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Insights into Maritime Shipping's Carbon Footprint

Assessing the State of Carbon Dioxide Emissions in Maritime Shipping Through Big Data Analysis

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Abstract

This is the abstract.

Acknowledgements

I would like to thank...

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Chapter 1

Introduction

1.1 Background and Motivation

In the 21st century, Climate change is the biggest challenge faced by humanity. It poses a substantial danger to the survival of the inhabitants of our planet. Human activities such as deforestation and burning of fossil fuels have led to a rise in global temperatures. Becuase of this rise, there has been a rise in sea levels, extreme weather events, and loss of biodiversity. There is an urgent need to reduce greenhouse gas emissions and transition to a sustainable, low-carbon future.

Maritime is essential to the global economy, transporting 90% of the world's goods by volume. It is also a major source of greenhouse gas emissions, with the International Maritime Organization (IMO) estimating that maritime shipping accounts for 3% of global carbon dioxide emissions. While 3% may seem small, it is important to note that this is a rapidly growing sector. Without action, maritime shipping contribution to carbon emissions can increase upto 10-13% in the next few decades.. Due to this fact, there is a growing global effort to reduce emissions from this sector. (King, 2022).

In accordance with sustainable Development Goal 13, in 2018, the inital stratergy was adopted by IMO's Environmental Protection Committee (MEPC), during its 72nd session at IMO Headquarters in London, United Kingdom. Accorging to this stratergy, the IMO will work towards reducing the total annual greenhouse gas emissions from international shipping by at least 50% by 2050 compared to 2008 ("UN body adopts climate change strategy for shipping", 2018). In 76th ssssion MEPC in 2021, serval mandatory measures were adopted to reduce greenhouse gas emissions from international shipping, which will help in achieving the goal of reducing emissions by 50% by 2050 ("UN body adopts climate change strategy for shipping", n.d.). One of the important measures is the carbon intensity indicator (CII).

Maritime shipping is a complex and highly volatile system, generating very large data sets. Big data analytics can be used to understand the complex system and make informed decisions. It can facilitate operations such as monitoring of emission and predictive analysis of vessel performance. This can help in reducing emissions and improving the efficiency of

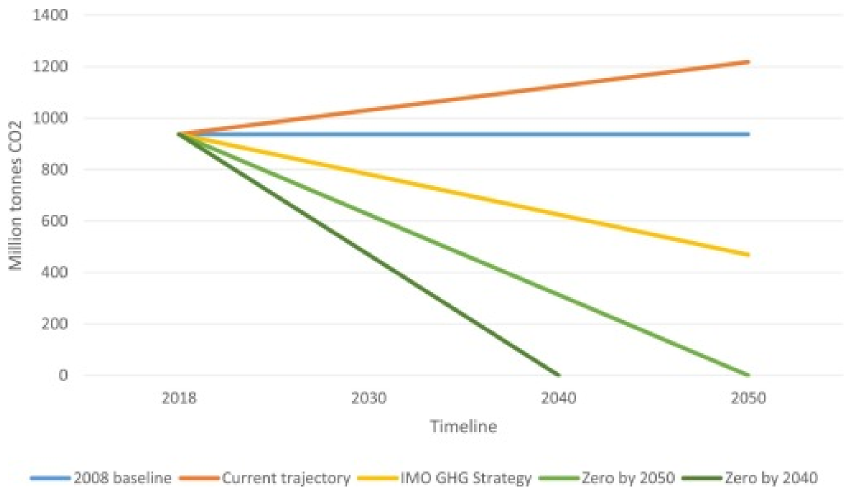

Figure 1.1: Emission trajectories for different levels of ambition for emission reduction targets

the maritime sector (Zaman et al., 2017).

1.2 Big Data Analysis

Big data analytics is where advanced analytic techniques operate on big data sets. Hence, big data analytics is really about two things — *big data* and *analytics*.

1.2.1 Big Data

As the name suggests, big data is a large amount of data. There are other important attributes of big data. These are: data variety and data velocity.

Thus we can define big data using 3 V's: *volume*, *variety*, and *velocity* as showin in figure 1.2.

Beyond these three V's, Big Data is also about how complicated the computing problem is. Given the number of variables and number of data points for analysing the maritime shipping data. It is a very complicated problem. Thus, in addition to the three V's identified by IBM, it would also be necessary to take complexity into account as shown in figure 1.3 (Pence, 2014).

1.2.2 What is Big Data Analytics?

Big data analytics is the process of examining large and varied data sets to uncover hidden patterns, unknown correlations, market trends, customer preferences and other useful information that can help organizations make more-informed business decisions.

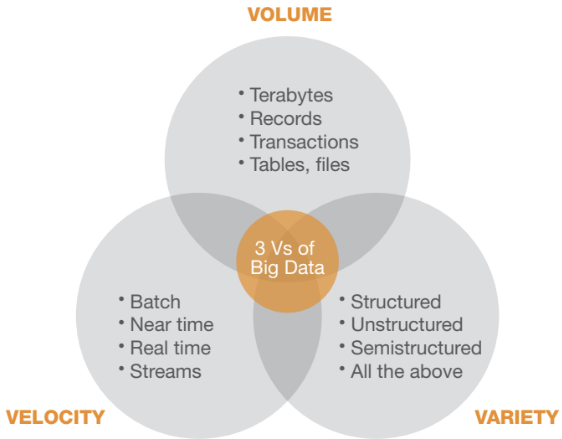

Figure 1.2: Big Data: 3 V's (Lukoianove & Rubin, 2013)

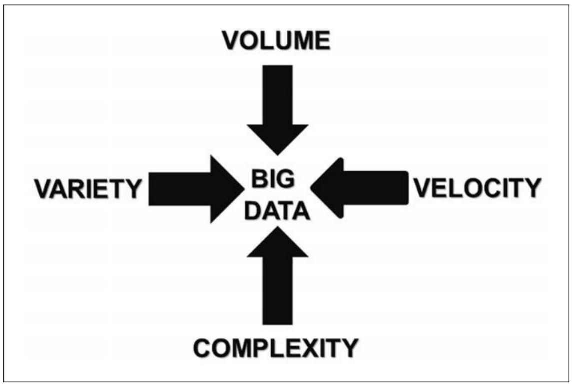

Figure 1.3: Big Data: Beyong 3 V's - volume, velocity, variety, and complexity

1.3 Indicators

Indicators play a crucial role in assessing and monitoring carbon emissions in the maritime shipping industry. They provide valuable insights into the environmental performance of vessels, facilitate comparisons between different ships or fleets, and help track progress towards emission reduction targets. By measuring various aspects of emissions and energy efficiency, these indicators enable stakeholders to identify opportunities for improvement and implement effective strategies to mitigate the environmental impact of shipping operations.

In this section, we will discuss several key indicators commonly used in the monitoring and evaluation of carbon emissions in maritime shipping. These indicators cover a range of factors, including carbon intensity, energy efficiency, fuel consumption, and cargo transport work. Each indicator offers a unique perspective on emissions, providing researchers, policymakers, and industry stakeholders with valuable information to support decision-making and foster sustainable practices.

It is important to note that the selection and use of indicators may vary depending on the specific research objectives, data availability, and regulatory frameworks in place. The combination of different indicators allows for a comprehensive assessment of emissions and enables a deeper understanding of the efficiency and environmental performance of shipping activities.

Below is the list of indicators discussed in this section:

1. Carbon Intensity Indicator (CII)
2. Energy Efficiency Operational Indicator (EEOI)
3. Energy Efficiency Design Index (EEDI)
4. Energy Efficiency eXisting ship Index (EEXI)

1.3.1 Carbon Intensity Indicator (CII)

The International Maritime Organization (IMO) has introduced a new carbon intensity (CII) measure for ships, which is a more accurate way to evaluate a vessel's environmental impact than total carbon emissions. CII is calculated using the Annual Efficiency Ratio (AER) formula, taking into account a ship's fuel consumption, CO2 emission factor, annual distance sailed, and design deadweight.

To calculate CII in the most basic form:

$$\text{CII} = \frac{\text{Carbon Emission}}{\text{Distance Travelled} \times \text{Cargo Capacity}} \tag{1.1}$$

Vessels are rated A to E based on their CII results, and those with a D or E rating for three consecutive years or an E rating in one year must submit a corrective action plan. The IMO will enforce CII regulations for all ships over 5,000 GT and require an enhanced Ship Energy Efficiency Management Plan (SEEMP) with CII-related content from January 2023. The SEEMP must include the ship's required annual operational CII target and an implementation plan to achieve it over the next three years. (Chuah, Mokhtar, Ruslan, et al., 2023).

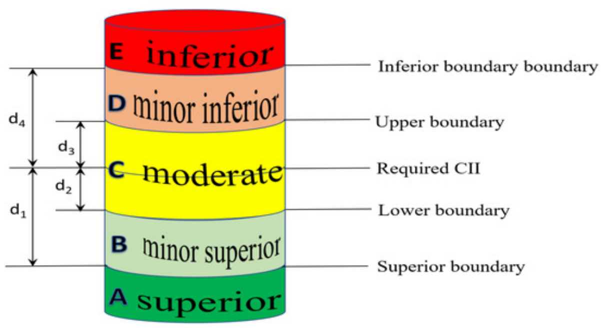

Figure 1.4: Schematic diagram of the CII ratings and boundaries. (Tsai & Lin, 2023)

The article Rodriguez et al., 2020, discusses the increasing popularity of Energy and Carbon Intensity indicators among policy makers, which are calculated as units of energy or mass of emissions per unit of Gross Domestic Product (GDP). These indicators are gaining momentum due to support from think tanks, public organizations, consulting groups, and academics focused on energy and climate change policy development. The ways in which intensity indicators are framed and perceived in public debates generated by these intermediaries are important as they can influence policy making and the development of better sets of indicators to assess how well countries are addressing climate change and resource efficiency policies. Intensity indicators are appealing for emerging economies as they are not incompatible with high rates of economic growth and do not imply the imposition of absolute emission/energy caps.

1.3.2 Energy Efficiency Operational Indicator (EEOI)

The Energy Efficiency Operational Indicator (EEOI) is a tool used to measure the CO2 gas emissions per unit of transport work, indicating the operational efficiency of a ship. The EEOI is calculated annually and is subject to changes after each voyage due to various external factors, such as navigation conditions, sea area, weather, temperature, and cargo weight.

The EEOI provides an accurate measure for each voyage, and its unit depends on the type of cargo or transport work, such as tons CO2/(tons/nautical miles), tons CO2/(TEU/nautical miles), or tons CO2/(person/nautical miles). The formula for calculating the EEOI is represented by formula (1.2), where a lower value indicates a more energy-efficient ship (Prill et al., 2020).

$$\text{EEOI} = \frac{\text{Carbon Emission}}{\text{Performed Transport Work}} \tag{1.2}$$

For the calculation of EEOI for a specific voyage, formula (1.3) is used.

$$\text{EEOI} = \frac{\sum_j F_{Cj} \cdot C_{Fj}}{m_{\text{cargo}} \cdot D_j} \tag{1.3}$$

However, when dealing with a large number of ships, formula (1.3) is expressed as equation (1.4), taking into account parameters such as fuel type, voyage number, fuel consumption, fuel-to-CO2 conversion factor, cargo weight, and distance traveled (Tran, 2017).

$$\text{Average}_{\text{EEOI}} = \frac{\sum_i \sum_j (F_{C_i} \cdot C_{F_j})}{\sum_i (m_{\text{cargo},i} \cdot D_i)} \tag{1.4}$$

where:

j : Fuel type used
i : Navigation voyage number
FC_{ij} : Mass of consumed fuel j at voyage i
CF_j : Fuel mass to CO2 mass conversion factor with fuel j
m_{cargo} : Weight of cargo carried (tons) on ship
D_i : Distance of voyage i (nautical miles)

The fuel-to-CO2 conversion factor (CF) is a non-dimensional factor that converts fuel consumption, measured in grams, to CO2 gas emissions, also measured in grams, based on the carbon content. The below table

1.1 is showed the certain value of CF follows the type of fuel.

No.	Type of fuel	Reference	Carbon content	CF (t-CO2/t-Fuel)
1	Diesel/gas oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2	Light fuel oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3	Heavy fuel oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
4	Liquefied petroleum gas (LPG)	Propane, butane	0.819, 0.827	3.000000, 3.030000
5	Liquefied natural gas (LNG)		0.75	2.750000

Table 1.1: The value of CF (t-CO2/t-Fuel) (Tran, 2017).

1.3.3 Energy Efficiency Design Index (EEDI)

Energy Efficiency Design Index (EEDI) is a legislation proposed by the International Maritime Organization (IMO) to estimate the energy efficiency of ships and calculate their CO2 emissions per unit of transport work done during the ship design phase. EEDI is based on a complex formula that takes into account the ship's emissions, capacity, and speed, and the lower the ship's EEDI index, the less CO2 emissions it produces.

EEDI is a non-prescriptive mechanism that allows the shipping industry to use the latest technologies for designing commercial vessels as long as they meet the required energy efficiency levels and parameters. It lays down a minimum energy efficiency level, per capacity mile, for different ship types and sizes, including tankers, bulk carriers, gas carriers, general cargo ships, container ships, refrigerated cargo carriers, and combination carriers.

The EEDI formula has two components: attained EEDI and required EEDI. The attained EEDI is calculated using a complex formulation based on the vessel's emissions, capacity, and speed, while the required EEDI is the minimum level of energy efficiency that a ship must meet as per its ship type and size. The attained EEDI is verified based on the ship's design and construction, and the required EEDI is the target that the ship must achieve during its operation (Ren et al., 2019).

EEDI calculation module as part of Marpol Annex VI, following the directive MEPC.1/Circ.681 at the MEPC meeting conducted by the IMO in 2011. This regulation came into effect on January 1, 2013. The EEDI formula (Equation 1) specified by IMO (2011) is represented by the equation (1.5) (TOKUŞLU, 2020).

$$EEDI = \frac{P \cdot \mathrm{SFC} \cdot \mathrm{Cf}}{DWT \cdot \mathrm{Vref}} \tag{1.5}$$

where:

P : 70% of the power of the engine (main and auxiliary) in kW

SFC : Amount of fuel burned by the engines in kW (specific fuel consumption)

Cf : Emission rate of fuel used by the ship (presented in Table 1)

DWT : Ship's capacity (in tons)

V_{ref} : Speed of the ship (in knots)

1.3.4 Energy Efficiency eXisting ship Index (EEXI)

The Energy Efficiency Existing Ship Index (EEXI) is a regulation introduced by the International Maritime Organization (IMO) aimed at improving the energy efficiency of existing ships. It is part of the broader effort to reduce greenhouse gas emissions from the shipping industry and combat climate change. The EEXI is designed to complement the Energy Efficiency Design Index (EEDI), which focuses on new ship designs (Czermański et al., 2022).

The EEXI is part of a comprehensive framework that includes short-term, mid-term, and long-term measures. The short-term measures focus on technical and operational improvements, such as retrofitting ships with energy-efficient technologies. The mid-term measures involve market-based mechanisms to incentivize emission reductions, while the long-term measures explore alternative fuels and propulsion systems (Chuah, Mokhtar, Mhd Ruslan, et al., 2023).

The calculation of the Energy Efficiency Existing Ship Index (EEXI) can be optimized by considering the ship's maximum continuous rating (MCR) at 100% capacity. This approach ensures that improvements in technical efficiency closely align with the ship's actual operational fuel use. By accounting for the engine power limits (EPLs) within the engine margin, which have minimal impact on ship operations, a more accurate assessment of energy efficiency can be achieved. Currently, the proposed calculation methods for the EEXI involve using either 75% of the limited MCR (MCRlim), similar to the Energy Efficiency Design Index (EEDI), or a higher value of 87% MCRlim, which only considers the engine margin. However, utilizing ship characteristics data from IHS Markit and applying the appropriate calculation method, the attained EEXI score can still be estimated, providing valuable insights into a ship's energy performance.

$$\text{Attained EEXI} = 3.1144 \times \frac{MESFOC \times \sum_{i=1}^{nME} P_{ME,i} + AESFOC \times P_{AE}}{\text{Capacity} \times \text{Vref}} \tag{1.6}$$

The estimation of the attained EEXI score using ship characteristics data from IHS Markit, as outlined in Equation (1.6), contributes to a more comprehensive understanding of a ship's energy efficiency. This information supports decision-making processes related to optimizing operational fuel consumption, implementing retrofit measures, and promoting environmental sustainability in the maritime industry. By calculating the EEXI at 100% MCR, the assessment takes into account the EPLs within the engine margin, which are not expected to significantly affect ship operations. This approach ensures that technical efficiency improvements are properly aligned with the ship's actual operational fuel use, enabling informed decision-making for enhancing operational fuel consumption and reducing environmental impact. Through the utilization of ship characteristics data and the appropriate calculation method, the attained EEXI score serves as a valuable tool for assessing energy efficiency and driving advancements in the maritime sector.

1.4 Problem Statement

Carbon emissions from maritime shipping have been identified as a major contributor to global greenhouse gas emissions, with the International Maritime Organization estimating that shipping is responsible for around 3% of global CO2 emissions (King, 2022). To address this issue, the shipping industry has set targets to reduce its carbon footprint, and governments and international organizations have introduced policies and regulations to encourage emissions reduction.

However, measuring and monitoring carbon emissions from maritime shipping can be challenging due to the complexity of the industry and the lack of reliable data. The Energy Efficiency Operational Indicator (EEOI) and the Carbon Intensity Indicator (CII) have been proposed as two metrics to assess the carbon efficiency of ships and enable comparison between different vessels and fleets (Chuah, Mokhtar, Mhd Ruslan, et al., 2023; Zhang et al., 2019). However, there is a need to better understand the relationship between EEOI and carbon emissions, as well as to identify the factors that influence this metrics.

Therefore, the aim of this thesis is to conduct a big data analysis of carbon emissions in maritime shipping, using EEXI as the main metric. Specifically, the study will:

- Calculate EEOI for a sample of vessels using real-world data on fuel consumption and other operational parameters.
- Analyze the relationship between EEOI, CII, and carbon emissions, using statistical methods and machine learning algorithms.
- Identify the factors that influence EEOI and CII, such as vessel age, size, speed, and route, and examine their impact on carbon emissions.
- Evaluate the usefulness of EEOI and CII as metrics for monitoring and reducing carbon emissions in maritime shipping, and recommend potential improvements to these metrics.

Overall, the findings of this thesis will contribute to a better understanding of the carbon efficiency of maritime shipping and inform the development of policies and strategies for emissions reduction in this sector.

1.5 Research Question

This theis will focus on answering following research questions:

1. What is the relationship between vessel age and carbon emissions in maritime shipping?
2. How do shipping routes affect carbon emissions in maritime shipping?
3. What role do fuel types and engine technologies play in carbon emissions in maritime shipping?
4. How can EEOI and CII be used to monitor and reduce carbon emissions in maritime shipping?

1.6 Report Outline

Chapter 2

Literature Review

In response to the urgent need to reduce carbon emissions and combat climate change, researchers and industry stakeholders have focused on developing and implementing strategies to reduce carbon emissions in maritime shipping.

Figure 2.1 shows that the number of publications on energy efficiency and emission reduction in the maritime industry has grown exponentially since 2016. The number of publications from 2006 to 2015 was 76, while from 2016 to 2021, there were 260 publications, indicating a significant increase in interest in decarbonization in the maritime industry. (Jimenez et al., 2022)

Figure 2.1: Number of publications per year in energy efficiency and emission reduction in the maritime domain

One promising area of research is the use of big data analysis to measure and improve carbon efficiency in maritime shipping. Big data analysis involves the collection and analysis of large and complex data sets to identify patterns, trends, and insights. In the context of maritime shipping, big data analysis can be used to measure carbon emissions and identify opportunities for improvement.

The purpose of this literatsure review is to examine the current state of research on carbon emissions in maritime shipping, with a focus on the Energy The Energy Efficiency eXisting ship Index (EEXI) and Carbon Intensity Indicator (CII) as key metrics for measuring carbon efficiency. The review will provide an overview of the current state of research on these metrics, their strengths and limitations, and their relevance for the maritime shipping industry.

The review will begin by exploring the importance of reducing carbon emissions in maritime shipping and the regulatory and policy frameworks that have been established to address this issue. It will then provide an overview of the EEXI and CII metrics, including their definitions, methodologies for calculating them, and their role in measuring carbon efficiency.

The literature review will also examine the current research on the relationship between EEXI, CII, and carbon emissions in maritime shipping, with a particular focus on the use of big data analysis to measure and improve carbon efficiency. It will explore the potential for big data analysis to provide more accurate and comprehensive data on carbon emissions, and to identify opportunities for operational and technological improvements.

Overall, this literature review will provide a comprehensive overview of the current state of research on carbon emissions in maritime shipping, with a focus on the EEXI and CII metrics and the potential for big data analysis to guide and inform strategies for improving carbon efficiency in the industry.

2.1 Litrature Review

Review by Issa et al., 2022 shows that Maritime shipping is a crucial aspect of global trade and the global economy, with over 85% of the volume of global trade in goods transported by sea. However, maritime transport also has significant environmental impacts, including carbon emissions. Approximately 3.3% of the world's carbon dioxide (CO2) emissions are attributable to maritime transport, with emissions from marine diesel oil (MDO), marine fuel oil (MFO), and heavy fuel oil (HFO) all contributing to the problem. Reducing carbon emissions in the maritime shipping industry is a significant challenge, but there are a range of strategies that can be used to achieve this goal. Alternative fuels, energy efficiency improvements, and operational measures all have the potential to reduce emissions, but they also have significant economic and resource constraints.

Paper by Grzelakowski et al., 2022 mentions that Despite its significant contribution to global economic growth, maritime transport also generates negative externalities, primarily in the form of greenhouse gas (GHG) emissions. They discus how digitalization and the use of artificial intelligence (AI) are being explored as potential ways to reduce emissions in maritime shipping. AI algorithms can optimize shipping routes, reduce fuel consumption, and minimize emissions. Additionally, digitalization can enable better data collection and analysis, which can facilitate more accurate emissions reporting and monitoring.

According to Kao et al., 2022, the use of automatic identification system (AIS) to estimate ship emissions, which is an advantage due to the system's ability to provide real-time navigational information. Studies have been conducted utilizing AIS data to estimate ship emissions in different regions, such as Hong Kong and the Pearl River Delta, Las Palmas Port, Qingdao Port, Tianjin port, Naples port, and unidentified vessels with missing ship parameters.

The studies have focused on macro-scale spatial and temporal resolution, high-resolution ship emission inventory, high temporal-spatial ship emission inventory, higher spatial-temporal resolution, and real-time ship emission monitoring. It proposes simulation model based on AIS data, specification and what-if scenarios as shown in Figure 2.2

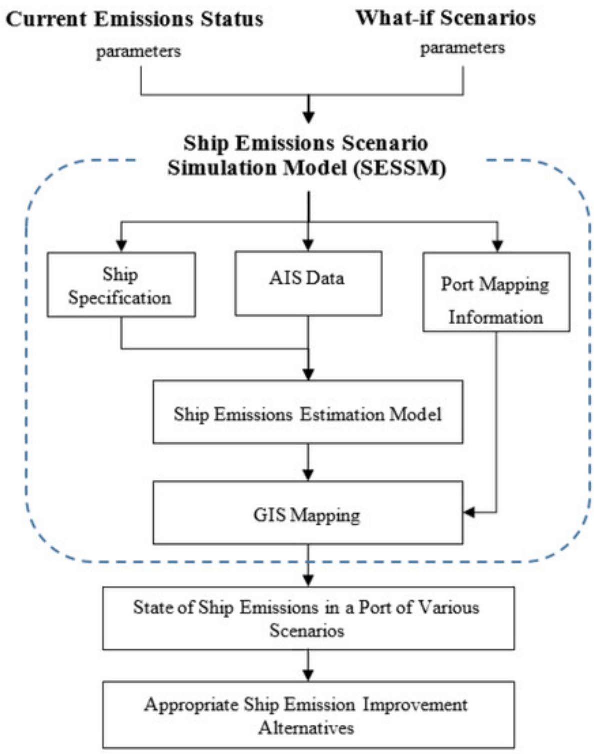

Figure 2.2: Simulation framework

Research by Sou et al., 2022, discusses the need for carbon intensity indicators (CIIs) as performance monitoring tools in the shipping industry, particularly for tracking energy efficiency trends and progress towards climate targets. The review highlights the lack of consensus on suitable CIIs, as proposed by various countries to the International Maritime Organization (IMO), and the need for a more comprehensive understanding of global progress towards carbon intensity targets from both demand and supply side indicators. The study aims to address this issue by analyzing CIIs for shipping and the factors that influence the carbon intensity of shipping at the global level. Index decomposition analysis (IDA) is used to quantify the contribution of various factors, including energy efficiency, to changes in carbon intensity from 2012 to 2018.

According to report by Stevenson, 2021, The International Maritime Organization will introduce Energy Efficiency eXisting ship Index (EEXI) and Carbon Intensity Indicator (CII) regulations in 2023 as part of the wider decarbonisation goals for shipping. More than three-quarters of the existing fleet will not initially meet EEXI baselines and will need to take action to achieve compliance, with overridable engine power limitations (oEPL) expected to be a popular option. However, the effect on vessel operations over a year will be quite small due to the relatively small number of hours where steaming speeds would exceed oEPL limits. The compliance with EEXI can result in modest improvements in AER, CII, and annual CO_2. emissions.

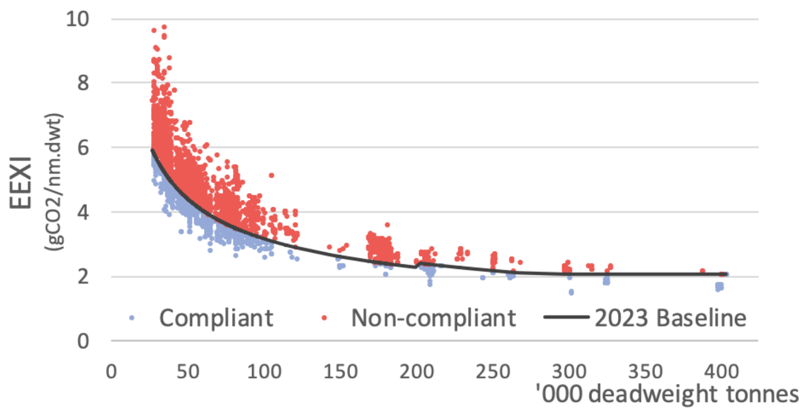

Figure 2.3: EEXI BULKER ESTIMATES VS. 2023 BASELINE

The International Maritime Organization (IMO) has made maritime decarbonization a priority, setting targets to reduce greenhouse gas emissions from ships. To achieve these targets, the IMO has adopted mandatory measures, including the carbon intensity indicator (CII), which measures carbon emissions per unit transport work for each ship. But in Wang et al., 2021 argues there are potential paradoxes with the CII, as it may increase carbon emissions in some situations. There are at least four potential versions of the CII, including supply-based, demand-based, distance-based, and sailing time-based, but the IMO has not yet agreed on which to use. More elaborate models and indicators should be developed to analyze the potential impacts of the CII and achieve utmost carbon emissions reduction.

In Munim et al., 2020 author explains how Big data and artificial intelligence (AI) have become essential components of data-driven decision-making in most industries. However, the maritime industry still relies on intuition more than on data, mainly because of the vast size of its network and planning problems. The maritime industry generates large amounts of data that, if appropriately utilised in decision-making, can improve maritime safety, reduce environmental impacts, and minimise cost. In this review, we focus on studies that deal with big data and AI applications within the maritime context to map the conceptual structure of the field and identify future research avenues. AIS data to investigate the impact of speed reduction on fuel consumption and carbon emissions in the shipping industry. The study found that a 10% reduction in ship speed could result in a 17% reduction in fuel consumption and a corresponding reduction in carbon emissions. The authors suggested that reducing ship speed is an effective way to reduce fuel consumption and carbon emissions in the maritime industry.

2.1.1 Conclusion

In this section, we have reviewed the literature on carbon emissions in maritime shipping, with a focus on the EEXI and CII metrics and the potential for big data analysis to guide and inform strategies for improving carbon efficiency in the industry.

In conclusion, the literature reviewed emphasizes the importance of addressing the significant environmental impact of carbon emissions in the maritime shipping industry. While

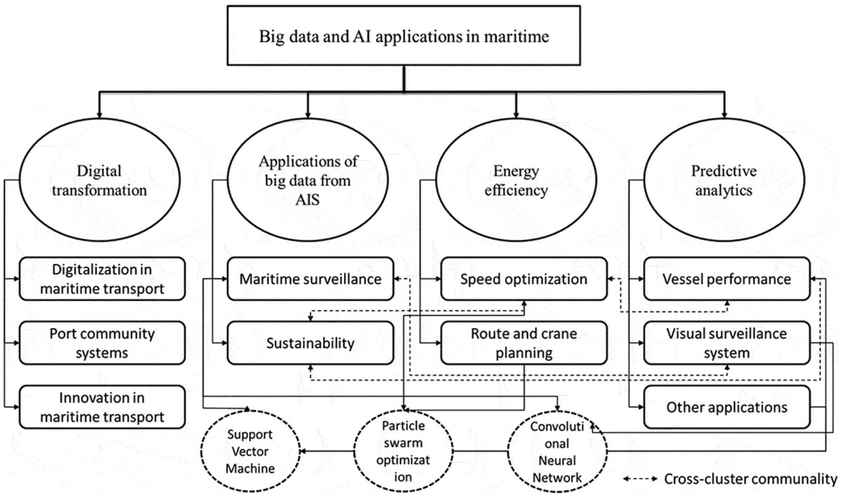

Figure 2.4: Application of Big dada and AI in maritime industry

there are various strategies to reduce emissions, such as alternative fuels, energy efficiency improvements, and operational measures, they have significant economic and resource constraints. Digitalization and the use of artificial intelligence (AI) are being explored as potential ways to reduce emissions by optimizing shipping routes, reducing fuel consumption, and minimizing emissions. Furthermore, the use of automatic identification system (AIS) data can facilitate real-time emissions monitoring, while carbon intensity indicators (CIIs) can be used as performance monitoring tools. The International Maritime Organization (IMO) has made maritime decarbonization a priority by setting targets to reduce greenhouse gas emissions from ships and introducing regulations like EEXI and CII. However, potential paradoxes with the CII and lack of consensus on suitable CIIs highlight the need for more elaborate models and indicators to achieve utmost carbon emissions reduction. Big data and AI applications have the potential to improve maritime safety, reduce environmental impacts, and minimize costs. Overall, more research is needed to address the challenges of monitoring and reducing carbon emissions in the maritime shipping industry while meeting global trade demands.

Bibliography

Chuah, L. F., Mokhtar, K., Mhd Ruslan, S. M., Bakar, A. A., Abdullah, M. A., Osman, N. H., Bokhari, A., Mubashir, M., & Show, P. L. (2023). Implementation of the energy efficiency existing ship index and carbon intensity indicator on domestic ship for marine environmental protection. *Environmental Research*, *222*, 115348. https://doi.org/https://doi.org/10.1016/j.envres.2023.115348

Chuah, L. F., Mokhtar, K., Ruslan, S. M. M., Bakar, A. A., Abdullah, M. A., Osman, N. H., Bokhari, A., Mubashir, M., & Show, P. L. (2023). Implementation of the energy efficiency existing ship index and carbon intensity indicator on domestic ship for marine environmental protection. *Environmental research*, *222*, 115348.

Czermański, E., Oniszczuk-Jastrząbek, A., Spangenberg, E. F., Kozłowski, Ł., Adamowicz, M., Jankiewicz, J., & Cirella, G. T. (2022). Implementation of the energy efficiency existing ship index: An important but costly step towards ocean protection. *Marine Policy*, *145*, 105259.

Grzelakowski, A. S., Herdzik, J., & Skiba, S. (2022). Maritime shipping decarbonization: Roadmap to meet zero-emission target in shipping as a link in the global supply chains. *Energies*, *15*(17). https://doi.org/10.3390/en15176150

Issa, M., Ilinca, A., & Martini, F. (2022). Ship energy efficiency and maritime sector initiatives to reduce carbon emissions. *Energies*, *15*(21). https://doi.org/10.3390/en15217910

Jimenez, V. J., Kim, H., & Munim, Z. H. (2022). A review of ship energy efficiency research and directions towards emission reduction in the maritime industry. *Journal of Cleaner Production*, *366*, 132888. https://doi.org/https://doi.org/10.1016/j.jclepro.2022.132888

Kao, S.-L., Chung, W.-H., & Chen, C.-W. (2022). Ais-based scenario simulation for the control and improvement of ship emissions in ports. *Journal of Marine Science and Engineering*, *10*(2). https://doi.org/10.3390/jmse10020129

King, A. (2022, September). Emissions-free sailing is full steam ahead for ocean-going shipping.

Lukoianove, T., & Rubin, V. (2013). Veracity roadmap: Is big data objective, truthful and credible? *ASIST 2013: 76th Annual Meeting of the Association for Information Science and Technology: Beyond the Cloud: Rethinking Information Boundaries*, *24*. https://doi.org/10.7152/acro.v24i1.14671

Munim, Z. H., Dushenko, M., Jimenez, V. J., Shakil, M. H., & Imset, M. (2020). Big data and artificial intelligence in the maritime industry: A bibliometric review and future research directions. *Maritime Policy & Management*, *47*(5), 577–597. https://doi.org/10.1080/03088839.2020.1788731

Pence, H. E. (2014). What is big data and why is it important? *Journal of Educational Technology Systems*, *43*(2), 159–171.

Prill, K., Behrendt, C., Szczepanek, M., & Michalska-Pożoga, I. (2020). A new method of determining energy efficiency operational indicator for specialized ships. *Energies*, *13*(5), 1082.

Ren, H., Ding, Y., & Sui, C. (2019). Influence of eedi (energy efficiency design index) on ship–engine–propeller matching. *Journal of Marine Science and Engineering*, *7*(12), 425.

Rodriguez, M., Pansera, M., & Lorenzo, P. C. (2020). Do indicators have politics? a review of the use of energy and carbon intensity indicators in public debates. *Journal of Cleaner Production*, *243*, 118602.

Sou, W. S., Goh, T., Lee, X. N., Ng, S. H., & Chai, K.-H. (2022). Reducing the carbon intensity of international shipping – the impact of energy efficiency measures. *Energy Policy*, *170*, 113239. https://doi.org/https://doi.org/10.1016/j.enpol.2022.113239

Stevenson, A. (2021, June). Bulker eexi compliance boosts cii ratings. *SSY online*. https://www.ssyonline.com/media/2165/eexi-effects-bulkers-jun22rev-1.pdf

TOKUŞLU, A. (2020). Analyzing the energy efficiency design index (eedi) performance of a container ship. *International Journal of Environment and Geoinformatics*, *7*(2), 114–119.

Tran, T. A. (2017). A research on the energy efficiency operational indicator eeoi calculation tool on m/v nsu justice of vinic transportation company, vietnam. *Journal of Ocean Engineering and Science*, *2*(1), 55–60.

Tsai, Y.-M., & Lin, C.-Y. (2023). Effects of the carbon intensity index rating system on the development of the northeast passage. *Journal of Marine Science and Engineering*, *11*(7), 1341.

Un body adopts climate change strategy for shipping. (n.d.). *imo.org*. https://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx

Un body adopts climate change strategy for shipping. (2018). *imo.org*. https://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx

Wang, S., Psaraftis, H. N., & Qi, J. (2021). Paradox of international maritime organization's carbon intensity indicator. *Communications in Transportation Research*, *1*, 100005. https://doi.org/https://doi.org/10.1016/j.commtr.2021.100005

Zaman, I., Pazouki, K., Norman, R., Younessi, S., & Coleman, S. (2017). Challenges and opportunities of big data analytics for upcoming regulations and future transformation of the shipping industry [10th International Conference on Marine Technology, MARTEC 2016]. *Procedia Engineering*, *194*, 537–544. https://doi.org/https://doi.org/10.1016/j.proeng.2017.08.182

Zhang, S., Li, Y., Yuan, H., & Sun, D. (2019). An alternative benchmarking tool for operational energy efficiency of ships and its policy implications. *Journal of Cleaner Production*, *240*, 118223. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.118223