced the EEDI in 2011, which serves as a goal-based standard for new ships. For existing vessels, the same index, renamed in EEXI, was established under the amendment MEPC 333(76). EEXI functions similarly to the EEDI, aiming to measure and evaluate the performance of existing vessels. It covers the same range of ship types and sizes as the EEDI, providing a comprehensive framework for assessing energy efficiency across the maritime industry.

## 6.1ENERGY EFFICIENCY EXISTING SHIP INDEX (EEXI)

The EEXI is a value that measures the energy efficiency of an existing ship based on its design features, such as its engine power, fuel consumption, cargo capacity and a reference speed. The EEXI value is calculated using a formula that considers a ship's technical specifications, including its engine(s) power, the reference speed, and the deadweight.

The EEXI regulation applies to various ship types including bulk carriers, gas carriers, tankers, container ships, general cargo ships, refrigerated cargo carriers, combination carriers, ro-ro cargo ships, ro-ro passenger ships, LNG carriers, cruise passenger ships having non-conventional propulsion of 400GT.

It came into effect on January 1, 2023, which means that ships must comply with the EEXI requirements by this date. Ship-owners could comply with the EEXI regulation by either improving the energy efficiency of their ships or by implementing alternative measures such as using low-carbon fuels or purchasing carbon offsets.

In order for a ship to comply with the EEXI requirements, there is a requirement to take solely technical measures.

The first step is to calculate the EEXI value of the ship. Once the EEXI value is calculated, there are two different pathways to follow. The first case is when the attained EEXI value of the ship is lower than the required EEXI value. In this case, the ship is already compliant with the EEXI regulation, and no further action is required. However, in this case, ship-owners can still take measures to further improve the energy efficiency of their ships and reduce their carbon footprint.

The second case is when the calculated EEXI value is higher than the required EEXI value. In this case, ship-owners need to take measures to improve the energy efficiency of their ships. There are many technical measures that can be taken to improve a ship's energy efficiency, such as installing more efficient engines, improving the hull design, and implementing energy-efficient technologies. The aim of these measures is to reduce the ship's fuel consumption and greenhouse gas emissions.

There are many new technologies that can be used to improve the energy efficiency of ships, such as waste heat recovery systems, air lubrication systems, and advanced propulsion systems. These technologies can help to reduce fuel consumption and emissions while improving the overall performance of the ship. (Vakili, 2023)

Essential comments outlined in the regulation for the concept and structure of the EEXI:

- It is a static value that depends on the construction and design characteristics of the vessel and its installed energy systems.
- It is calculated based on the EEDI formula and baseline, which is a measure of a ship's energy efficiency when it is designed and built.
- It measures emissions per ton-mile but in a certain condition (i.e. the EEXI condition), which means that it considers the ship's design and construction and does not consider other factors such as cargo type, weather conditions, or operating speed.
- To comply with the EEXI regulation, many ships will require technical modifications such as shaft or engine power limitation (EPL). EPL involves limiting the power output of the ship's engine or the speed of its propeller shaft to reduce fuel consumption and emissions. This may require physical modifications to the ship's engine or propulsion system. (IMO, 2021b)

The EEXI is subject to the Propeller and Propulsion Efficiency, Hydrodynamic/Hull Efficiency and Machinery Efficiency. (Barreiro. et.al, 2022)

1. Propeller and Propulsion Efficiency: It includes the efficiency of the ship's propulsion system, including the design of the propeller, the power output of the engine, and the efficiency of the transmission system. A more efficient propulsion system can reduce fuel consumption and emissions and improve the ship's EEXI.
2. Hydrodynamic/Hull Efficiency: It considers the design of the ship's hull, including its shape, size, and material. A more streamlined and efficient hull design can reduce drag and resistance, which in turn reduces fuel consumption and emissions and improves the ship's EEXI.
3. Machinery Efficiency: It considers the efficiency of the ship's auxiliary systems, such as the air conditioning, lighting, and other electrical systems. A more efficient machinery system can reduce energy consumption and improve the ship's EEXI.

By improving the above areas, ship-owners can increase their ships' energy efficiency and reduce their carbon footprint. This can be achieved through a combination of design modifications, technology upgrades, and operational improvements

In general, the attained EEXI shall be less than the required (theoretical) EEXI. In order to demonstrate compliance with the EEXI regulation, ships need to prepare a **technical file** that includes information about the ship's design, construction, and energy efficiency. The technical file should include the following information: (DNV, 2024)

- The ship's EEXI value, as calculated using the IMO's guidelines
- Documentation of any structural modifications or other measures taken to improve the ship's energy efficiency
- Technical specifications of the ship's propulsion system, machinery, and hull design
- Documentation of the ship's energy consumption and emissions, including fuel consumption data and engine performance data

Ships are also required to obtain an International Energy Efficiency (IEE) Certificate, which serves as proof of compliance with the EEXI regulation. The IEE Certificate is issued by the ship's flag state and is valid for the life of the ship, subject to periodic surveys and inspections. (Papaefthymiou, 2022)

The IEE Certificate is based on the ship's EEXI value and confirms that the ship complies with the EEXI regulation. It also includes information about any structural modifications or other measures taken to improve the ship's energy efficiency.

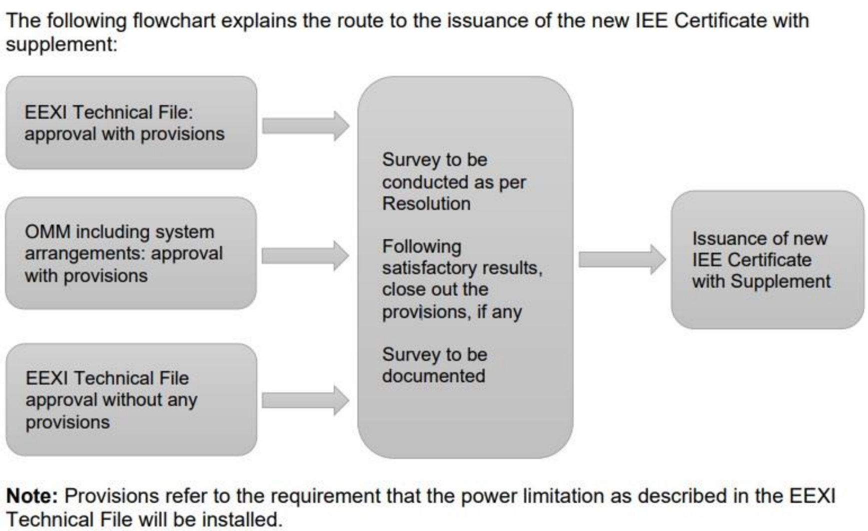



*Figure 8: Flowchart for the issuance of the IEE Certificate (ClassNK, 2022)*

If not instructed differently by the Flag Administration, the endorsement of the EEXI Technical File and Onboard Management Manual (OMM) will be conducted in accordance with IMO resolutions and IACS guidelines. (ClassNK, 2022)

## 6.2 Categorizing of Innovative Energy Efficiency Technologies

Innovative energy efficiency technologies are classified by IMO into three main categories: (A), (B), and (C), with categories (B) and (C) further divided into two sub-categories each. (IMO, 2013)

- Category (A) likely includes technologies that provide significant energy efficiency improvements and have a direct impact on the EEDI formula. These technologies shift the power curve and they have a significant impact on the combination of propulsive power

(PP) and reference speed $V_{ref}$ used in the EEDI formula. These technologies can either reduce PP for a given $V_{ref}$ or increase $V_{ref}$ for a given PP, resulting in a different combination of the two. They should be treated as a part of vessel in EEDI Calculation Guidelines and EEDI Survey Guidelines.

- Category (B) technologies refer to those that can reduce the required propulsive power (PP) for a given reference speed $V_{ref}$ but do not generate electricity. The energy saved as a result of using these technologies is counted as effective power $P_{eff}$ and is used in the calculation of the EEDI value for a ship.
    - Category (B-1) technologies refer to technologies that can be used at any time during the operation of the ship to reduce the required propulsive power (PP) for a given reference speed $V_{ref}$ without generating electricity.
    - Category (B-2) technologies refer to technologies that can only be used at their full output under limited conditions to reduce the required propulsive power (PP) for a given reference speed $V_{ref}$ without generating electricity.
- Category (C): Technologies that generate electricity. The saved energy is counted as PAEeff
    - Category (C-1): Technologies that are applicable at any point during operation, and consequently, the availability factor $f_{eff}$ should be considered as 1.00.
    - Category (C-2): Technologies that can operate at their maximum capacity only under specific constraints. The setting of availability factor $f_{eff}$ should be less than 1.00.

| Innovative Energy Efficiency Technologies | | | | |
|---|---|---|---|---|
| Reduction of Main Engine Power | | | Reduction of Auxiliary Power | |
| *Category A* | *Category B-1* | *Category B-2* | *Category C-1* | *Category C-2* |
| Cannot be separated from overall performance of the vessel | Can be treated separately from the overall performance of the vessel | | Effective at all time | Depending on ambient environment |
| | $f_{eff}=1$ | $f_{eff}<1$ | $f_{eff}=1$ | $f_{eff}<1$ |
| - low friction coating<br>- bare optimization<br>- rudder resistance<br>- propeller design | - hull air lubrication system (air cavity via air injection to reduce ship resistance) (can be switched off) | - wind assistance (sails, Flettner-Rotors, kites) | - waste heat recovery system (exhaust gas heat recovery and conversion to electric power) | - photovoltaic cells |

*Figure 9: Categorizing of Innovative Energy Efficiency (IMO, 2021)*

## 6.3 Calculation of the Attained Energy Efficiency Existing Ship Index (EEXI)

The achieved Energy Efficiency Existing Ship Index (EEXI) serves as an indicator of a ship's energy efficiency (g/t*nm) and is determined through the following formula:

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

*Figure 10: EEXI Formula Source: MEPC.1/Circ.815 17June2013*

- In case the Normal Maximum Sea Load is provided by shaft generators then $SFC_{ME}$ and $CF_{ME}$ may be used for that part of the power instead of $SFC_{AE}$ and $CF_{AE}$
- If $PTI_i$ > 0 the average weighted value of ($SFC_{ME} \cdot CF_{ME}$) and ($SFC_{AE} \cdot CF_{AE}$) to be used for calculation of $P_{eff}$

*Important Note:* This formula is not applicable to a ship with diesel-electric propulsion turbine propulsion or hybrid propulsion system. (IMO, 2022)

- ***Engine power (P)*** Individual engine power depending on application (e. g. PME = 75 % maximum continuous rating for diesel-mechanic propulsion).
- $\boldsymbol{P_{MEi}}$ Power of main engines

$\boldsymbol{P_{ME\,(i)}}$ is 83% of the limited installed power (MCR lim) or 75% of the original installed power (MCR), whichever is lower, for each main engine (i)

- $\boldsymbol{P_{effi}}$ Main engine power reduction due to individual technologies for mechanical energy efficiency. Is the output of mechanical energy efficient technology for propulsion at 75% of main engine power
- $\boldsymbol{PAE_{ffi}}$ Innovative mechanical energy efficient technology for auxiliary engine.
- $\boldsymbol{P_{AE}}$ Auxiliary engine power reduction due to individual technologies for electrical energy efficiency. In passenger ships $P_{AE}$ is calculated by the electric power (excluding propulsion). In cases the ship is engaged in a voyage at reference speed $V_{ref}$ as given in the electric power table, divided by the average efficiency of the generator(s) weighted by power.

When electric power table is not available, the $P_{AE}$ value may be approximated either by:

1. annual average figure of $P_{AE}$ at sea from onboard monitoring obtained prior to the EEXI certification
2. for cruise passenger ships, approximated value of power of auxiliary engines $P_{AE,app}$ , as defined below:
   *$P_{AE}$, = 0.1193 × GT + 1814.4 [kW]*
3. for ro-ro passenger ships, the estimated value of auxiliary engine power $P_{AE,app}$, as defined below:
   *$P_{AE}$, = 0.866 × GT0.732 [kW]*

*For ships with total propulsion power above 10,000 kW, $P_{AE}$ is defined as per below formula:*

$$P_{AE\,(\sum MCR_{ME})} = \left(0.025 * \left(\sum_{i=1}^{nME} MCR_{ME(i)} + \frac{\sum_{i=1}^{nPTI} P_{PTI(i)}}{0.75}\right)\right) + 250$$

*For ships with total propulsion power below 10,000 kW, $P_{AE}$ is defined as per below formula:*

$$P_{AE\,(\sum MCR_{ME})} = 0.05 * \left(\sum_{i=1}^{nME} MCR_{ME(i)} + \frac{\sum_{i=1}^{nPTI} P_{PTI_{(i)}}}{0.75}\right)$$

- $\boldsymbol{PPT_{(i)}}$ - 75 % of rated power consumption of shaft motor. $PPT_{(i)}$ is calculated as per below formula:

$$\sum P_{PTI(i)} = \frac{\sum(0.75 * \ P_{SM,\max(i)}}{n_{Gen}}$$

Where:

  - $PSM, max(i)$ is the rated power consumption of each shaft motor
  - n$Gen$ is the weighted average efficiency of the generator(s)

- $\boldsymbol{PPTO_{(i)}}$– Shaft generator

In case there is a shaft generator(s) installed, $\text{PPTO}_{(\text{i})}$ is 75% of electrical output power of each shaft generator. In case shaft generator(s) are installed to steam turbine, $(i)$ is 83% of the rated electrical output power and the factor of 0.75 should be replaced to 0.83.

There are two choices for computing the impact of shaft generators:

<u>Option 1:</u>

The maximum allowable deduction for the calculation of $(i)$ is to be no more than $PAE$. For this case $\Sigma(i)$ is calculated as:

$$\sum_{=1}^{nME} P_{ME\,(i)} = 0.75 * \left( \sum_{i=1}^{n} MCR_{ME\,(i)} - \sum_{i=1}^{nPTO} 0.75 * MCR_{PTO\,(i)} \right)$$

Where:

$$\sum\nolimits_{i=1}^{nPTO} 0.75 * \ MCR_{PTO(i)} \leq {}^{P_{AE}}/_{0.75}$$

<u>Option 2:</u>

$\Sigma(i)$ is 75% of that limited power for determining the reference speed, $V_{ref}$ and for EEXI calculation when there is an engine installed with higher rated power output that is constrained by verified technical methods.

- $(i)$ - Individual power of main engines. When using an overridable shaft/engine power limitation system in accordance with the 2021 Guidelines, it is important to ensure that the power reserve is used only when necessary, and that the ship's overall energy efficiency is not compromised.

Regarding LNG Carriers equipped with diesel electric propulsion system, $P_{ME\,(i)}$ is calculated by the following formula:

$$P_{MEi} = 0.83 \times \frac{MPPP_{Motor(i)}}{n_i}$$

Where: $(i)$ is the rated output of motor specified in the certified document.

$ni$ is to be taken as the product of electrical efficiency of generator, transformer, converter and motor, taking into consideration the weighted average as necessary.

*Ship design parameters*

- $\boldsymbol{V_{ref}}$ - *Ship speed* at reference conditions (see $P_{ME}$ definition, etc.) The ship speed Vref should be obtained from an approved **speed-power curve** as defined in the 2014 Guidelines for the examination and certification of the Energy Efficiency Design Index (EEDI).

  $V_{ref}$ Speed is calculated when the weather is calm with no wind and no waves. This speed corresponds to the summer load line draft for all ships except containerships and to the 70% of the DWT for containership. (NKClass, 2022)

  In general, $V_{ref}$ may be obtained from the sea trial report:

$$V_{ref} = V_{S,EEDI} \times \left[\frac{P_{ME}}{P_{S,EEDI}}\right]^{\frac{1}{3}} \text{ [Knots]}$$

  Where:
  $V_{S,EEDI}$, is the service speed during sea trials at the EEDI draft and
  $P_{S,EEDI}$ is the main engine power corresponding to $V_{S,EEDI}$

  Specifically, for containerships, bulk carriers and tankers Vref may be obtained from the below formula:

$$V_{ref} = k^{\frac{1}{3}} \times \left(\frac{DWT_{s,service}}{Capacity}\right)^{\frac{2}{9}} \times V_{S,service} \times \left[\frac{P_{ME}}{P_{s,service}}\right]^{\frac{1}{3}} \text{ (knot)}$$

$V_{s,service}$ is the sea trial service speed under the design draught

$P_{S,service}$ is power of the main engine corresponding to $V_{S,service}$

$DWT_{S,service}$ is the deadweight under the design draught

$k$ i is the scale coefficient

For LNG carriers equipped with diesel electric or steam turbine propulsion systems $Vref$ is the relevant speed at 83% of $MPPMotor$ or $MCRSteamTubine$ respectively.

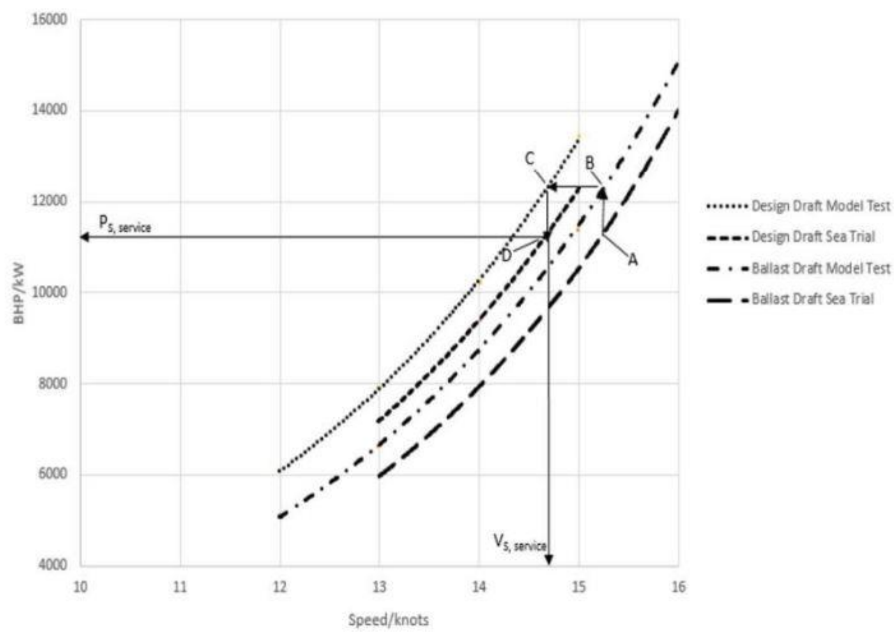



*Figure 11: calibration of the speed obtained at sea trials at ballast draft to the speed at design draft*

If speed-power curve is not available or the sea trial report does not contain EEDI or design load draught condition, $Vref_{app}$ defined as per below formulas :

$$V_{ref,app} = (V_{ref,app} - m_v) \times \left[\frac{\sum PME}{0.75 * MCR_{avg}}\right]^{\frac{1}{3}} \text{ [knot]}$$

Only for LNGs

$$V_{ref,app} = (V_{ref,app} - m_{v)} \text{ x } \left[\frac{\Sigma MPP_{Motor}}{MPP_{avg}}\right]^{\frac{1}{3}} \quad \text{[knot]}$$

Where:

$V_{ref,avg}$ is a statistical mean of distribution of ship speed in given ship size, to be calculated as follows:

$V_{ref,avg}$ = A* $B^C$ where A, B and C are the parameters given in the table bellow.

(MEPC.333(76)(1),[S.D.])

*Table 1: Parameters to calculate Vref, avg*

Parameters to calculate $V_{ref,avg}$

| Ship type | A | B | C |
|---|---|---|---|
| Bulk carrier | 10.6585 | DWT of the ship | 0.02706 |
| Gas carrier | 7.4462 | DWT of the ship | 0.07604 |
| Tanker | 8.1358 | DWT of the ship | 0.05383 |
| Containership | 3.2395 | DWT of the ship<br>where DWT ≤ 80,000<br>80,000<br>where DWT > 80,000 | 0.18294 |
| General cargo ship | 2.4538 | DWT of the ship | 0.18832 |
| Refrigerated cargo carrier | 1.0600 | DWT of the ship | 0.31518 |
| Combination carrier | 8.1391 | DWT of the ship | 0.05378 |
| LNG carrier | 11.0536 | DWT of the ship | 0.05030 |
| Ro-ro cargo ship (vehicle carrier) | 16.6773 | DWT of the ship | 0.01802 |
| Ro-ro cargo ship | 8.0793 | DWT of the ship | 0.09123 |
| Ro-ro passenger ship | 4.1140 | DWT of the ship | 0.19863 |
| Cruise passenger ship having non-conventional propulsion | 5.1240 | GT of the ship | 0.12714 |

- $m_v$ is a performance margin of a ship, which should be 5% of $V_{ref,vg}$ or 1 knot, whichever is lower.
- $CR_{avg}$ is a statistical mean of distribution of MCRs for main engines and is to be calculated as follows: $MCR_{avg} = D * E\ F$ D, E and F are the parameters given in the table below.

*Table 2: Parameters to calculate MCRavg or MPPavg*

Parameters to calculate $MCR_{avg}$ or $MPP_{avg}$ (= D x $E^F$)

| Ship type | D | E | F |
|---|---|---|---|
| Bulk carrier | 23.7510 | DWT of the ship | 0.54087 |
| Gas carrier | 21.4704 | DWT of the ship | 0.59522 |
| Tanker | 22.8415 | DWT of the ship | 0.55826 |
| Containership | 0.5042 | DWT of the ship where DWT ≤ 95,000<br>95,000 where DWT > 95,000 | 1.03046 |
| General cargo ship | 0.8816 | DWT of the ship | 0.92050 |
| Refrigerated cargo carrier | 0.0272 | DWT of the ship | 1.38634 |
| Combination carrier | 22.8536 | DWT of the ship | 0.55820 |
| LNG carrier | 20.7096 | DWT of the ship | 0.63477 |
| Ro-ro cargo ship (vehicle carrier) | 262.7693 | DWT of the ship | 0.39973 |
| Ro-ro cargo ship | 37.7708 | DWT of the ship | 0.63450 |
| Ro-ro passenger ship | 9.1338 | DWT of the ship | 0.91116 |
| Cruise passenger ship having non-conventional propulsion | 1.3550 | GT of the ship | 0.88664 |

- **Capacity** - Deadweight tonnage (DWT) rating for bulk ships and tankers; a percentage of DWT for container ships; DWT indicates how much can be loaded onto a ship; gross tonnage for passenger ships (cruise).

*Correction and adjustment factors (F)*

Non-dimensional elements incorporated into the EEDI formula to address particular current or expected circumstances that might otherwise distort the assessments of individual vessels.

- $\boldsymbol{f_{eff(i)}}$ - Availability factor of individual energy efficiency technologies (=1.0 if readily available)
- $\mathbf{f_j}$ - Correction factor for ship-specific design elements, e.g. ice-classed ships which require extra weight for thicker hulls
- $\mathbf{f_i}$ - Capacity adjustment factor for any technical /regulatory limitation on capacity (=1.0 if none)
- $\mathbf{f_c}$ - Cubic capacity correction factor (for chemical tankers, LNG carriers and RoPax)
- $\boldsymbol{f_l}$ - Correction factor to compensate deadweight losses through cargo-related equipment like cranes, RoRo ramps, etc.

Specific fuel consumption (SFC) SFC corresponding to the PME should be interpolated by using SFCs listed in an applicable test report included in an approved NOx Technical File of the main engine. For the engines which do not have a test report included in the NOX Technical File and which do not have the SFC specified by the manufacturer, the SFC can be approximated by $SFC_{app}$ defined as follows:

- $SFCME_{app}$ = 190 [g/kWh]
- $SFCAE_{app}$ = 215 [g/kWh]

Fuel use per unit of engine power

$\boldsymbol{SFC_{ME}}$ - Main engine (composite)
$\mathbf{SFC_{AE}}$ - Auxiliary engine
$\boldsymbol{SFC_{AE*}}$ - Auxiliary engine (adjusted for shaft generators)
$\boldsymbol{SFC_{MEi}}$ - Main engine (individual)

**CF** - *Conversion factor between fuel consumption and CO2 emission*.
For those engines which do not have a test report included in the NOx Technical File and which do not have the SFC specified by the manufacturer, the CF corresponding to $SFC_{app}$ should be defined as follows:

- $CF$ = 3.114 [$t \cdot CO2/t \cdot Fuel$] for diesel ships (incl. HFO use in practice)

*CF value as follows:*

*Table 3: CF Values*

| Type of fuel | Reference | Carbon content | $C_F$ (t-$CO_2$/t-Fuel) |
|---|---|---|---|
| 1 Diesel/Gas Oil | ISO 8217 Grades DMX through DMB | 0.8744 | 3.206 |
| 2 Light Fuel Oil (LFO) | ISO 8217 Grades RMA through RMD | 0.8594 | 3.151 |
| 3 Heavy Fuel Oil (HFO) | ISO 8217 Grades RME through RMK | 0.8493 | 3.114 |
| 4 Liquefied Petroleum Gas (LPG) | Propane | 0.8182 | 3.000 |
| | Butane | 0.8264 | 3.030 |
| 5 Liquefied Natural Gas (LNG) | | 0.7500 | 2.750 |
| 6 Methanol | | 0.3750 | 1.375 |
| 7 Ethanol | | 0.5217 | 1.913 |

## 6.4 Verification of the attained EEXI

To demonstrate compliance with the EEXI regulations, ship owners and operators must submit a Technical File containing the necessary information for the verification and other relevant background documents to a verifier. The verifier will review the Technical File and verify that the ship's EEDI is in compliance with the required EEXI. Once the ship is verified as compliant, a certificate of compliance, will be issued which must be carried on board the ship *unless the attained EEDI of the ship satisfies the required EEXI.*

*The EEXI Technical File must be documented in English, at a minimum.*

The EEXI Technical File has to include, but not be limited to the following:

1. Deadweight (DWT) or gross tonnage (GT) for ro-ro passenger ship and cruise passenger equipped with unconventional propulsion.
2. MCR of the main and auxiliary engines
3. $MCR_{lim}$ in cases where the overridable Shaft/Engine Power Limitation system is installed
4. the ship speed ($V_{ref}$)
5. $V_{ref,app}$ for ships predating EEDI, particularly in instances where the speed-power curve is unavailable.
6. An approved speed-power curve under the EEDI condition
7. Estimation process and methodology of the power curves
8. A report from a sea trial that encompasses the results, potentially calibrated through tank testing, conducted under actual sea conditions.
9. An in-service performance measurement report
10. Calculation procedure for $V_{ref,app}$ for ships predating EEDI, especially when the speed-power curve is unavailable.
11. Type of fuel
12. The fuel consumption rate (SFC) of both the primary and auxiliary engines.
13. The electric power table
14. The recorded documentation of the yearly average value of the load on the auxiliary engine while at sea.
15. Calculation process of $PAE_{app}$

16. Key particulars, vessel category, and pertinent details for classifying the ship into its designated category, classification notations, and a summary of both the propulsion and electricity supply systems aboard.
17. Description of energy-saving equipment
18. Computed value of the achieved EEXI, inclusive of the computation summary. The summary should encompass, at the very least, each parameter's calculated value and the process employed in determining the achieved EEXI.
19. For LNG carriers:
    - Type and outline of propulsion systems
    - LNG cargo tank capacity in m3 and BOR
    - MPPMotor and $\eta(i)$ for diesel electric
    - Propeller shaft power downstream of the transmission gear at a reduced rate. ($MPPMotor_{lim}$)
    - Maximum continuous rated power $MCRSteamTurbine$ for steam turbine
    - $MCRSteamTurbine_{lim}$ for steam turbine in cases where the overridable Shaft -Engine Power Limitation is installed
      $SFCSteamTurbine$ for steam turbine

# CHAPTER 7: ENERGY EFFICIENCY DESIGN SHIP INDEX (EEDI)

## 7.1 INTRODUCTION TO THE EEDI

The EEDI is a metric that measures the energy efficiency of a ship. It is used to limit the amount of greenhouse gas emissions from ships and reduce their impact on the environment. The EEDI requirements vary depending on the ship's type and size. The reference line value for the required EEDI was established in 2013 and is based on the EEDI values of ships built after the year 2000.

In January 2013 the EEDI began requiring new builds to function at a minimum energy efficiency level per ton mile. New vessels had to comply with a carbon reduction level set to increase every five years. There are three phases established by IMO

Phase 0: ships built between 2013-2015 are required to have a design efficiency at least equal to the baseline (set standard for design efficiency that was established prior to 2013).

Phase 1: ships built between 2015-2020 are required to have a design efficiency, at least, 10% below the reference line.

Phase 2: - ships constructed from 2021-2025 must possess a design efficiency that is a minimum of 20% lower than the reference standard.

Phase 3: ships constructed post-2025 must exhibit a design efficiency that is at least 30% lower than the reference standard. (Transport & Environment, 2017)

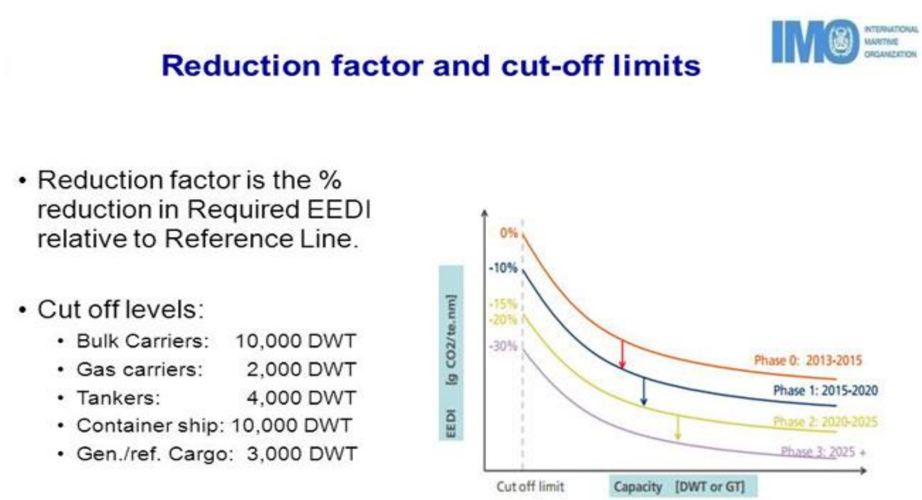



*Figure 12*: Reduction factor and cut-off limits

## 7.2 Energy Efficiency Design Index (EEDI)

The final calculation formula of the EEDI is the same with the one of the EEXI which was finalized with MEPC 66/21 Annex 5

EEDI is applicable to new ships. The aim is to guarantee that newly constructed ships are designed with energy efficiency in mind. However, it cannot be utilized as a performance indicator for the operational energy efficiency of the current fleet of vessels. EEDI Formula and its parameters are explained below:

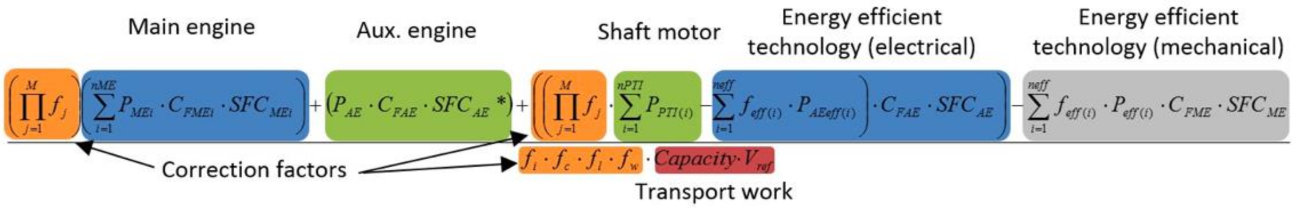



Figure 13: EEDI Formula

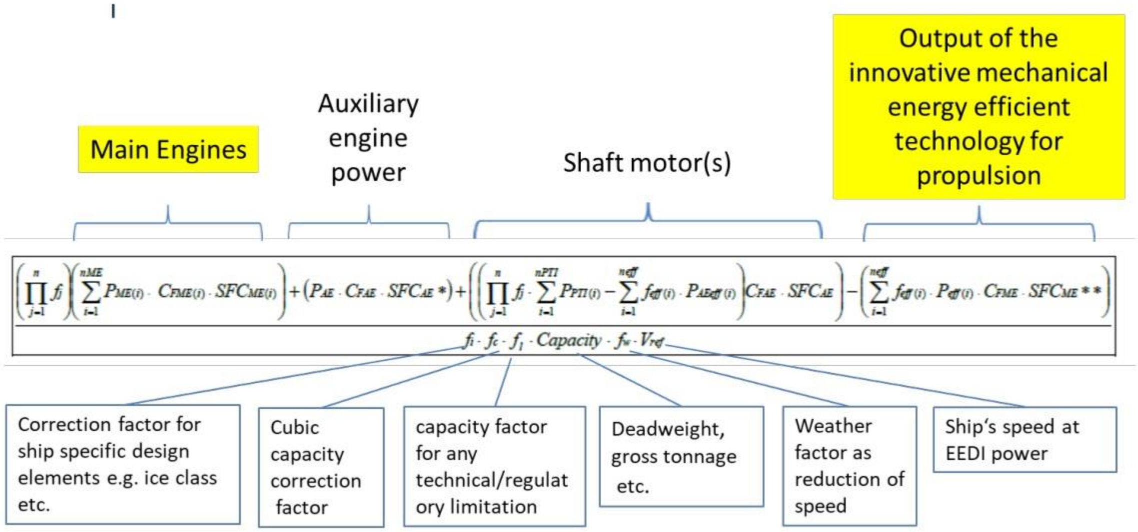



*Figure 14*: Explanation of the EEDI Formula

The EEDI is a mandatory measure that promotes the use of energy efficient equipment and engines on the new build ships. The EEDI allows ship designers and builders to use new technologies so that ships to meet the energy efficiency levels. EEDI applies to the following ship types:

Bulk carriers, Container ships, Gas carriers, LNG carriers, roll on roll off cargo ships, Tankers, Combination carriers, Cruise passenger ships, General cargo ships, Refrigerated cargo carriers, Roll on, roll-off passenger ships, Vehicle carriers.

The EEDI requirements does not apply to cargo ships with icebreaking capability or ships which have non-conventional propulsion (including diesel-electric propulsion, turbine propulsion, and hybrid propulsion system) with the exception of cruise ships and LNG carriers featuring unconventional propulsion systems, delivered on or after September 1, 2019. (RINA, 2023)

EEDI estimates grams of CO2 per transport work (g of CO2 per ton-mile) and can be expressed as the ration of "**Environmental Cost**" divided by "**Benefit for Society**".

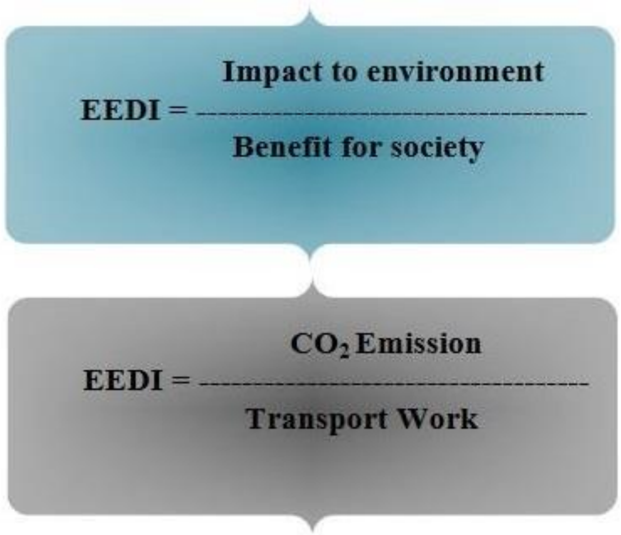



Figure 15: EEDI Calculation

It is a function of:

- Installed Power
- Speed of Vessel
- Cargo carried

The major purpose of EEDI is to promote efforts by all stakeholders to reduce CO2 emissions by reflecting a ship's energy efficiency in actual use. (IRCLASS, 2023)

It encourages ongoing technical advancements in all the elements that impact a ship's fuel efficiency. It also separates the technical and design-based measures from the operational and commercial ones.

EEDI is applicable only in the new ships while intends to ensure that new ships will be more energy efficient.

*The EEDI formula takes into consideration* the use of low carbon fuels, performance of ships in waves and the need for ice strengthening of certain ships.

$$\text{EEDI} = \frac{\textbf{Impact to environment}}{\textbf{Benefit to society}} = \frac{\textbf{Power*SFC* FC}}{\textbf{Deadweight *speed}}$$

*Figure 16: EEDI=Impact/Benefit*

Efficiency improvements of new ships relative to the EEDI baseline according to the type of cargo ship are shown to the Table 4.

*Table 4: Energy Efficiency trends on different types of cargo ships (Barreiro. et.al, 2022)*

| Type of cargo ship | Efficiency improvements of new ships relative to the baseline EEDI value of 2013. | Share of ships built in 2013–2017 already complying with the post-2025 EEDI target. |
|---|---|---|
| Containerships | 58% more efficient | 71% of built containerships |
| General cargo ships | 57% more efficient | 69% of built general cargo ships |
| Gas carriers | 42% more efficient | 13% of built gas carriers |
| Oil Tankers | 35% more efficient | 26% of built oil tankers |
| Bulk Carriers | 27% more efficient | 1% of built Bulk Carriers |

# CHAPTER 8: SEEMP (SHIP ENERGY EFFICIENCY MANAGEMENT PLAN)

IMO adopted the Ship Energy Efficiency Management Plan (SEEMP) in 2011 as the management framework for shipping companies to improve energy efficiency and reduce greenhouse gas emissions from their ships. (Government, Australian, 2023). The SEEMP is considered an operational measure. It is a standardized approach for monitoring, reporting, and optimizing the energy efficiency parameters, that can result in significant cost savings and environmental benefits.

Within the SEEMP, IMO promotes the use of the Energy Efficiency Operational Indicator (EEOI), which is a metric to measure the carbon emissions per unit of transport work performed. By using the EEOI as a monitoring tool, shipping companies can track the energy efficiency of their ships and identify opportunities to reduce fuel consumption and GHGs.

The SEEMP incorporates best practices for fuel-efficient ship operation, including measures such as optimal speed, voyage planning, and maintenance practices. It also provides guidelines for the voluntary use of the EEOI on ships, which can help to establish a baseline for measuring and tracking energy efficiency over time.

The SEEMP consists of three parts:

- Part I: A ship-specific management plan that outlines measures to improve energy efficiency and reduce emissions.
- Part II: Data collection plan implementation for ship fuel oil consumption
- Part III: Ship operational carbon intensity plan

Part I is mandatory for all ships above 400 GT and is necessary to be kept on board for all ships above 400 GT. (Tran, Journal of Ocean Engineering and Science, 2017)

For the Data Collection System, all vessels exceeding 5,000 gross tons are obligated to comply with Part II. This requires ships to monitor and report their fuel consumption, as well as other relevant information such as distance traveled and cargo carried, on an annual basis. The data collected is used to establish a ship-specific EEOI and provides a baseline for companies to assess their energy efficiency performance and identify areas for improvement.

A verified Part III is required for all ships subject to the CII, which includes cargo, ro-ro, and cruise passenger vessels above 5,000 GT. Part III includes a specific carbon intensity target, which must be met by each ship based on its size and type of operation. To comply with this requirement, companies must implement measures to reduce their carbon intensity and improve their energy efficiency performance.

Proposed solutions for operational energy efficiency encompass:

- Speed optimization: By adjusting speed to match the vessel's optimum speed, considering factors such as wind, wave, and current conditions, fuel consumption can be reduced, resulting in lower emissions.
- Weather routing: By using advanced weather forecasting technologies and routing software, ships can optimize their routes and take advantage of favorable conditions. This can help reduce fuel consumption and emissions, while also improving safety and reducing operational costs.
- Hull monitoring and maintenance: Regular monitoring and maintenance of the hull, propellers, and other underwater components can help reduce friction and improve hydrodynamic performance. This can result in lower fuel consumption and emissions, as well as improved vessel speed and maneuverability.
- Installation of heat recovery systems: They capture waste heat from engine exhaust gases and use it to generate electricity or heat water for onboard use. By using this waste heat, ships can reduce the amount of fuel needed to generate electricity and heat water, resulting in lower fuel consumption and emissions.

In general, SEEMP Parts I and III are categorized into the subsequent sections:

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

In summary, the SEEMP is an important framework for shipping companies to improve their energy efficiency and reduce their environmental impact. Part I is mandatory for all ships above 400 GT, while Parts II and III apply to ships above 5,000 GT and are mandatory for the data collection system and carbon intensity indicator, respectively.

# CHAPTER 9: THE CARBON INTENSITY INDICATOR (CII)

The CII is an operational index enforced by MARPOL VI to reduce the carbon intensity (CO2 emissions per transport work) at the ship level. It is a goal-based standard with a rating system for ships which will become increasingly stringent towards 2030. It entered into force in 2023 and it is expected that ships will be forced to take measures at the operational level to improve their rating and reduce CO2 emissions.

CII applies to all ships above 5,000 GT: bulk carriers, gas carriers, tankers, container ships, general cargo ships, refrigerated cargo carriers, combination carriers, LNG carriers, vehicle carriers, Ro-Ro cargo vessels, Ro-Ro passenger vessels and cruise ships.

The CII is calculated based on the Annual Efficiency Ratio (AER). The AER is a measure of a ship's carbon efficiency calculated by dividing the total carbon emissions from all ballast and laden voyages, anchorage, and port stays by the total distance sailed in a year and the deadweight of the ship. The resulting value is expressed as grams of CO2 per deadweight ton mile (gCO2/DWT mile). This measure considers all carbon emissions associated with a ship's operations, including those from auxiliary engines, boilers, and generators. The CII, on the other hand, is a relative measure that compares a ship's AER to the average AER for ships of the same type and size. It is calculated by dividing a ship's AER by the average AER for similar ships, and then multiplying the result by 100. The resulting value is expressed as a percentage, with values below 100 indicating better carbon efficiency than the average for similar ships, and values above 100 indicating poorer carbon efficiency.

The CII is one of the key indicators used by the International Maritime Organization (IMO) to assess the carbon efficiency of ships, and it is expected to become mandatory for large ships in the near future. (Mettala, 2021)

$$AER = \frac{Annual\ CO2\ emissions}{Deadweight\ X\ Distance\ sailed}$$

*The CII Rating is calculated based on the Annual Efficiency Ratio, which gauges a ship's operational carbon emissions throughout the year*

CII ratings are based on the AER results of individual ships, and they are used to group ships into different efficiency categories.

The CII ratings range from A to E, with A being the most efficient and E being the least efficient.

Ships with an A rating are considered to be the most environmentally friendly, as they have the lowest carbon emissions per unit of cargo carried. Ships with a B or C rating are also considered to be relatively efficient, while those with a D or E rating are considered to be less efficient and more polluting.

The CII rating system is intended to provide a clear and simple way for shippers, charterers, and other stakeholders to assess the carbon efficiency of different ships and make more informed decisions about which ships to use for their operations. By promoting more efficient and less polluting ships, the CII rating system is expected to play a key role in reducing the carbon footprint of the shipping industry and promoting sustainable shipping practices.

By the year 2023, the reduction factor will be established at 5%. CII rating thresholds will be lowered by 5% compared to the initial thresholds based on the 2019 data. This means that ships will need to improve their carbon efficiency by at least 5% to maintain their current CII rating. (IMO, 2022)

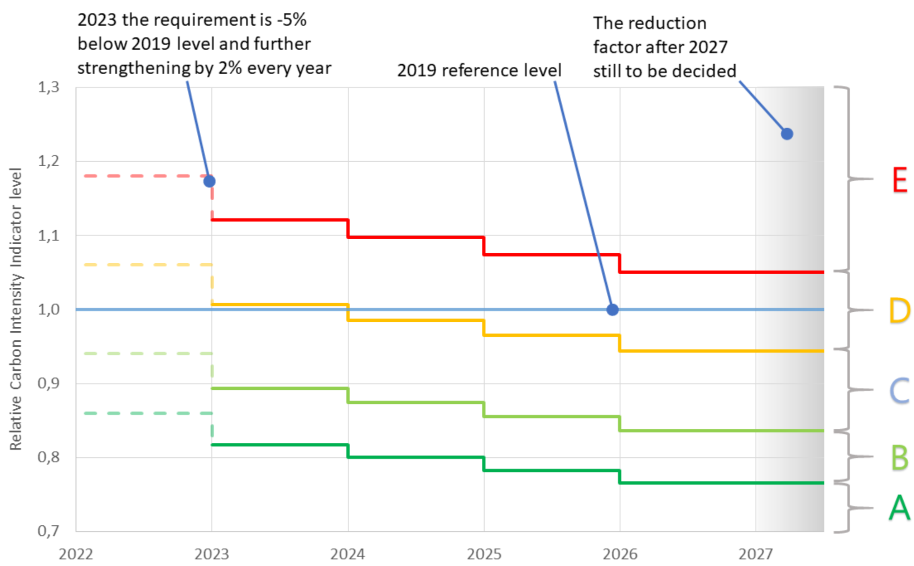



*Figure 17*: Carbon Intensity Indicator level (2022-2027)

If a ship is rated D or E, it indicates that the ship's carbon efficiency is relatively poor, and the owner or operator of that ship may be seen as not doing enough to address climate change.

However, the direct impact of a D or E rating is relatively limited, and the primary requirement for ship-owners is to update their SEEMP to address the areas where improvements can be made. (ClassNK, 2023)

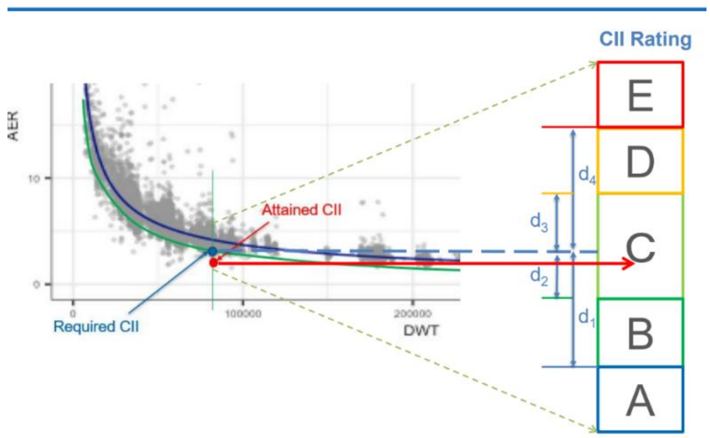



*Figure 18: Outline of CII rating (ClassNK, 2023)*

***<u>How to calculate CII</u>*** (ClassNK, 2023)

Attained annual operational CII ($CII_{Ship}$) formula for voyage adjustments and correction factors

$$AER = \frac{Annual\ CO2\ emissions}{Deadweight\ X\ Distance\ sailed} = \frac{\Sigma_j FC_j\ XC_j}{DWT\ X\ D} = \frac{g_{CO2}}{DWT\ mile}$$

*Figure 19: AER Calculation (ClassNK, 2023)*

The CII rating is determined by the Annual Efficiency Ratio, which assesses a ship's operational carbon emissions throughout a year.

- $j$ is the fuel type
- $CFj$ represents the fuel mass to CO2 mass conversion factor for fuel type
- $FCj$ is the total mass of consumed fuel of type $j$
- $FCvoyage$, is the mass (in grams) of fuel of type $j$
- $TFj$ = $(1 - AFTanker) \cdot FCS$, represents the quantity of fuel j removed for STS or shuttle tanker operation, where $FCS$, = $FC$
- $yi$ is a consecutive numbering system starting at $y2023$ = 0, $y2024$ = 1, $y2025$ = 2
- $FCelectrical$, is the mass (in grams) of fuel type

- $FCboiler$, is the mass (in grams) of fuel type $j$
- $FCothers$, is the mass (in grams) of fuel type
- $fi$ is the capacity correction factor
- $fm$ is the factor for ice-classed ships
- $fc$ represents the cubic capacity correction factors for chemical tankers
- $fi$, VSE represents the correction factor for ship-specific
- $Capacity$ is deadweight or gross tonnes as defined for each specific ship type
- $Dt$ represents the total distance travelled (in nautical miles)
- $Dx$ represents distance travelled (in nautical miles) for voyage

Regardless of whether any exclusion or correction factors are applied, the ship should report the total fuel oil consumption (in metric tonnes) for each type of fuel used during the voyage, as well as the total hours under way (in hours) and the total distance travelled (in nautical miles).

*Table 5: CII Calculation (G1) (ClassNK, 2023)*

| Ship types | Calculation method | Note |
|---|---|---|
| Bulk carriers, Tankers, Container ships, Gas carriers, LNG carriers, Ro-ro cargo ships, General cargo ships, Refrigerated cargo carrier Combination carriers | $\frac{\text{CO2 } Emission}{Deadweight \times Distance\ sailed}$ | Deadweight: Corresponding to Maximum Summer load draft<br><br>= the value on IEE Cert supplement |
| cruise passenger ships Ro-ro cargo ships (vehicle carriers) Ro-ro passenger ships | $\frac{\text{CO2 } Emission}{Gross\ Tonnage \times Distance\ sailed}$ | |

*Table 6: CII Reference Line (G2) (ClassNK, 2023)*

$$CII\ ref = a\ Capacity^{-C}$$

| 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 | 40853 | 0.812 |
| 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 | 5739 | 0.631 |
| Ro-ro cargo ship | | DWT | 10952 | 0.637 |
| Ro-ro passenger ship | | GT | 7540 | 0.587 |
| Cruise passenger ship | | GT | 930 | 0.383 |

*Table 7: Required CII (G3) (ClassNK, 2023)*

$$Required\ CII = \frac{100 - Z}{100} CII_{Ref}$$

Table 1: Reduction factor (Z%) for the CII relative to the 2019 reference line
Year Reduction factor relative to 2019

| Year | Reduction Factor (Z) |
|---|---|
| 2023 | 5% |
| 2024 | 7% |
| 2025 | 9% |
| 2026 | 11% |
| 2027 | ** |
| 2028 | ** |
| 2029 | ** |
| 2030 | ** |

Reduction factor Z will be starting from 5% in 2023 and 2% will be added yearly

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

*Table 8: CII Rating (G4) (ClassNK, 2023)*

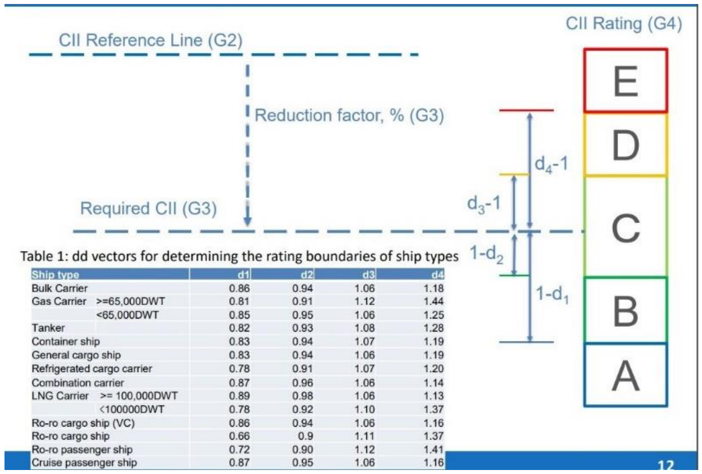



Table 1: dd vectors for determining the rating boundaries of ship types

| Ship type | | d1 | d2 | d3 | d4 |
|---|---|---|---|---|---|
| Bulk Carrier | | 0.86 | 0.94 | 1.06 | 1.18 |
| Gas Carrier | >=65,000DWT | 0.81 | 0.91 | 1.12 | 1.44 |
| | <65,000DWT | 0.85 | 0.95 | 1.06 | 1.25 |
| Tanker | | 0.82 | 0.93 | 1.08 | 1.28 |
| Container ship | | 0.83 | 0.94 | 1.07 | 1.19 |
| General cargo ship | | 0.83 | 0.94 | 1.06 | 1.19 |
| Refrigerated cargo carrier | | 0.78 | 0.91 | 1.07 | 1.20 |
| Combination carrier | | 0.87 | 0.96 | 1.06 | 1.14 |
| LNG Carrier | >= 100,000DWT | 0.89 | 0.98 | 1.06 | 1.13 |
| | <100000DWT | 0.78 | 0.92 | 1.10 | 1.37 |
| Ro-ro cargo ship (VC) | | 0.86 | 0.94 | 1.06 | 1.16 |
| Ro-ro cargo ship | | 0.66 | 0.9 | 1.11 | 1.37 |
| Ro-ro passenger ship | | 0.72 | 0.90 | 1.12 | 1.41 |
| Cruise passenger ship | | 0.87 | 0.95 | 1.06 | 1.16 |

The annual operational CII for individual ships is computed by dividing the total mass of emitted $CO_2$ (M) by the total transport work (W).

$$\text{Attained } CII_{ship} = {}^{M}/_{W}$$

Mass of $CO_2$ emissions (M)

$$M = FC_j \text{ X } C_{Fj}$$

- $j$ is the fuel type
- FCj is the total mass (in grams) of consumed fuel oil of type j
- CFj represents the fuel oil mass to $CO_2$ mass conversion factor for fuel oil type

Transport work (W)

$$W_s = C\ X\ D_t$$

C represents the ship's capacity:

- Bulk carriers, tankers, container ships, gas carriers, LNG carriers, general cargo ships, refrigerated cargo carriers, and combination carriers should utilize deadweight tonnage (DWT) as the measure of capacity.

- Cruise passenger ships, ro-ro cargo ships (vehicle carriers), ro-ro cargo ships, and ro-ro passenger ships should employ gross tonnage (GT) as the measure of capacity

Dt represents the total distance travelled (in nautical miles)

# CHAPTER 10: CASE STUDIES WITH EEXI AND CII ASSESSMENTS

## 10.1 INTRODUCTION TO THE CASE STUDIES

Two separate case studies are conducted for two distinct types of vessels, labeled as Vessel No1 and Vessel No2. Vessel No1 is a Gas Carrier, and Vessel No2 is a Chemical Tanker. The calculations will encompass both the required and attained values of EEXI and CII. Additionally, examinations of the impact of speed reduction and engine power limitation will be undertaken to assess the extent that these parameters can influence the two indicators. At the time that the case studies were carried out the two vessels have not installed an energy efficiency technology.

## 10.2 SOFTWARE DESCRIPTION

The Software used in this thesis is the ShipFORCE designed for the automated calculation and reporting of the IMO EEXI and CII. This program is connected with SEEMP planning and implementation modules.

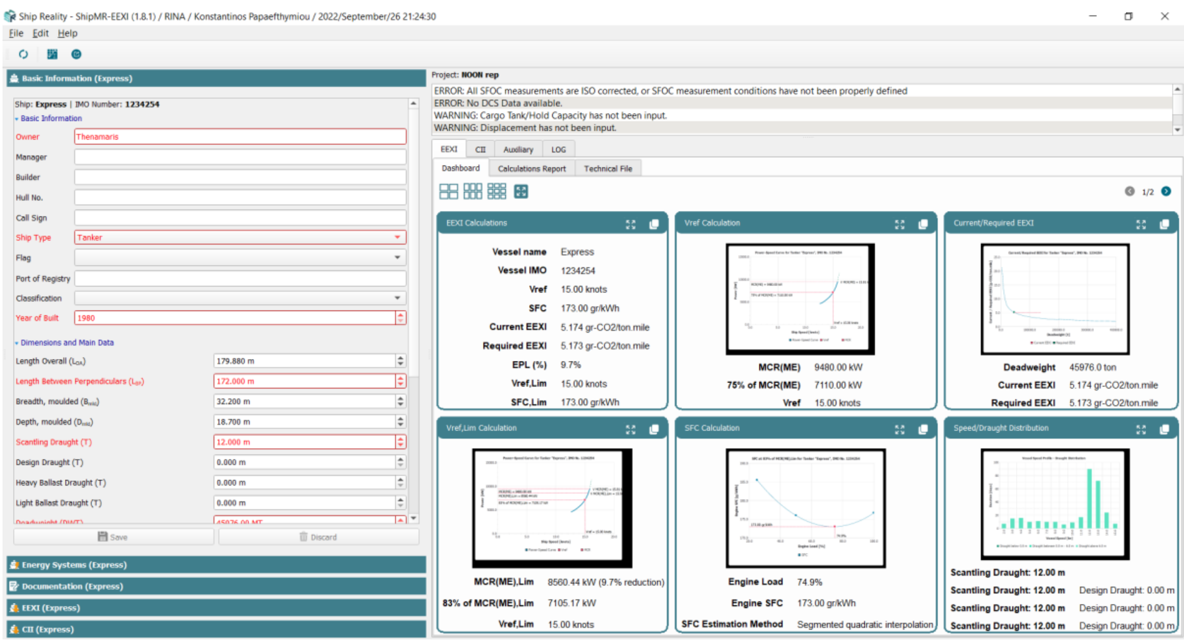



*Figure 20: Software interface*

ShipFORCE has been developed by ShipReality Ltd, a company which develops software for shipping. It is a Cloud-based collaborative platform which can utilize data from external cloud service providers and company servers.

The platform is producing a digital representation of the ship from the information and documents of the vessel and performs fast and accurate calculations (all EEXI methods included) for all vessel types, sizes and ship notations. Automated generation of high-quality reports for EEXI, CII are possible and decision support calculations with various parameters affecting the energy efficiency can be performed. The department of Maritime Studies owns an academic license of the program.

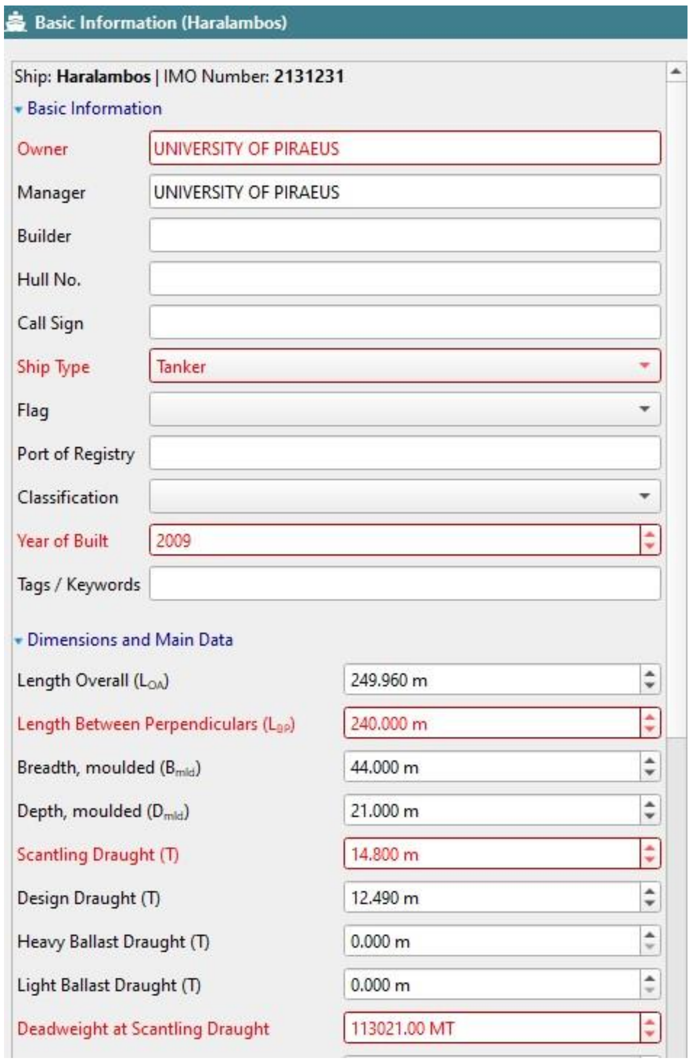



*Figure 21: ShipFORCE Software input panel (Shipreality, 2023)*

## 10.3 Calculations case study 1

In the 1st case study, our initial action involves the calculation of the attained and required EEXI based on the provided data for a Gas Carrier constructed in 2014.

The ships data needed for the digital representation of the vessel are shown in the following three tables. Table 9, shows the main particulars of the vessel, and Table 10, and 11 give information about the energy systems and the fuels used onboard. All these data have been appropriately inserted into the software.

*Table 9: Vessel Characteristics for EEXI Calculation*

| | |
|---|---|
| Vessel Type | Gas Carrier |
| Year of Built | 2014 |
| Length Between Perpendiculars | 152.20 [m] |
| Breadth | 25.60 [m] |
| Depth, main deck | 17.30 [m] |
| Summer Load Draught | 11.90 [m] |
| Deadweight at Summer (Scantling) Draught | 26798.0 [ton] |
| Gross Tonnage | 5320 GRT |

*Table 10: Main Engine Characteristics*

| | |
|---|---|
| Maximum Continuous Rating | 7950.00 [kW] |
| Rotational Speed at MCR | 117.0 [RPM] |
| Specific Fuel Consumption at 75% (SFC) | 173.10 [g/kWh] |
| CO2 Conversion Factor | 3.114 [t/t] |
| Number of Sets | 1 |

*Table 11: Auxiliary Engine Characteristics*

| | |
|---|---|
| Maximum Continuous Rating | 800.00 [kW] |
| Rotational Speed at MCR | 900.0 [RPM] |
| Specific Fuel Consumption at 75% (SFC) | 195.50 [g/kWh] |
| CO2 Conversion Factor | 3.206 [t/t] |
| Number of Sets | 5 |

The following Tables show the parameters used for the calculation and the results obtained as regards the attained EEXI and the required EEXI value for vessel 1.

*Table 12: Calculation of Current EEXI*

| | |
|---|---|
| P(ME) at 75% MCR | 5565.00 [kW] |
| Capacity | 26798.0 tn |
| fj | 1 |
| fi | 1 |
| fc | 1 |
| fl | 1 |

| | |
|---|---|
| fw | 1 |
| fm | 1 |
| Vref | 14.62 knots |
| Attained EEXI | **8.20 g-CO2/ton-mile** |

*Table 13: Required EEXI*

| Ship Type | Gas Carrier |
|---|---|
| a | 1120 |
| b | 26798 |
| c | 0.456 |
| EEDI Reference line value | 10.72 |
| Deadweight | 26798 |
| Reduction Factor | 30 |
| Required EEXI = (1 - 30 / 100) x 10.72 = 7.50 (g-CO2/ton. Mile) | |
| Required EEXI | **7.5 g-CO2/ton-mile** |

Required EEXI = (1 - 30 / 100) x 10.72 = 7.50 (g-CO2/ton. Mile)

## 10.4 EEXI Assessment for case study 1

The Current EEXI of the vessel is 8.20 g-CO2/ton. mile while the Required EEXI of the vessel is 7.50 g-CO2/ton. mile

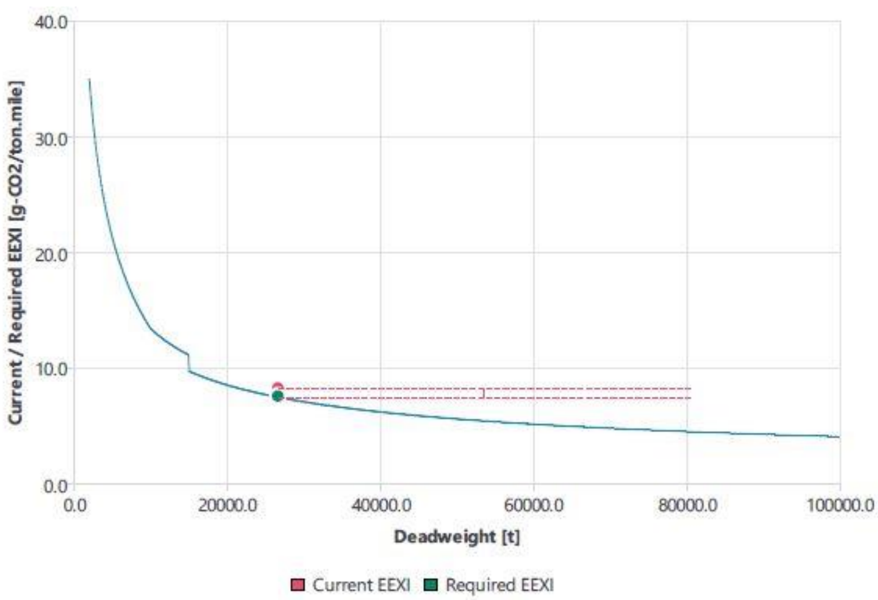



*Figure 22: Current/Required EEXI for Vessel No1*

Vessel No1 does not meet the requirements of EEXI Regulation. A reduction to EEXI of 8.20 - 7.50 = 0.70 g-CO2/ton. Mile is further required.

The gap between the current and necessary EEXI is evident in Figure 22.

In order to meet the required reduction of the EEXI we will proceed with the calculation of the Mechanical Engine Power Limitation as well as the speed reduction.

*Table 14: Engine Power Limitation Calculations*

| | |
|---|---|
| MCR(ME) | 7950.00 [Kw] |
| MCR(ME),Lim | 6980.10 [kW] |
| P(ME) | 4837.57 [kW] |
| SFC(ME) | 173.10 [g/kWh] |
| Power Reduction | 12.2 [%] |
| Actual attained EEXI | 7.5[g-CO2/ton. Mile] |

Finally, the Vessel No1 requires a 12.2% power limitation to meet the required reduction in EEXI.

*Table 15: Speed Reduction*

| | |
|---|---|
| Speed Vref | 14.62 [Knots] |
| Speed Vref,Lim | 14.09 [Knots] |
| Speed Reduction | 3.61 [%] |
| Actual attained EEXI | 7.5 g-CO2/ton-mile |

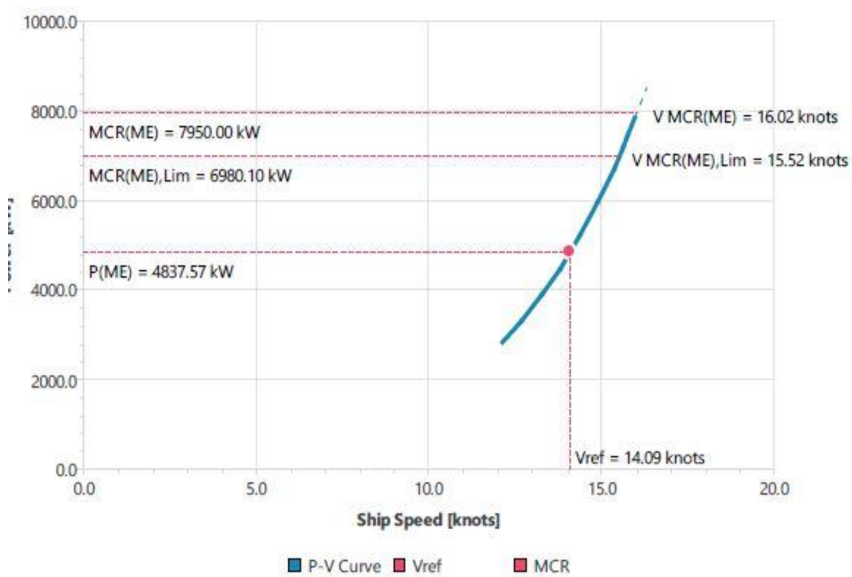



*Figure 23: Power-Speed Curve of Vessel No1 at Scantling Draught. Calculation of Vref*

This power limitation corresponds to a 3.61 % speed reduction to meet the required EEXI as shown in Figure 23.

Alternatively, and in case the EPL is not the preferred option, the EEXI of vessel 1, may be also improved though the application of Energy Efficiency Technologies (EET). In general, the energy efficiency technologies have low influence in closing the gap between attained and required EEXI values. However, this gap here is within the range (approx. 10%) of their effectiveness.

## 10.5 CII Assessment for case study 1

In the CII assessment for vessel 1 the initial step is to calculate the attained and required CII. The operational data of the ships have been provided by the shipping company (trips with distance covered, fuels used, capacities etc.) for the calendar year 2021. These data are forwarded from onboard to the shipping company in daily basis in the form of noon reports. All noon reports of the vessel form year 2021 have been collected. Example of the vessel's noon reports is presented in ANNEX I.

Data retrieved form the IMO DCS (Data Collection System) reporting of the shipping company. DCS is a regulatory requirement and data on fuel consumption and related parameters should be submitted annually for verification. From the IMO DCS, the following data have been provided (annual data):

- Fuel Consumption Data: This includes data on the amount of fuel consumed by the ship during the reporting period, measured in metric tons.
- Distance Travelled: The distance traveled by the ship during the reporting period, measured in nautical miles.
- Hours Underway: The total time the ship spends underway during the reporting period, measured in hours.
- Cargo Carried: Some ships are also required to report information on the type and quantity of cargo carried during the reporting period.
- Voyage Information: Certain voyage-specific data may also be required, such as departure and arrival ports, duration of voyages, and other relevant information.

After obtaining the attained CII results, we will classify the vessel into CII rating categories from A to E. If the vessel falls into the E or D rating, additional results will be presented to demonstrate how reducing the vessel's speed will influence the indicator over the next few years, as per the inserted data.

The ship's information and the CII calculations are shown in the following tables.

*Table 16: Vessel Characteristics for CII Calculation*

| | |
|---|---|
| Vessel Type | Gas Carrier |
| Year of Built | 2014 |
| Length Between Perpendiculars | 152.20 [m] |
| Breadth | 25.60 [m] |
| Depth, main deck | 17.30 [m] |
| Summer Load Draught | 11.90 [m] |
| Deadweight at Summer (Scantling) Draught | 26798.0 [ton] |
| Lightship Weight | 10262.0 [ton] |

*Table 17: Main Engine Characteristics*

| | |
|---|---|
| Maximum Continuous Rating | 7950.00 [kW] |
| Rotational Speed at MCR | 117.0 [RPM] |
| Specific Fuel Consumption at 75% (SFC) | 173.10 [g/kWh] |
| CO2 Conversion Factor | 3.114 [t/t] |
| Number of Sets | 1 |

*Table 18: Auxiliary Engine Characteristics*

| | |
|---|---|
| Maximum Continuous Rating | 800.00 [kW] |
| Rotational Speed at MCR | 900.0 [RPM] |
| Specific Fuel Consumption at 75% (SFC) | 195.50 [g/kWh] |
| CO2 Conversion Factor | 3.206 [t/t] |
| Number of Sets | 5 |

*Table 19: PTO/PTI Characteristics*

| | |
|---|---|
| PTO 1 | |
| Manufacturer | a |
| Type | a |
| Rated Electrical Output Power | 3.00 [kW] |

*Table 20: Reference CII*

| | |
|---|---|
| *CII Reference* | |
| a | 8104 |
| Capacity | 26798 |
| c | 0.639 |

| | |
|---|---|
| CII (Ref) | 11.999 [g-CO2/ton.mile] |
| *Required Annual Operational CII* | |
| Z | 2% |
| CII | 11.759 [g-CO2/ton.mile] |

The required CII is calculated according to the MEPC guidelines with the following formula:

$$CII = (1 - Z/100) \times CII(Ref)$$

*Table 21: Attained CII*

| | |
|---|---|
| *Attained CII* | |
| M (total mass of CO2) M=FCj + CFj | 11755897,2 |
| W(total transport work in ton mile) W=CxDt | 875.517.458 |
| C [tonnes] | 26798 |
| Dt [miles] | 32671 |
| **Attained CII** | **13.427 [g-CO2/ton.mile]** |
| fi | 1 |
| fm | 1 |
| fc | 1 |
| fiVSE | 1 |

The attained CII is calculated following again the MEPC guidelines documents as the ratio of the total mass of $CO_2$ (M) to the total transport work (W).

*Table 22: Annual fuel consumption and fuel conversion factors for Calendar Year 2021*

| **Fuel** | **Annual Cons[ton]** | **Conv Factor[ton-CO2/ton-Fuel]** |
|---|---|---|
| LFO | 3139.4 | 3.151 |
| MGO/MDO | 581.3 | 3.206 |

The corrected factor CII is 0.000 g-CO2/ton.mile

Figure 24 shows the CII rating areas (A: green, to E: red) for the specific ship type and capacity. The calculated rating of the case study vessel 1, in the calendar year 2021, is D.

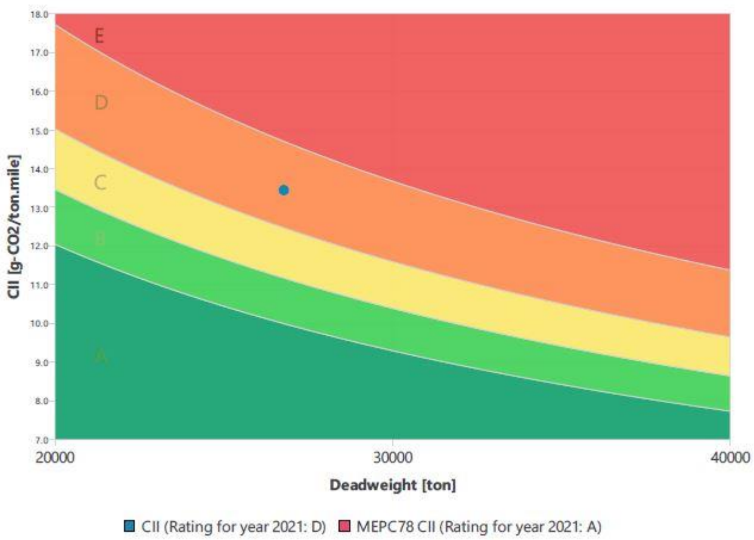



*Figure 24: Rating of the vessel No1*

According to the CII for ships that achieve a D rating for three consecutive years (or an E rating in a single year), a corrective action plan needs to be developed as part of the SEEMP, and that plan should be submitted for approval to the Recognized Organization (i.e. the Class Society). CII is greatly affected by idle ship time (time with no distance covered). For the ship of the case study the following table shows the impact of idle entries in the DCS reporting for year 2021.

*Table 23: Impact of Idle DCS Entries to CII [%]*

| Year | Impact of Idle DCS Entries to CII [%] |
|---|---|
| 2021 | 34.02 |

The software has a projection function for the CII rating in the upcoming years, which is performed with the assumption that the ship will keep the same operational profile. The projection in shown in Table 24.

*Table 24: CII Compliance forecast of vessel No1 based on DCS Data*

| Year | Impact of Idle DCS Entries to CII [%] |
|---|---|
| 2018 | - |
| 2019 | - |
| 2020 | - |
| 2021 | - |
| 2022 | D |
| 2023 | D |
| 2024 | D |

| | |
|---|---|
| 2025 | D |
| 2026 | E |
| 2027 | E |
| 2028 | E |
| 2029 | E |
| 2030 | E |
| 2031 | E |
| 2032 | E |

This CII rating forecast for the vessel No1 utilizes the available DCS data and accepts that no improvement strategies for energy efficiency will be employed. As indicated in Table 24, the vessel is projected to stay in D rating the following four years and reach an E rating in 2026. According to MARPOL VI, for a vessel that falls for three years in D rating or an E rating in a single year, a corrective action plan needs to be developed as part of the SEEMP and submitted for approval.

One effective strategy for achieving such improvement which can be implemented without CAPEX is through speed reduction and insert this plan in the revised SEEMP.

The projection is considering different levels of speed reduction for the vessel No1 for all voyage conditions (Laden, Ballast), in the following years and calculates the CII rating. As shown in Table 25, it is possible for the ship to achieve a favorable rating (i.e. C) with only 5% (equal to 0.75 knots) speed reduction in the upcoming years until 2026. Since the CII limits are getting stricter year by year, the ship operator may have to further reduce the speed (at 10%, or 1.5 knots) to stay within the D rating up to 2030.

*Table 25: CII Speed Reduction Compliance forecast of vessel No1, for years 2023-2030*

| Speed Reduction | 2023* | 2024* | 2025* | 2026* | 2027* | 2028* | 2029* | 2030* |
|---|---|---|---|---|---|---|---|---|
| 0% - 0.00kn | C | C | C | D | D | D | D | D |
| 5% - 0.75kn | C | C | C | C | D | D | D | D |
| 10% - 1.50kn | C | C | C | C | C | D | D | D |
| 15% - 2.25kn | C | C | C | C | C | D | D | D |
| 20% - 2.99kn | C | C | C | C | C | D | D | D |
| 25% - 3.74kn | C | C | C | C | C | D | D | D |
| 30% - 4.49kn | C | C | C | C | D | D | D | D |

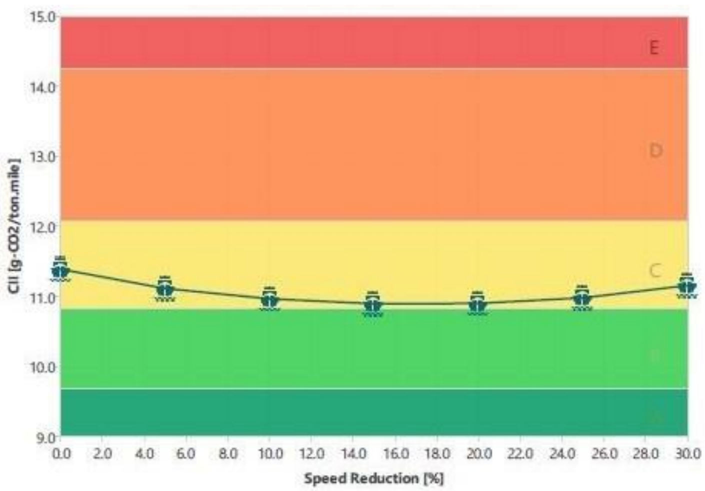



*Figure 25: CII Speed Reduction Forecast*

*Table 26: CII Speed Reduction forecast table of vessel No1, for year 2023*

| **Speed Reduction** | **Distance** | **FOC Reduction** | **CO2 Emitted** | **Attained CII** |
|---|---|---|---|---|
| [%] | [miles/y] | [ton/y] | [ton-CO2/y] | [g-CO2/ton.mile] |
| 0 | 32671 | 633.3 | 9970.7 | 11.388 |
| 5 | 31037.4 | 894.2 | 9243.2 | 11.113 |
| 10 | 29403.9 | 1105.5 | 8640.9 | 10.966 |
| 15 | 27770.3 | 1290.4 | 8108.2 | 10.895 |
| 20 | 26136.8 | 1453.4 | 7635.2 | 10.901 |
| 25 | 24503.3 | 1600.2 | 7210 | 10.98 |
| 30 | 22869.7 | 1729 | 6837.2 | 11.156 |

In general, reducing the speed of a vessel often leads to improved energy efficiency and a lower CII rating. Slower speeds can result in reduced fuel consumption and emissions per transport work. This is because the propulsive power required is approximately proportional to the cube of a cargo vessel's speed. For vessel 1, the impact of different speed reduction strategies in Fuel Oil Consumption (FOC), $CO_2$ emissions and CII for the vessel are shown in Table 26.

However, it is important to comment that the continuous speed reduction can improve the energy efficiency parameters and the CII rating up to a certain threshold, which corresponds to 18-20% speed reduction for the vessel of the case study (as illustrated in Figure 25). Beyond this point, the CII rating remains constant, or over time, it may even deteriorate.

Consequently, the operational speed reduction might be an effective and low-cost strategy to comply with the CII regulation but it has limited effect when a more drastic energy efficiency improvement is required. New more environmentally friendly methods are needed in this case. For the case study vessel 1, a possible strategy could be the planning for an installation of energy efficiency devices from year 2026 onwards, to enhance the vessel's rating up to year 2030.

## 10.6 CALCULATIONS CASE STUDY 2

The ship of the second case study is a 113000 dwt Chemical Tanker, built in 2009. The vessel's characteristics, particulars and energy production sources are given in Tables 27, 28, and 29. These are inserted in the ShipFORCE software.

The first step of the assessment involves the calculations of the attained and required EEXI values (provided in Table 27, and 28).

*Table 27: Vessel Characteristics for EEXI Calculation*

| | |
|---|---|
| Vessel Type | Chemical Tanker |
| Year of Built | 2009 |
| Length Between Perpendiculars | 240.00 [m] |
| Breadth | 44.00 [m] |
| Depth, main deck | 21.00 [m] |
| Summer Load Draught | 14.80 [m] |
| Deadweight at Summer (Scantling) Draught | 113021.0 [ton] |
| Gross Tonnage | 62775.0 GRT |

*Table 28: Main Engine Characteristics*

| | |
|---|---|
| Maximum Continuous Rating | 15820.00 [kW] |
| Rotational Speed at MCR | 105.0 [RPM] |
| Specific Fuel Consumption at 75% (SFC) | 172.08 [g/kWh] |
| CO2 Conversion Factor | 3.206 [t/t] |
| Number of Sets | 1 |

*Table 29: Auxiliary Engine Characteristics*

| | |
|---|---|
| Maximum Continuous Rating | 970.00 [kW] |
| Rotational Speed at MCR | 720.0 [RPM] |
| Specific Fuel Consumption at 75% (SFC) | 215.00 [g/kWh] |
| CO2 Conversion Factor | 3.114 [t/t] |
| Number of Sets | 1 |

*Table 30: Calculation of Current EEXI*

| | |
|---|---|
| P(ME) at 75% MCR | 11319.38 [kW] |
| Capacity | 113021 tn |
| fj | 1 |
| fi | 1 |
| fc | 1 |
| fl | 1 |
| fw | 1 |
| fm | 1 |
| Vref | 14.30 knots |
| Attained EEXI | **4.09 g-CO2/ton-mile** |

*Table 31: Required EEXI*

| | |
|---|---|
| Ship Type | Chemical Tanker |
| a | 1218.8 |
| b | 113021 |
| c | 0.488 |
| EEDI Reference line value | 4.17 |
| Deadweight | 113021 |
| Reduction Factor | 20 |
| Required EEXI = (1 - 20 / 100) x 4.17 = 3.33 (g-CO2/ton. Mile) | |
| Required EEXI | **3.33 g-CO2/ton-mile** |

## 10.7 EEXI Assessment for case study 2

The Current EEXI of the vessel is 4.09 g-CO2/ton.mile which is higher than the Required EEXI (3.33 g-CO2/ton.mile).

Vessel No2 does not meet the requirements of the EEXI Regulation. A reduction to EEXI of 4.09 – 3.33 = 0.76 g-CO2/ton.mile is further required.

The gap between the current and required EEXI is evident in Figure 26.

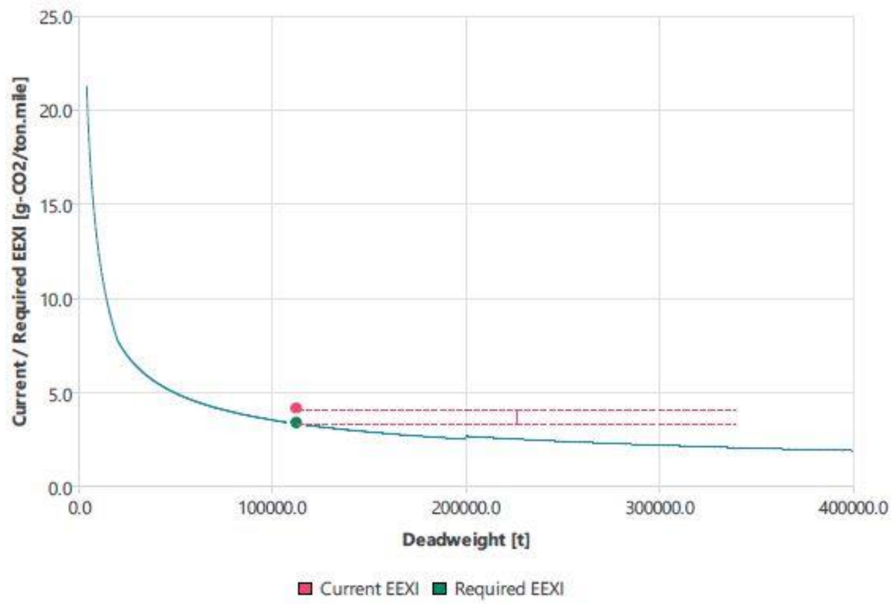



*Figure 26: Current/Required EEXI for Vessel No*

Vessel 2, has a higher gap to fill in order to meet the required reduction of the EEXI. As commented in the EEDI chapter, the index is highly dependent on the speed used in the calculations (the reference speed). The implementation of energy efficiency technologies is not able to achieve an EEXI reduction higher than 10% and therefore cannot be considered here. The solution of the mechanical Engine Power Limitation (EPL) is applied which corresponds to set a speed limit for the ship.

*Table 32: Engine Power Limitation Calculations*

| | |
|---|---|
| MCR(ME) | 15820.0 [Kw] |
| MCR(ME),Lim | 10725.96 [kW] |
| P(ME) | 7498.84 [kW] |
| SFC(ME) | 176.88 [g/kWh] |
| Power Reduction | 32.2 [%] |
| Actual attained EEXI | **3.33 [g-CO2/ton.mile]** |

The calculations show that the vessel No2 should implement a 32.2% power reduction to meet the required EEXI value. This corresponds to a 14.1% speed reduction, which means that the ship will not be able to sail with speeds higher than 12.29 knots (see Table 33). For the case study ship which has a design speed of 16.45 knots (see Figure 26) this is a considerable speed loss. It is common for cargo ships to operate in lower speeds than the design speed, practicing the so-called slow steaming. However, the speed limit required to meet the EEXI regulation in this case study, needs to be evaluated by the ship operator (maybe by exploring the ship's historical operational data) as it might be a not affordable speed loss from a commercial perspective.

*Table 33: Speed Reduction to meet the EEXI regulation*

| | |
|---|---|
| Speed Vref | 14.30 [Knots] |
| Speed Vref,Lim | 12.29 [Knots] |
| Speed Reduction | 14.10 [%] |
| Actual attained EEXI | **3.33 g-CO2/ton-mile** |

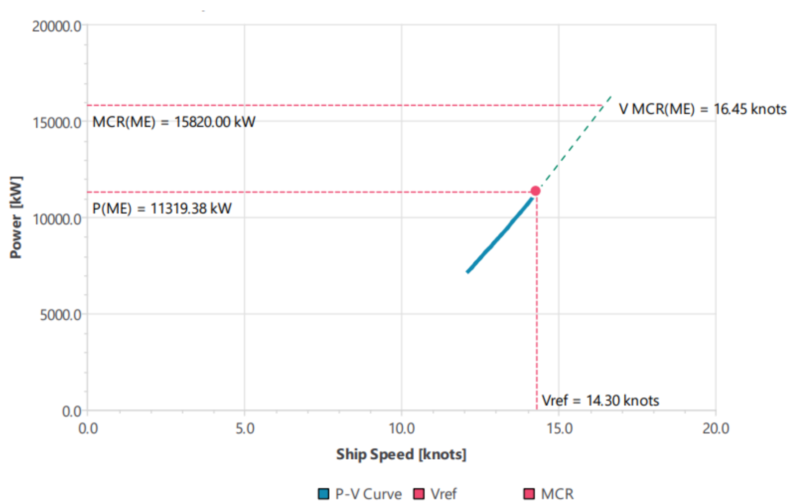



*Figure 27: Power-Speed Curve of Vessel No2 at Scantling Draught, Calculation of Vref*

## 10.8 CASE STUDY 2 - CII ASSESSMENT

In the CII assessment for vessel 2 the same steps are followed as in case study 1. First the attained and required CII are calculated using operational data (noon reports and DCS data) of the ship provided by the shipping company for the calendar year 2023.

The ship has used different fuels during the calendar year (see Table 36). The results for the required and attained CII values are shown in Tables 34, and 35.

*Table 33: CII Reference*

| *CII Reference* | |
|---|---|
| a | 4745 |
| Capacity | 113021 |
| c | 0.622 |
| CII (Ref) | 3.413 [g-CO2/ton.mile] |
| *Required Annual Operational CII* | |
| Z | 5% |
| **Required CII** | 3.243 [g-CO2/ton.mile] |

*Table 34: Attained CII*

| *Attained CII* | |
|---|---|
| M (total mass of CO2) M=FCj X CFj | 16847.5068 |
| W(total transport work in ton mile) W=CxDt | 4658047 |
| C [tonnes] | 113021 |
| Dt [miles] | 41214 |
| **Attained CII** | **3.617 [g-CO2/ton.mile]** |
| fi | 1 |
| fm | 1 |
| fc | 1 |
| fiVSE | 1 |

*Table 35: Annual Fuel Consumption and fuel conversion factors for Calendar Year 2021*

| **Fuel** | **Annual Cons[ton]** | **Conv Factor[ton-CO2/ton-Fuel]** |
|---|---|---|
| HFO | 4683.8 | 3.114 |
| MGO/MDO | 705.6 | 3.206 |

Figure 28 presents the CII rating boundaries area for different capacity values for chemical tankers. The case study ship achieves for the calendar year 2023, achieves a D rating for CII.

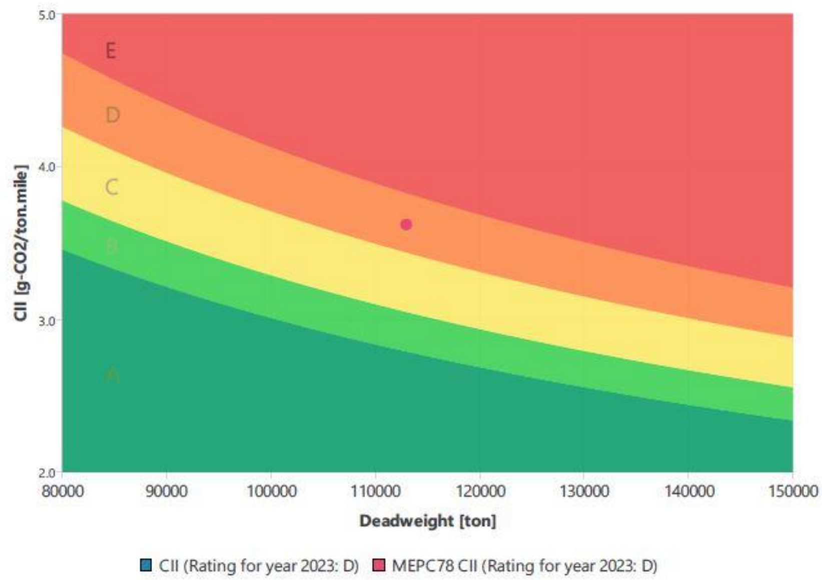



*Figure 28: Rating of the vessel No2*

According to the CII regulations for ships that achieve a D rating for three consecutive years (or an E rating in a single year), a corrective action plan needs to be developed as part of the SEEMP, and that plan should be submitted for approval to the Recognized Organization (i.e. the Class Society).

CII is greatly affected by idle ship time (time with no distance covered). For the ship of the case study the following table shows the impact of idle entries in the DCS reporting for year 2023.

*Table 36: Impact of Idle DCS Entries to CII [%]*

| Year | Impact of Idle DCS Entries to CII [%] |
|---|---|
| 2023 | 5.53 |

CII rating during the upcoming years is assessed and presented as per below table *9*

*Table 37: CII Compliance forecast of vessel No2 based on DCS Data*

| Year | Impact of Idle DCS Entries to CII [%] |
|---|---|
| 2018 | - |
| 2019 | - |
| 2020 | - |
| 2021 | - |

| | |
|---|---|
| 2022 | - |
| 2023 | - |
| 2024 | D |
| 2025 | D |
| 2026 | E |
| 2027 | E |
| 2028 | E |
| 2029 | E |
| 2030 | E |
| 2031 | E |
| 2032 | E |

Table 38 provides a forecast for the CII compliance of vessel No2 according to the DCS data that have been imported to the software. The calculations are done with the assumption that no improvement strategies will be employed by the vessel in the projected years.

As outlined in Table 38, the vessel is anticipated to attain an E rating by 2026. Consequently, measures need to be employed to enhance this rating, with the objective of elevating it from E to at least a C rating.

Case study 2 investigates the effectiveness of a speed adjustment strategy for achieving desired CII improvements. The calculations are performed with the ShipFORCE software and include a projection of the attained CII of the vessel in following years up to 2030. The results are shown in Table 39.

For the case study vessel, it appears that a favorable operational speed reduction strategy is in the range of 10% (equal to 1.23 knots) in the following years up to 2026. This strategy will allow the CII of the ship to stay in C rating up to 2026. According to the regulation, a C rating means that the vessel is energy efficient and no plans for improvements need to be submitted to the Recognized Organization or Flag for verification.

However, the 10% speed reduction will result in the ship getting into the D rating area from year 2026 and for three consecutive years. This will trigger extra measures by the company that should be reported in the SEEMP plan. To avoid this the ship should employ a 15% speed reduction (equal to 1.85 knots) or higher. By considering different levels of speed reduction for the vessel No2 for all voyage conditions (Laden, Ballast), the shop operator may choose the most effective one which also matches better to the ship operating profile.

*Table 38: CII Speed Reduction Compliance forecast of vessel No2, for years 2023-2030*

| Speed Reduction | 2023* | 2024* | 2025* | 2026* | 2027* | 2028* | 2029* | 2030* |
|---|---|---|---|---|---|---|---|---|
| 0% - 0.00kn | D | D | D | E | E | E | E | E |
| 5% - 0.62kn | D | D | D | D | D | E | E | E |
| 10% - 1.23kn | C | C | C | D | D | D | E | E |
| 15% - 1.85kn | C | C | C | C | C | D | D | D |
| 20% - 2.46kn | B | C | C | C | C | C | D | D |
| 25% - 3.08kn | B | B | B | C | C | C | C | D |
| 30% - 3.69kn | A | B | B | B | B | C | C | C |

*Table 39: CII Speed Reduction forecast table of vessel No2, for year 2023*

| **Speed Reduction** | **Distance** | **FOC Reduction** | **CO2 Emitted** | **Attained CII** |
|---|---|---|---|---|
| [%] | [miles/y] | [ton/y] | [ton-CO2/y] | [g-CO2/ton.mile] |
| 0 | 41214.0 | 0.0 | 16847.6 | 3.617 |
| 5 | 39153.3 | 574.9 | 15256.4 | 3.448 |
| 10 | 37092.6 | 1106.0 | 13785.4 | 3.288 |
| 15 | 35031.9 | 1597.6 | 12422.8 | 3.138 |
| 20 | 32971.2 | 2051.3 | 11166.4 | 2.997 |
| 25 | 30910.5 | 2470.6 | 10004.6 | 2.864 |
| 30 | 28849.8 | 2850.8 | 8949.8 | 2.745 |

In Table 39, the effect of the projected speed reductions in fuel consumption and emissions for the case study ship are presented. Slower speeds can result in reduced fuel consumption and emissions per unit of transport work. In this case study, it appears that based on the operational data of the vessel and according to selected speed reduction scenarios the CII rating seems to be consistently declining.

In table 40, it is observed that the decrease in speed corresponds proportionally to the distance traveled by the vessel, leading to reductions in fuel oil consumption and CO2 emissions. Ultimately, these outcomes contribute to a gradual decrease in the calculated Carbon Intensity Indicator (CII).

# CONCLUSION

This thesis performed an assessment, at the ship level, of selected and widely implemented technical and operational solutions for the improvement of energy efficiency and the reduction of GHG emissions, in the context of the recently enforced amendments to MARPOL VI. For this assessment the study has measured the performance of the ship against EEXI, and CII, which have been recently introduced by IMO as mandatory goal-based standards for the ship energy efficiency. Compliance with these may be possible with different solutions (technical and operational). Due to the limited time given to ships to comply, there is evidence from the industry that certain solutions, such as the engine power limitation, and the speed adjustment/reduction, are currently the widely preferred options from the ship operators.

Therefore, the study selected to perform an assessment of the effectiveness of the above prevailing options for EEXI and CII compliance, using real data from the design and operation of two different ships. Two case studies one for a Gas Carrier (Vessel No1) and one for a Chemical Tanker (Vessel No2) were formed in this respect. Both ships are in operation and must comply with the MARPOL VI amendments. The data collection process from the ship operators, succeeded to retrieve all necessary information for the accurate calculation of the EEXI and CII. From the data collection process, it became apparent that the two vessels come with no energy efficiency technologies.

For the calculations the study used the ShipFORCE platform, a commercial software which is available (via an academic license) in the Department of Maritime Studies. Through the detailed calculations and simulations performed with the software, the research evaluated the impact of speed reduction and engine power limitation in the EEXI and CII levels.

Regarding the EEXI assessment, the calculations of the attained and required EEXI values, revealed that additional measures are needed for both vessels in order to comply. In general, the energy efficiency technologies have low influence in closing the gap between attained and required EEXI values. For vessel 1, this gap was found within the range (approx. 10%) of effectiveness of the energy saving devices. The implementation of an EPL for the first vessel resulted in a relatively low speed reduction (by technical means) which will have a negligible effect in the operation of the vessel. The EEXI calculations for the second vessel revealed a poor performance against the index which is out of the range of energy efficiency devices and can be filled only with the technical measure of EPL. The EPL for the second vessel will result in a drastic speed limit which means that the vessel will not have available a range of speeds above 12.30 knots. This unavailability of speed needs to be evaluated by the ship operator whether it can be affordable, by considering the operating pattern of the vessel. In case the speed loss is not affordable the ship may need to consider additional technical measures for energy efficiency in combination with the EPL.

Regarding the Carbon Intensity Indicator (CII) assessment the results indicated that implementing a strategy of reducing the vessels speed (from an operational perspective) could be an effective approach for meeting the CII requirement. In general, reducing the speed of a vessel often leads to improved energy efficiency and a lower CII rating. Slower speeds can result in reduced fuel consumption and emissions per unit of transport work. From the CII projections part of the case studies, it was made evident that with implementing an annual speed reduction strategy in the range of 10% it is possible to alter the CII rating to a more favorable one (getting from D to C or avoiding E ratings). However, this effect is positive up to a certain threshold as demonstrated in case study 1. Beyond this point, the CII may even deteriorate. Moreover, in a ship which has already implemented an EPL to comply with EEXI, and therefore a speed limit, the additional reduction of speed to attain a favorable CII rating needs to be considered carefully, with looking at the historical data of operation, as it might not be affordable from a commercial perspective.

The CII and the EEXI are mandatory instruments aiming to reduce GHG emissions and advancing energy efficiency at the ship level. The CII prioritizes operational efficiency, while the EEXI concentrates on enhancing the technical efficiency of existing ships. In conjunction with other regulations established by the IMO these indicators collectively strive to catalyze substantial enhancements in the environmental performance of the industry. The target set by IMO, is through these measures the international shipping to achieve an overall reduction of 30% in annual GHG emissions.

This thesis provided insights on the potential impact of speed reduction as a practical solution in the short-term to achieve regulatory compliance and energy efficiency gains. These solutions may support ship operators to overcome the first period of implementation of CII and EEXI regulations. It is apparent that the ongoing efforts for reducing GHG emissions in the shipping industry, will need to consider other more drastic solutions for vessels efficiency such as new fuels and new energy sources for onboard use.

In summary, this thesis offers critical insights into the effectiveness of prevailing technical and operational solutions for achieving energy efficiency and reducing GHG emissions in compliance with MARPOL VI amendments. The detailed assessments using real ship data underscore the challenges ships face in meeting EEXI and CII standards, particularly the limited impact of existing energy efficiency technologies. By highlighting the potential of speed reduction as a viable short-term strategy, the thesis provides ship operators with practical pathways to navigate the initial phase of CII and EEXI implementation. As the shipping industry intensifies efforts to curb GHG emissions, it will be imperative to explore more transformative measures, including the adoption of new fuels and innovative onboard energy sources, to achieve sustainable vessel efficiency in the long term.

# ANNEX I

A noon report is a data sheet prepared daily onboard. The report includes the vessel's position and other standardized data to assess the performance of the ship based on its speed and environmental forces including weather conditions. Noon Reports are sent by the master to the company and shore management at a fixed time on daily basis (normally it is sent during noon, hence it's called "noon report").

| 6 | Mandatory data fields | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Date | Time | Voyage | | Position | | | | | | Event | Time elapsed | | Distance | Cargo | | |
| 8 | | | From | To | Latitude | | | Longitude | | | -Departure -Arrival -Noon -STS | Since previous event | Time at anchor | Distance sailed | Weight of cargo or deadweight | Volume | Passengers |
| 9 | | | double click to view the list | double click to view the list | Degree | Minutes | North / South | Degree | Minutes | East / West | | | | | | | |
| 10 | UTC yyyy-mm-dd | UTC hh:mm | UN / LOCODE | UN / LOCODE | [°] | ['] | | [°] | ['] | | | h | h | nm | mt | m3 | nr |
| 11 | 2022/01/01 | 12:00 | Bonny-NGBON | Port Harcourt-NGPHC | 4 | 43.56 | North | 7 | 5.03 | East | Noon | 24.00 | 0.00 | 0.00 | 8880.49 | | |
| 12 | 2022/01/01 | 19:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 4 | 12.10 | North | 6 | 59.51 | East | Departure | 7.00 | 0.00 | 0.00 | 8880.49 | | |
| 13 | 2022/01/02 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 4 | 56.11 | North | 4 | 9.08 | East | Noon | 17.00 | 0.00 | 262.00 | 8880.49 | | |
| 14 | 2022/01/02 | 17:42 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 13.03 | North | 3 | 26.15 | East | Arrival | 5.70 | 0.00 | 89.00 | 8880.49 | | |
| 15 | 2022/01/03 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 18.30 | 0.00 | 0.00 | 8880.49 | | |
| 16 | 2022/01/04 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 24.00 | 0.00 | 0.00 | 8880.49 | | |
| 17 | 2022/01/05 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 24.00 | 0.00 | 0.00 | 8880.49 | | |
| 18 | 2022/01/06 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 24.00 | 0.00 | 0.00 | 8880.49 | | |
| 19 | 2022/01/07 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 24.00 | 0.00 | 0.00 | 8880.49 | | |
| 20 | 2022/01/08 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 24.00 | 0.00 | 0.00 | 6775.23 | | |
| 21 | 2022/01/09 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 24.00 | 0.00 | 0.00 | 6377.87 | | |
| 22 | 2022/01/10 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 24.00 | 0.00 | 0.00 | 6169.79 | | |
| 23 | 2022/01/11 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 24.00 | 0.00 | 0.00 | 6168.79 | | |
| 24 | 2022/01/12 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 27.39 | North | 3 | 22.31 | East | Noon | 24.00 | 0.00 | 0.00 | 6169.79 | | |
| 25 | 2022/01/13 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 27.39 | North | 3 | 22.31 | East | Noon | 24.00 | 0.00 | 0.00 | 6169.79 | | |
| 26 | 2022/01/14 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 27.39 | North | 3 | 22.31 | East | Noon | 24.00 | 0.00 | 0.00 | 5806.16 | | |
| 27 | 2022/01/15 | 12:00 | Port Harcourt-NGPHC | Lagos-NGLOS | 6 | 26.06 | North | 3 | 22.28 | East | Noon | 24.00 | 0.00 | 0.00 | 2296.78 | | |
| 28 | 2022/01/15 | 23:30 | Lagos-NGLOS | Lome-TGLFW | 6 | 10.55 | North | 3 | 23.84 | East | Departure | 11.50 | 0.00 | 15.00 | 845.56 | | |
| 29 | 2022/01/16 | 10:00 | Lagos-NGLOS | Lome-TGLFW | 5 | 58.41 | North | 1 | 21.50 | East | Arrival | 10.50 | 0.00 | 165.00 | 845.56 | | |
| 30 | 2022/01/16 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 6 | 2.55 | North | 1 | 18.79 | East | Noon | 2.00 | 2.00 | 0.00 | 845.56 | | |
| 31 | 2022/01/17 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 6 | 2.26 | North | 1 | 15.15 | East | Noon | 24.00 | 24.00 | 0.00 | 845.56 | | |
| 32 | 2022/01/18 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 6 | 2.73 | North | 1 | 13.37 | East | Noon | 24.00 | 24.00 | 0.00 | 9856.82 | | |
| 33 | 2022/01/19 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 6 | 2.58 | North | 1 | 13.33 | East | Noon | 24.00 | 24.00 | 0.00 | 9856.82 | | |
| 34 | 2022/01/20 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 6 | 2.58 | North | 1 | 13.31 | East | Noon | 24.00 | 24.00 | 0.00 | 9856.82 | | |
| 35 | 2022/01/21 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 6 | 2.58 | North | 1 | 13.33 | East | Noon | 24.00 | 24.00 | 0.00 | 9856.82 | | |
| 36 | 2022/01/22 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 6 | 2.58 | North | 1 | 13.31 | East | Noon | 24.00 | 24.00 | 0.00 | 9856.82 | | |
| 37 | 2022/01/23 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 6 | 2.58 | North | 1 | 13.33 | East | Noon | 24.00 | 24.00 | 0.00 | 9856.82 | | |
| 38 | 2022/01/24 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 6 | 1.83 | North | 1 | 12.61 | East | Noon | 24.00 | 24.00 | 0.00 | 9856.82 | | |
| 39 | 2022/01/25 | 12:00 | Lagos-NGLOS | Lome-TGLFW | 5 | 58.75 | North | 1 | 14.13 | East | Noon | 24.00 | 24.00 | 0.00 | 12412.94 | | |
| 40 | 2022/01/25 | 19:18 | Lome-TGLFW | Saldanha Bay-ZASDB | 5 | 55.85 | North | 1 | 15.08 | East | Departure | 7.30 | 0.00 | 0.00 | 12412.94 | | |
| 41 | 2022/01/26 | 12:00 | Lome-TGLFW | Saldanha Bay-ZASDB | 2 | 2.58 | North | 2 | 47.62 | East | Noon | 16.70 | 0.00 | 260.00 | 12412.94 | | |
| 42 | 2022/01/27 | 12:00 | Lome-TGLFW | Saldanha Bay-ZASDB | 3 | 7.23 | South | 4 | 44.49 | East | Noon | 23.00 | 0.00 | 330.00 | 12412.94 | | |
| 43 | 2022/01/28 | 12:00 | Lome-TGLFW | Saldanha Bay-ZASDB | 8 | 29.52 | South | 6 | 44.90 | East | Noon | 24.00 | 0.00 | 343.00 | 12412.94 | | |
| 44 | 2022/01/29 | 12:00 | Lome-TGLFW | Saldanha Bay-ZASDB | 13 | 44.92 | South | 8 | 44.58 | East | Noon | 23.00 | 0.00 | 336.00 | 12412.94 | | |
| 45 | 2022/01/30 | 12:00 | Lome-TGLFW | Saldanha Bay-ZASDB | 19 | 12.32 | South | 10 | 43.51 | East | Noon | 24.00 | 0.00 | 345.00 | 12412.94 | | |
| 46 | 2022/01/31 | 12:00 | Lome-TGLFW | Saldanha Bay-ZASDB | 24 | 58.95 | South | 12 | 31.67 | East | Noon | 24.00 | 0.00 | 340.00 | 12412.94 | | |
| 47 | 2022/02/01 | 12:00 | Lome-TGLFW | Saldanha Bay-ZASDB | 30 | 0.10 | South | 14 | 55.71 | East | Noon | 24.00 | 0.00 | 348.00 | 12412.94 | | |
| 48 | 2022/02/02 | 03:30 | Lome-TGLFW | Saldanha Bay-ZASDB | 33 | 2.75 | South | 17 | 41.81 | East | Arrival | 15.30 | 0.00 | 234.00 | 12412.94 | | |
| 49 | 2022/02/02 | 12:00 | Lome-TGLFW | Saldanha Bay-ZASDB | 33 | 1.95 | South | 17 | 59.68 | East | Noon | 8.50 | 0.00 | 0.00 | 12412.94 | | |
| 50 | 2022/02/03 | 12:00 | Lome-TGLFW | Saldanha Bay-ZASDB | 33 | 1.95 | South | 17 | 59.68 | East | Noon | 24.00 | 0.00 | 0.00 | 9353.05 | | |
| 51 | 2022/02/03 | 16:00 | Saldanha Bay-ZASDB | Lome-TGLFW | 33 | 3.95 | South | 17 | 48.12 | East | Departure | 4.00 | 0.00 | 0.00 | 9097.36 | | |

| 6 | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | Machinery | | | | | | | | | | | ROB | | | | | | | | | |
| 8 | Total Fuel consumption | | | | | | | | | | | Remaining on board | | | | | | | | | |
| 9 | HFO | LFO | MGO | MDO | LPG | LNG | Methanol | Ethanol | Other fuel consumptio | Other fuel type | Other fuel | HFO | LFO | MGO | MDO | LPG | LNG | Methanol | Ethanol | Other fuel | Other fuel type |
| 10 | mt | mt | mt | mt | mt | mt | mt | mt | mt | (txt) | (nr) | mt | mt | mt | mt | mt | mt | mt | mt | mt | (txt) |
| 11 | 0.00 | 4.51 | 0.00 | | | | | | | | | 0.00 | 96.51 | 287.73 | | | | | | | |
| 12 | 0.00 | 2.46 | 0.00 | | | | | | | | | 0.00 | 96.05 | 287.73 | | | | | | | |
| 13 | 0.00 | 20.09 | 0.00 | | | | | | | | | 0.00 | 75.96 | 287.73 | | | | | | | |
| 14 | 0.00 | 7.35 | 0.00 | | | | | | | | | 0.00 | 68.61 | 287.73 | | | | | | | |
| 15 | 0.00 | 3.47 | 0.00 | | | | | | | | | 0.00 | 65.14 | 287.73 | | | | | | | |
| 16 | 0.00 | 3.91 | 0.00 | | | | | | | | | 0.00 | 61.23 | 287.73 | | | | | | | |
| 17 | 0.00 | 3.93 | 0.00 | | | | | | | | | 0.00 | 57.30 | 287.73 | | | | | | | |
| 18 | 0.00 | 4.05 | 0.00 | | | | | | | | | 0.00 | 53.25 | 287.73 | | | | | | | |
| 19 | 0.00 | 4.15 | 0.00 | | | | | | | | | 0.00 | 49.10 | 287.73 | | | | | | | |
| 20 | 0.00 | 4.72 | 0.00 | | | | | | | | | 0.00 | 44.38 | 287.73 | | | | | | | |
| 21 | 0.00 | 3.80 | 0.00 | | | | | | | | | 0.00 | 40.58 | 287.73 | | | | | | | |
| 22 | 0.00 | 4.02 | 0.00 | | | | | | | | | 0.00 | 36.56 | 287.73 | | | | | | | |
| 23 | 0.00 | 3.54 | 0.00 | | | | | | | | | 0.00 | 33.02 | 287.73 | | | | | | | |
| 24 | 0.00 | 3.86 | 0.00 | | | | | | | | | 0.00 | 29.16 | 287.73 | | | | | | | |
| 25 | 0.00 | 3.51 | 0.00 | | | | | | | | | 0.00 | 25.65 | 287.73 | | | | | | | |
| 26 | 0.00 | 3.68 | 0.00 | | | | | | | | | 0.00 | 21.97 | 287.73 | | | | | | | |
| 27 | 0.00 | 4.74 | 0.00 | | | | | | | | | 0.00 | 17.23 | 287.73 | | | | | | | |
| 28 | 0.00 | 2.47 | 0.00 | | | | | | | | | 0.00 | 14.76 | 287.73 | | | | | | | |
| 29 | 0.00 | 12.28 | 0.00 | | | | | | | | | 0.00 | 2.48 | 287.73 | | | | | | | |
| 30 | 0.00 | 0.00 | 1.05 | | | | | | | | | 0.00 | 2.48 | 286.68 | | | | | | | |
| 31 | 0.00 | 0.00 | 5.74 | | | | | | | | | 552.48 | 0.00 | 280.94 | | | | | | | |
| 32 | 0.00 | 0.00 | 6.34 | | | | | | | | | 552.48 | 0.00 | 274.60 | | | | | | | |
| 33 | 0.00 | 0.00 | 4.63 | | | | | | | | | 552.48 | 0.00 | 269.97 | | | | | | | |
| 34 | 0.00 | 0.00 | 5.00 | | | | | | | | | 552.48 | 0.00 | 264.97 | | | | | | | |
| 35 | 0.00 | 0.00 | 4.83 | | | | | | | | | 552.48 | 0.00 | 260.14 | | | | | | | |
| 36 | 0.00 | 0.00 | 4.38 | | | | | | | | | 552.48 | 0.00 | 255.76 | | | | | | | |
| 37 | 0.00 | 0.00 | 3.99 | | | | | | | | | 552.48 | 0.00 | 251.77 | | | | | | | |
| 38 | 0.00 | 0.00 | 4.18 | | | | | | | | | 552.48 | 0.00 | 247.59 | | | | | | | |
| 39 | 0.00 | 0.00 | 6.45 | | | | | | | | | 552.48 | 0.00 | 241.14 | | | | | | | |
| 40 | 0.00 | 0.00 | 1.43 | | | | | | | | | 552.48 | 0.00 | 239.71 | | | | | | | |
| 41 | 0.00 | 0.00 | 21.05 | | | | | | | | | 552.48 | 0.00 | 218.66 | | | | | | | |
| 42 | 0.00 | 0.00 | 30.71 | | | | | | | | | 552.48 | 0.00 | 187.95 | | | | | | | |
| 43 | 0.00 | 0.00 | 31.78 | | | | | | | | | 552.48 | 0.00 | 156.17 | | | | | | | |
| 44 | 0.00 | 0.00 | 30.62 | | | | | | | | | 552.48 | 0.00 | 125.55 | | | | | | | |
| 45 | 0.00 | 0.00 | 32.62 | | | | | | | | | 552.48 | 0.00 | 92.93 | | | | | | | |
| 46 | 0.00 | 0.00 | 31.75 | | | | | | | | | 552.48 | 0.00 | 61.18 | | | | | | | |
| 47 | 0.00 | 0.00 | 32.46 | | | | | | | | | 552.48 | 0.00 | 28.72 | | | | | | | |
| 48 | 21.45 | 0.00 | 0.00 | | | | | | | | | 531.03 | 0.00 | 28.72 | | | | | | | |
| 49 | 2.61 | 0.00 | 0.00 | | | | | | | | | 528.42 | 0.00 | 28.72 | | | | | | | |
| 50 | 5.81 | 0.00 | 0.00 | | | | | | | | | 522.61 | 0.00 | 28.72 | | | | | | | |
| 51 | 1.40 | 0.00 | 0.00 | | | | | | | | | 521.21 | 0.00 | 28.72 | | | | | | | |

| | A | B | C | D | N | O | P | Q | R | S | T |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mandatory data fields | | | | | | | | | | |
| 2 | Date | Time | Voyage | | Distance | Cargo | | | Machinery | | |
| 3 | | | From | To | Distance sailed | Weight of cargo or deadweight | Volume | Passengers | Total Fuel consumption | | |
| 4 | | | double click to view the list | double click to view the list | | | | | HFO | LFO | MGO |
| 5 | UTC yyyy-mm-dd | UTC hh:mm | UN / LOCODE | UN / LOCODE | nm | mt | m3 | nr | mt | mt | mt |
| 441 | 2022/12/28 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 5104.47 | | | 6.13 | 0.00 | 0.00 |
| 442 | 2022/12/29 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 2570.94 | | | 6.18 | 0.00 | 0.00 |
| 443 | 2022/12/30 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 92.00 | | | 6.16 | 0.00 | 0.00 |
| 444 | 2022/12/30 | 10:30 | AQABA=JOAQB | SUEZ=EGSUZ | 6.07 | 92.00 | | | 0.89 | 0.00 | 0.00 |
| 445 | 2022/12/31 | 03:48 | AQABA=JOAQB | SUEZ=EGSUZ | 272.00 | 92.00 | | | 20.50 | 0.00 | 0.00 |
| 446 | 2022/12/31 | 10:00 | AQABA=JOAQB | SUEZ=EGSUZ | 0.00 | 1178.20 | | | 3.72 | 0.00 | 0.00 |
| 447 | 2023/01/01 | 06:36 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 12531.04 | | | 4.84 | 0.00 | 0.00 |
| 448 | 2023/01/01 | 10:00 | SUEZ=EGSUZ | AQABA=JOAQB | 51.00 | 12531.04 | | | 4.16 | 0.00 | 0.00 |
| 449 | 2023/01/02 | 00:36 | SUEZ=EGSUZ | AQABA=JOAQB | 238.00 | 12531.04 | | | 17.31 | 0.00 | 0.00 |
| 450 | 2023/01/02 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 12531.04 | | | 1.59 | 0.00 | 0.00 |
| 451 | 2023/01/03 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 19.00 | 12531.04 | | | 4.08 | 0.00 | 0.00 |
| 452 | 2023/01/04 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 19.70 | 12531.04 | | | 4.32 | 0.00 | 0.00 |
| 453 | 2023/01/05 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 10485.24 | | | 5.68 | 0.00 | 0.00 |
| 454 | 2023/01/06 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 8057.77 | | | 5.97 | 0.00 | 0.00 |
| 455 | 2023/01/07 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 5588.64 | | | 5.96 | 0.00 | 0.00 |
| 456 | 2023/01/08 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 3175.61 | | | 6.03 | 0.00 | 0.00 |
| 457 | 2023/01/09 | 09:00 | AQABA=JOAQB | SUEZ=EGSUZ | 0.00 | 92.00 | | | 6.07 | 0.00 | 0.00 |
| 458 | 2023/01/09 | 11:48 | AQABA=JOAQB | SUEZ=EGSUZ | 6.00 | 92.00 | | | 0.63 | 0.00 | 0.00 |
| 459 | 2023/01/10 | 05:06 | AQABA=JOAQB | SUEZ=EGSUZ | 273.00 | 92.00 | | | 19.85 | 0.00 | 0.00 |
| 460 | 2023/01/10 | 10:00 | AQABA=JOAQB | SUEZ=EGSUZ | 0.00 | 954.62 | | | 0.59 | 0.00 | 0.00 |
| 461 | 2023/01/11 | 06:36 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 12641.99 | | | 6.75 | 0.00 | 0.00 |
| 462 | 2023/01/11 | 10:00 | SUEZ=EGSUZ | AQABA=JOAQB | 53.00 | 12641.99 | | | 3.19 | 0.00 | 0.00 |
| 463 | 2023/01/12 | 00:36 | SUEZ=EGSUZ | AQABA=JOAQB | 236.00 | 12641.99 | | | 17.29 | 0.00 | 0.00 |
| 464 | 2023/01/12 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 12641.99 | | | 2.00 | 0.00 | 0.00 |
| 465 | 2023/01/13 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 11.34 | 12641.99 | | | 5.06 | 0.00 | 0.00 |
| 466 | 2023/01/14 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 10855.81 | | | 5.43 | 0.00 | 0.00 |
| 467 | 2023/01/15 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 8331.40 | | | 6.03 | 0.00 | 0.00 |
| 468 | 2023/01/16 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 5592.92 | | | 6.09 | 0.00 | 0.00 |
| 469 | 2023/01/17 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 2477.48 | | | 6.40 | 0.00 | 0.00 |
| 470 | 2023/01/18 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 93.00 | | | 6.24 | 0.00 | 0.00 |
| 471 | 2023/01/18 | 12:30 | AQABA=JOAQB | SUEZ=EGSUZ | 0.00 | 93.00 | | | 1.43 | 0.00 | 0.00 |
| 472 | 2023/01/19 | 04:54 | AQABA=JOAQB | SUEZ=EGSUZ | 274.00 | 93.00 | | | 20.11 | 0.00 | 0.00 |
| 473 | 2023/01/19 | 10:00 | AQABA=JOAQB | SUEZ=EGSUZ | 0.00 | 745.02 | | | 1.73 | 0.00 | 0.00 |
| 474 | 2023/01/20 | 06:30 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 12537.23 | | | 6.53 | 0.00 | 0.00 |
| 475 | 2023/01/20 | 10:00 | SUEZ=EGSUZ | AQABA=JOAQB | 57.00 | 12537.23 | | | 3.74 | 0.00 | 0.00 |
| 476 | 2023/01/21 | 00:30 | SUEZ=EGSUZ | AQABA=JOAQB | 231.00 | 12537.23 | | | 17.64 | 0.00 | 0.00 |
| 477 | 2023/01/21 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 12537.23 | | | 2.38 | 0.00 | 0.00 |
| 478 | 2023/01/22 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 8.50 | 12537.23 | | | 3.92 | 0.00 | 0.00 |
| 479 | 2023/01/23 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 10722.94 | | | 5.32 | 0.00 | 0.00 |
| 480 | 2023/01/24 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 8669.57 | | | 5.14 | 0.00 | 0.00 |
| 481 | 2023/01/25 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 6565.95 | | | 5.64 | 0.00 | 0.00 |
| 482 | 2023/01/26 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 4303.19 | | | 5.76 | 0.00 | 0.00 |
| 483 | 2023/01/27 | 09:00 | SUEZ=EGSUZ | AQABA=JOAQB | 0.00 | 1810.21 | | | 5.69 | 0.00 | 0.00 |
| 484 | 2023/01/28 | 03:42 | AQABA=JOAQB | SUEZ=EGSUZ | 0.00 | 93.00 | | | 4.68 | 0.00 | 0.00 |
| 485 | 2023/01/28 | 09:00 | AQABA=JOAQB | SUEZ=EGSUZ | 72.00 | 93.00 | | | 5.70 | 0.00 | 0.00 |
| 486 | 2023/01/29 | 22:54 | AQABA=JOAQB | SUEZ=EGSUZ | 221.00 | 93.00 | | | 13.88 | 0.00 | 0.00 |
| 487 | 2023/01/29 | 06:18 | AQABA=JOAQB | SUEZ=EGSUZ | 0.00 | 93.00 | | | 1.11 | 0.00 | 0.00 |

| | U | V | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH | AI | AJ | AK | AL | AM | AN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | | | | | | Data fields voluntary | |
| 2 | | | | | | | | | ROB | | | | | | | | | | Duration | Distance |
| 3 | | | | | | | | | Remaining on board | | | | | | | | | | | |
| 4 | MDO | LPG | LNG | Methanol | Ethanol | Other fuel consumption | Other fuel type | Other fuel emission | HFO | LFO | MGO | MDO | LPG | LNG | Methanol | Ethanol | Other fuel | Other fuel type | Time spent in Ice | Distance sailed in ice |
| 5 | mt | mt | mt | mt | mt | mt | (txt) | (nr) | mt | mt | mt | mt | mt | mt | mt | mt | mt | (txt) | h | NM |
| 441 | | | | | | | | | 717.01 | 0.00 | 279.27 | | | | | | | | | |
| 442 | | | | | | | | | 710.83 | 0.00 | 279.27 | | | | | | | | | |
| 443 | | | | | | | | | 704.67 | 0.00 | 279.27 | | | | | | | | | |
| 444 | | | | | | | | | 703.78 | 0.00 | 279.27 | | | | | | | | | |
| 445 | | | | | | | | | 663.28 | 0.00 | 279.27 | | | | | | | | | |
| 446 | | | | | | | | | 679.56 | 0.00 | 279.27 | | | | | | | | | |
| 447 | | | | | | | | | 674.72 | 0.00 | 279.27 | | | | | | | | | |
| 448 | | | | | | | | | 670.56 | 0.00 | 279.27 | | | | | | | | | |
| 449 | | | | | | | | | 653.25 | 0.00 | 279.27 | | | | | | | | | |
| 450 | | | | | | | | | 651.66 | 0.00 | 279.27 | | | | | | | | | |
| 451 | | | | | | | | | 647.85 | 0.00 | 279.27 | | | | | | | | | |
| 452 | | | | | | | | | 643.26 | 0.00 | 279.27 | | | | | | | | | |
| 453 | | | | | | | | | 637.58 | 0.00 | 279.27 | | | | | | | | | |
| 454 | | | | | | | | | 631.61 | 0.00 | 279.27 | | | | | | | | | |
| 455 | | | | | | | | | 625.65 | 0.00 | 279.27 | | | | | | | | | |
| 456 | | | | | | | | | 619.62 | 0.00 | 279.27 | | | | | | | | | |
| 457 | | | | | | | | | 613.55 | 0.00 | 279.27 | | | | | | | | | |
| 458 | | | | | | | | | 612.92 | 0.00 | 279.27 | | | | | | | | | |
| 459 | | | | | | | | | 592.72 | 0.00 | 279.27 | | | | | | | | | |
| 460 | | | | | | | | | 592.13 | 0.00 | 279.27 | | | | | | | | | |
| 461 | | | | | | | | | 585.38 | 0.00 | 279.27 | | | | | | | | | |
| 462 | | | | | | | | | 582.19 | 0.00 | 279.27 | | | | | | | | | |
| 463 | | | | | | | | | 564.90 | 0.00 | 279.27 | | | | | | | | | |
| 464 | | | | | | | | | 562.90 | 0.00 | 279.27 | | | | | | | | | |
| 465 | | | | | | | | | 557.84 | 0.00 | 279.27 | | | | | | | | | |
| 466 | | | | | | | | | 552.41 | 0.00 | 279.27 | | | | | | | | | |
| 467 | | | | | | | | | 546.38 | 0.00 | 279.27 | | | | | | | | | |
| 468 | | | | | | | | | 540.29 | 0.00 | 279.27 | | | | | | | | | |
| 469 | | | | | | | | | 533.89 | 0.00 | 279.27 | | | | | | | | | |
| 470 | | | | | | | | | 527.65 | 0.00 | 279.27 | | | | | | | | | |
| 471 | | | | | | | | | 526.22 | 0.00 | 279.27 | | | | | | | | | |
| 472 | | | | | | | | | 506.11 | 0.00 | 279.27 | | | | | | | | | |
| 473 | | | | | | | | | 504.38 | 0.00 | 279.27 | | | | | | | | | |
| 474 | | | | | | | | | 497.85 | 0.00 | 279.27 | | | | | | | | | |
| 475 | | | | | | | | | 494.11 | 0.00 | 279.27 | | | | | | | | | |
| 476 | | | | | | | | | 476.47 | 0.00 | 279.27 | | | | | | | | | |
| 477 | | | | | | | | | 474.09 | 0.00 | 279.27 | | | | | | | | | |
| 478 | | | | | | | | | 470.17 | 0.00 | 279.27 | | | | | | | | | |
| 479 | | | | | | | | | 464.85 | 0.00 | 279.27 | | | | | | | | | |
| 480 | | | | | | | | | 459.71 | 0.00 | 279.27 | | | | | | | | | |
| 481 | | | | | | | | | 454.07 | 0.00 | 279.27 | | | | | | | | | |
| 482 | | | | | | | | | 448.31 | 0.00 | 279.27 | | | | | | | | | |
| 483 | | | | | | | | | 442.62 | 0.00 | 279.27 | | | | | | | | | |
| 484 | | | | | | | | | 437.93 | 0.00 | 279.27 | | | | | | | | | |
| 485 | | | | | | | | | 432.23 | 0.00 | 279.27 | | | | | | | | | |
| 486 | | | | | | | | | 418.35 | 0.00 | 279.27 | | | | | | | | | |
| 487 | | | | | | | | | 417.24 | 0.00 | 279.27 | | | | | | | | | |

The noon report is used to analyze the following parameters and performance:

– Consumption of fuel and lube on daily basis
– Total weight of cargo carried
– Distance covered from last port
– Distance to be covered for next port of call
– Time taken to complete the passage
– Time taken for port operation

– To order fuel/ lube oil as required
– To order fresh water as required
– To calculate the Energy Efficiency Operation Indicator

Example from DCS datasheets used for the CII calculations in the case studies.

| REPORTED DATA | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Start Date and Time (dd/MM/yyyy HH:mm UTC) | End Date and Time (dd/MM/yyyy HH:mm UTC) | Distance Traveled (nm) | Hours Underway | Loading State (L/B) | Exceptional Conditions (Y/N) | Sailing in Ice Conditions (Y/N) | STS Operation | Fuel Consumption (mt) | | |
| | | | | | | | | HFO | Diesel/Gas | |
| 02/01/2023 15:00 | 03/01/2023 17:00 | 293.000 | 25:00 | | N | N | N | 0.000 | 41.000 | |
| 03/01/2023 17:00 | 04/01/2023 17:00 | 246.000 | 22:00 | | N | N | N | 0.000 | 27.600 | |
| 04/01/2023 17:00 | 05/01/2023 17:00 | 0.000 | 02:00 | | N | N | N | 0.000 | 0.700 | |
| 05/01/2023 17:00 | 06/01/2023 17:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 3.000 | |
| 06/01/2023 17:00 | 07/01/2023 02:18 | 0.000 | 24:00 | | N | N | N | 0.000 | 3.000 | |
| 07/01/2023 02:18 | 08/01/2023 17:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 08/01/2023 17:00 | 09/01/2023 17:00 | 0.000 | 14:18 | | N | N | N | 0.000 | 5.250 | |
| 09/01/2023 17:00 | 10/01/2023 17:00 | 118.000 | 09:42 | | N | N | N | 0.000 | 9.000 | |
| 10/01/2023 17:00 | 11/01/2023 17:00 | 298.000 | 24:00 | | N | N | N | 17.200 | 8.300 | |
| 11/01/2023 17:00 | 12/01/2023 18:00 | 307.000 | 24:00 | | N | N | N | 27.500 | 0.000 | |
| 12/01/2023 18:00 | 13/01/2023 18:00 | 301.000 | 24:00 | | N | N | N | 30.000 | 0.000 | |
| 13/01/2023 18:00 | 14/01/2023 18:00 | 288.000 | 25:00 | | N | N | N | 24.350 | 0.000 | |
| 14/01/2023 18:00 | 15/01/2023 14:54 | 295.000 | 24:00 | | N | N | N | 29.500 | 0.000 | |
| 15/01/2023 14:54 | 16/01/2023 18:00 | 325.000 | 24:00 | | N | N | N | 24.400 | 4.930 | |
| 16/01/2023 18:00 | 17/01/2023 18:00 | 230.000 | 20:54 | | N | N | N | 0.000 | 29.500 | |
| 17/01/2023 18:00 | 18/01/2023 18:00 | 0.000 | 03:00 | | N | N | N | 0.000 | 1.500 | |
| 18/01/2023 18:00 | 19/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 19/01/2023 18:00 | 20/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 3.940 | |
| 20/01/2023 18:00 | 21/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 21/01/2023 18:00 | 22/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 22/01/2023 18:00 | 23/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 23/01/2023 18:00 | 24/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 24/01/2023 18:00 | 25/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 25/01/2023 18:00 | 26/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 26/01/2023 18:00 | 27/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 27/01/2023 18:00 | 28/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 7.700 | |
| 28/01/2023 18:00 | 29/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 0.000 | |
| 29/01/2023 18:00 | 30/01/2023 18:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 6.500 | |
| 30/01/2023 18:00 | 31/01/2023 17:00 | 0.000 | 24:00 | | N | N | N | 0.000 | 6.500 | |
| 31/01/2023 17:00 | 01/02/2023 17:00 | 300.000 | 24:00 | | N | N | N | 0.000 | 38.000 | |
| 01/02/2023 17:00 | 02/02/2023 17:00 | 258.000 | 23:00 | | N | N | N | 29.290 | 3.160 | |
| 02/02/2023 17:00 | 03/02/2023 17:00 | 297.000 | 24:00 | | N | N | N | 37.000 | 0.000 | |
| 03/02/2023 17:00 | 04/02/2023 16:00 | 315.000 | 24:00 | | N | N | N | 37.000 | 0.000 | |
| 04/02/2023 16:00 | 05/02/2023 16:00 | 280.000 | 24:00 | | N | N | N | 37.000 | 0.000 | |
| 05/02/2023 16:00 | 06/02/2023 15:00 | 277.000 | 23:00 | | N | N | N | 35.500 | 0.000 | |
| 06/02/2023 15:00 | 07/02/2023 15:00 | 282.000 | 24:00 | | N | N | N | 37.000 | 0.000 | |
| 07/02/2023 15:00 | 08/02/2023 14:00 | 280.000 | 23:00 | | N | N | N | 36.000 | 0.000 | |
| 08/02/2023 14:00 | 09/02/2023 13:00 | 278.000 | 24:00 | | N | N | N | 37.000 | 0.000 | |
| 09/02/2023 13:00 | 10/02/2023 13:00 | 274.000 | 23:00 | | N | N | N | 36.000 | 0.000 | |
| 10/02/2023 13:00 | 11/02/2023 13:00 | 272.000 | 23:00 | | N | N | N | 36.000 | 0.000 | |
| 11/02/2023 13:00 | 12/02/2023 12:00 | 279.000 | 24:00 | | N | N | N | 37.000 | 0.000 | |
| 12/02/2023 12:00 | 13/02/2023 12:00 | 276.000 | 24:00 | | N | N | N | 37.000 | 0.000 | |
| 13/02/2023 12:00 | 14/02/2023 11:00 | 262.000 | 23:00 | | N | N | N | 36.000 | 0.000 | |
| 14/02/2023 11:00 | 15/02/2023 10:12 | 263.000 | 24:00 | | N | N | N | 37.000 | 0.000 | |
| 15/02/2023 10:12 | 16/02/2023 11:00 | 258.000 | 23:00 | | N | N | N | 36.000 | 0.000 | |
| 16/02/2023 11:00 | 17/02/2023 11:00 | 267.000 | 23:12 | | N | N | N | 36.000 | 0.280 | |
| 17/02/2023 11:00 | 18/02/2023 11:00 | 0.000 | 00:48 | | N | N | N | 0.000 | 0.900 | |

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