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Uncovering Insights: Maritime Shipping's Carbon Footprint

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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

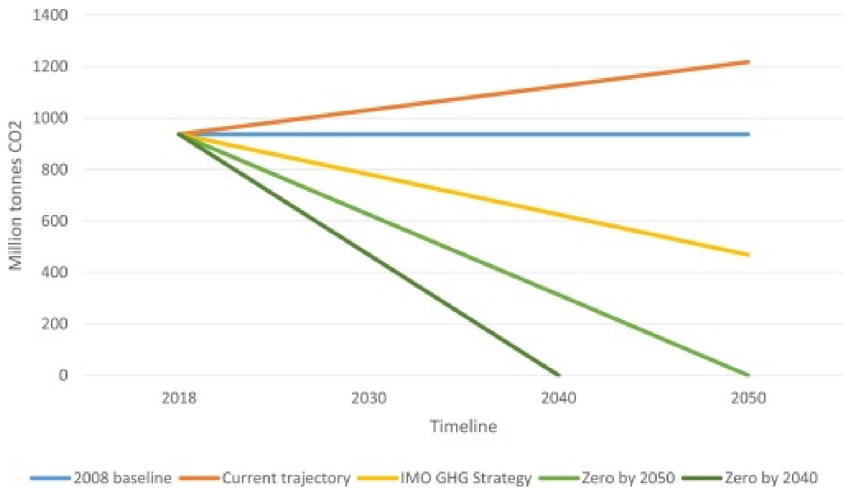

Figure 1.1: Emission trajectories for different levels of ambition for emission reduction targets the maritime sector (Zaman et al., 2017).

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.

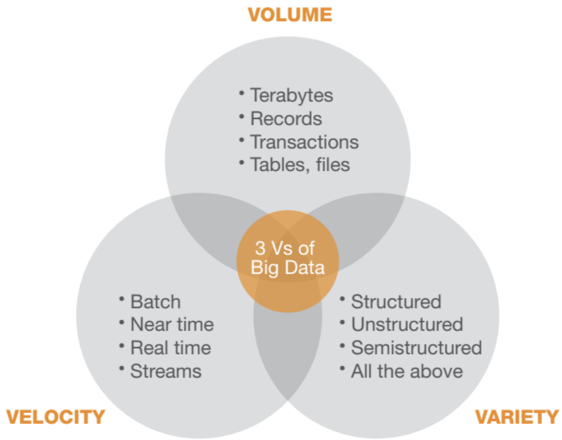

Figure 1.2: Big Data: 3 V's (Lukoianove & Rubin, 2013)

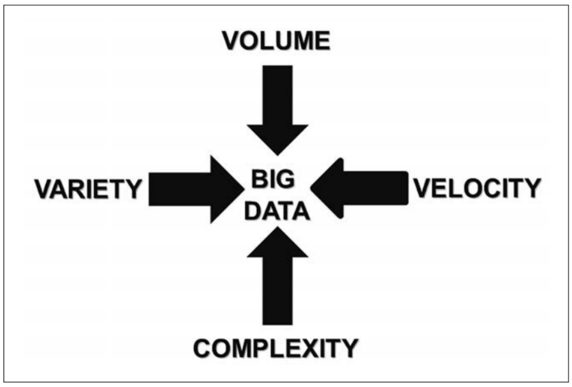

Figure 1.3: Big Data: Beyong 3 V's - volume, velocity, variety, and complexity

1.3 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 Existing Ship Index (EEXI) 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 et al., 2023; Zhang et al., 2019). However, there is a need to better understand the relationship between EEXI and carbon emissions, as well as to identify the factors that influence EEXI.

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 EEXI 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 EEXI and CII, such as vessel age, size, speed, and route, and examine their impact on carbon emissions.
- Evaluate the usefulness of EEXI 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.

1.4 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 EEXI and CII be used to monitor and reduce carbon emissions in maritime shipping?

1.5 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)

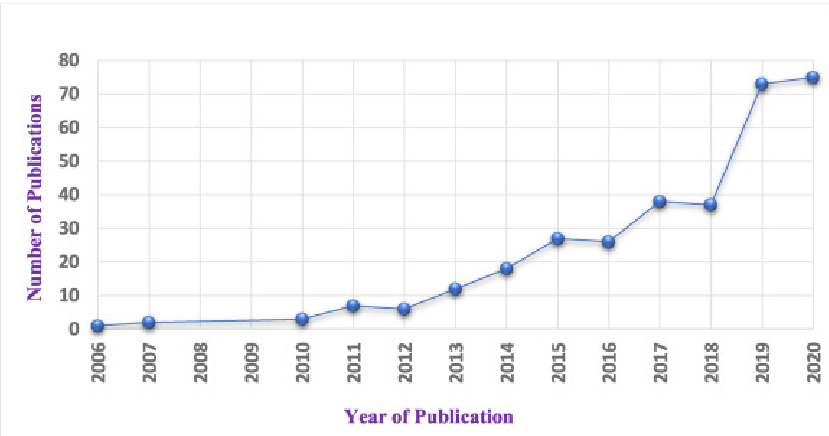

Figure 2.1: Number of publications per year in energy efficiency and emission reduction in the maritime domain

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 Efficiency Operational Indicator

(EEOI) 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 EEOI 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 EEOI, 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 EEOI 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

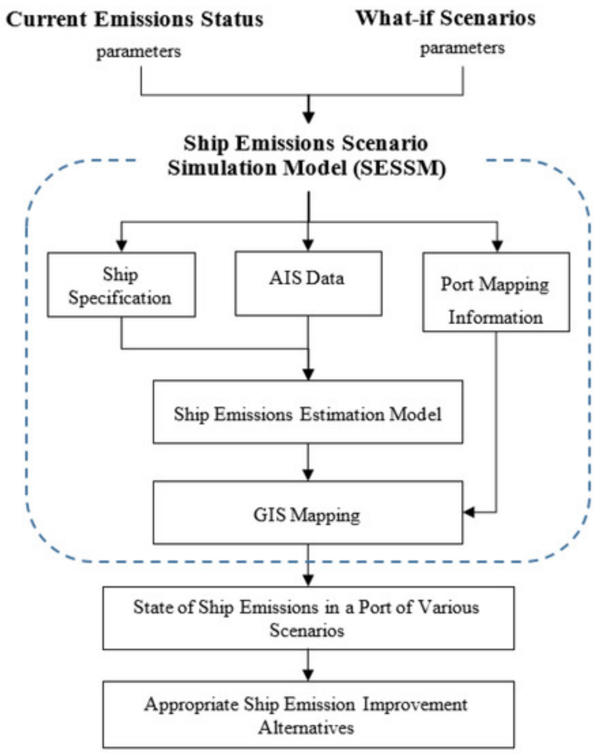

Figure 2.2: Simulation framework

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.

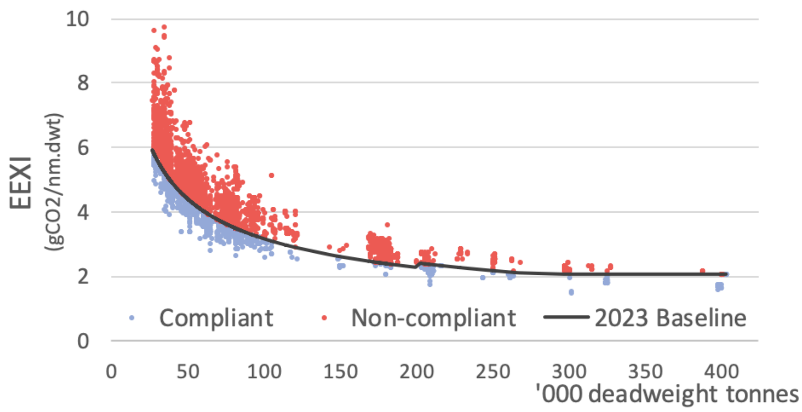

Figure 2.3: EEXI BULKER ESTIMATES VS. 2023 BASELINE

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

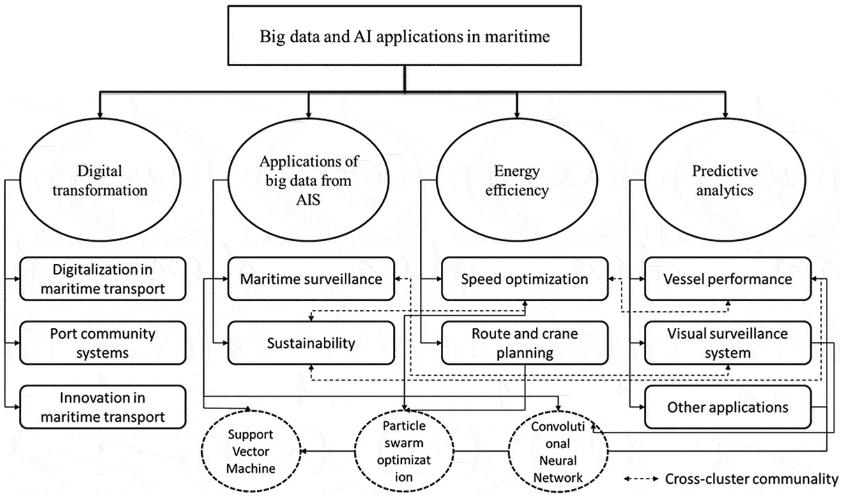

Figure 2.4: Application of Big dada and AI in maritime industry

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.

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