Erasmus University Rotterdam

MSc in Maritime Economics and Logistics

2023/2024

The Impact of Decarbonization on the Oil Tanker Ships Market

by

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Acknowledgements

This year at MEL was full of excitement, challenges and memories and I would like to extend my sincere gratitude to all the people who helped me to develop as a person confident to step up my career in the maritime professional world. As a Navigation Officer working on ships for 8 years, I always had the curiosity to know the financial dynamics behind the shipping industry. Since I sailed on oil tankers throughout my career, I had a particular interest in writing something about the oil market. MEL gave me a platform to learn about the economic facets of the industry from the devoted professors and maritime professionals in the form of guest lectures and seminars. Such a comprehensive research work was something I had never done before joining here. However, MEL program, through uncountable assignments gave me the confidence of writing a thesis like this.

Firstly, I would like to thank my research supervisor, Prof. Maurice Jansen, without whose support and guidance, this research would not have been possible. His continuous guidance and support were a key in the completion of this research. He guided me for various data sources and was available when I needed assistance. His critical feedback during our meetings was crucial in completing the thesis in a professional manner.

Furthermore, I would like to thank the MEL office team, Renee, Felicia and Martha. Their understanding, providing quick solutions and timely reminders helped me to pass the year smoothly.

Lastly, I am deeply grateful to my parents for their sacrifice in sending me abroad to study, even though it meant they would be left alone at home without me.

Abstract

The shipping industry especially the oil tanker sector is under immense pressure to cut down its Greenhouse Gas emissions (GHG) due to regulation set by the International Maritime Organization (IMO) in wake of climate change. This thesis investigates the effects of decarbonization on oil tankers, with a special emphasis on the financial and operational costs of implementing emission reduction technologies. Various policies set out by IMO in curbing the emissions will be studied. The study also seeks to find out whether it is more economical to retrofit existing vessels or order new builds as the industry transitions to decarbonization.

The analysis involved the use of quantitative data from places like the Clarksons Shipping Intelligence Network (SIN), UNCTAD, OPEC and the DNV Energy Transition Outlook. The analysis included the use of statistical techniques to analyze the trends in the fleets, retrofit costs, and the impact of enforcement of regulations on the uptake of technology. R Studio was used to establish relationships between variable factors and plot graphs for easy visualization of trends. The paper reveals that retrofitting is comparatively cheaper in the short run, however, new build vessels with modern technologies are considerably more effective in implementing IMO requirements in the long run. The study also finds out that the efficiency of a vessel is directly proportional to its earnings. The decision eventually lies with the shipowners and depends on the existing age of their fleet and how long they plan to use their newbuilds.

This paper advances the existing knowledge on how the oil tanker industry can overcome the barriers to decarbonization while sustaining its profitability. The results offer useful information for policy makers and stakeholders of the industry, highlighting the importance of a balanced approach in modernizing their fleets.

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List of Abbreviations

AF	Alternate Fuel
ALS	Air Lubrication Systems
CCUS	Carbon Capture, Utilization and Storage
CII	Carbon Intensity Indicator
CO_2	Carbon dioxide
COP	Conference of the Parties
DNV	Det Norske Veritas
DWT	Deadweight Tonnage
ECA	Emission Control Areas
EEA	European Economic Area
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing ship Index
EGCS	Exhaust Gas Cleaning System
EIA	U.S Energy Information Administration
ESTs	Energy Saving Technologies
EU ETS	European Union Emissions Trading System
GDP	Gross Domestic Product
GHG	Greenhouse Gases
GMP	Global Methane Pledge
GRT/GT	Gross Tonnage
IMO	International Maritime Organization
LNG	Liquified Natural Gas
LPG	Liquified Petroleum Gas
LR	Long Range (tankers)
m/m	Mass by mass

MARPOL	The International Convention for the Prevention of Pollution from ships
mb/d	Million barrels per day
mboe/d	Million barrels of oil equivalent per day
MEPC	Marine Environment Protection Committee
MoU	Memorandum of Understanding
MR	Medium Range (tankers)
MRV	Monitoring, Reporting and Verification
OCCS	Onboard Carbon Capture Storage
OECD	The Organization for Economic Cooperation and Development
OPEC	Organization of the Petroleum Exporting Countries
p.a	Per annum
SEEMP	shipboard Energy Efficiency Management Plan
SIN	Shipping Intelligence Network
SOx	Sulphur Oxide
TEU	Twenty-foot equivalent unit
UNCTAD	United Nations Conference on Trade and Development
VECS	Vapor Emission Control System
VLCC	Very Large Crude Carrier
VLSFO	Very Low Sulphur Fuel oil
VOC	Volatile Organic Compound
WTI	West Texas Intermediate

1 INTRODUCTION

1.1 Context and Background

Greenhouse gases (or GHG) are the gases – both men made and natural, in the earth's atmosphere that traps the heat which is released back into the air at night. While GHG are critical for life to sustain on Earth, the GHG Emissions have increased substantially since the Industrial Revolution of 1800s which has resulted in global warming and climate change. Carbon dioxide (CO_2) accounts for about 76% of total GHG emissions and hence drawn everybody's attention to reduce carbon emissions (or Decarbonization) (Global Emissions, 2022). As per Global Carbon Budget (2023), fossil fuels alone account for 90% of carbon emissions. As per 2022 data, Global CO_2 emissions stand at 37 billion tonnes, a figure doubled over the past 40 years (Ritchie & Roser, CO_2 emissions, 2020). Out of this, international shipping contributes to 706 million tonnes of CO_2 emissions (or 1.91%) (Connelly, Teter, & Cret, 2023). Within the transportation sector, CO_2 emissions from international shipping stands at 2nd position trailing far behind road, which contributes a massive 5.87 Gt of CO_2 emissions (Teter & Voswinkel, 2023). Carbon dioxide (CO_2) is considered the most harmful GHG because it gets trapped in the earth's atmosphere for centuries, which has resulted in rising global temperatures over the past decades.

Decarbonization is both a method of climate change mitigation and the process of significantly reducing or eliminating carbon dioxide (CO_2) and other GHG emissions from the atmosphere (IBM, 2023). Despite of various measures taken worldwide; global temperatures are continuing to rise. The global mean temperature has risen substantially from -0.17° C to 1.23° C from 1974 to 2024 which is an increase of 0.028° C or 16.5% increase per year. This increase has doubled in the last decade (from 0.67° to 1.23°). As recent as on 22-July-2024, Earth recorded its hottest temperature ever with 17.15° C toppling the prior day's record of 17.09° C (Barakett & Bush, 2024). The world is moving towards a cleaner energy, especially the developed economies who are pushing it harder to reduce carbon emissions substantially, but it is a challenge for the developing economies due to the high investments and availability required of renewable sources of energy.

Rise of GHG is emerging as the key challenge for a fast-growing shipping industry. Shipping roughly contributes 3% to global GHG emissions. IMO, over the past few years has been laying out stringent environmental regulations to minimize the emissions of GHG, particularly carbon emissions venting out from ships. It poses a challenge to, especially small ship owners since implementing these regulations require substantial investments. Large ship owners also face the similar heat because of their huge fleet. Carbon emissions can be reduced in shipping by adopting various operational measures such as reducing speed, spending lesser time on port, hull cleaning, or by retrofitting using available technologies like alternative fuels, scrubbers or opting for green scrapping of old ships to reduce the environmental impact. Where to invest, which technology to adapt remains a question of dilemma to the shipowners. An efficient vessel, while reducing the emissions also increases earnings for a ship but it comes at a cost of significant investment.

The power and transport sector contributes to nearly half of the world's GHG emissions. While shipping and aviation combined contributes just 2%, constructing regulations for shipping industry and implementing them is relatively easy as this industry is managed by IMO and does not need to depend on each country, saving time and making it effective (Ritchie, Rosado, & Roser, Breakdown of carbon dioxide, methane and nitrous oxide emissions by sector, 2024). However, the IMO's governing body council comprising of 40 member states acts in the decision-making process (OCIMF, n.d.). In July 2023, IMO has pledged to reach the target of net-zero emissions by or around 2050 (International Maritime Organization, 2023). Although the fossil fuels remain one of the important sources of energy, they are one of the biggest reasons for climate change. The focus of this thesis is to identify the long-term effects of decarbonization on the tanker ships industry. This will be done by studying the fleet composition of tankers, impacts of decarbonization policies on tankers, trends of newbuilding and scrapping ships, average age, oil demand and adoption of technologies by tankers.

Today, the clean energy sector employs 36 million workers, surpassing the fossil fuels sector which stands at 32 million workers. This trend was opposite till as latest as 4 years ago where workers employed in fossil fuels industry was 3 million more as compared to clean energy. It is estimated that 0.8 million workers in the oil and gas industry will lose their jobs by 2030 and 1.8 million workers will be retained and switched to clean energy sectors like solar PV, wind, electric vehicles (EVs) and battery manufacturing, heat pumps and critical minerals mining (World Energy Employment 2023, 2023).

It is estimated that nearly half of the CO_2 emissions come from container ships and bulk carriers combined whereas tankers (oil, chemical and gas) contribute to one-fourth of CO_2 emissions (Clarke, Barahona, & Queljoe, 2023). This difference can also be attributed to the fact that container ships and bulk carriers combined comprises of 32% of world's shipping fleet and tanker ships combined comprises of 22% (Marine Vessel Traffic, 2024). Global maritime trade is expected to grow by more than 2% between 2024-2028. The GHG emissions from this sector have risen 20% over the last decade. It is expected that if no action is taken, emissions could reach 130% of their 2008 levels by 2050, leave alone the full decarbonisation plan by 2050 which require massive investments with small island shipping-reliant developing states being the most vulnerable. Another concern in the decarbonization target is the ageing shipping fleet. As per early 2023, average ship's age was 22 years, with over half older than 15 years. These ships are too late to retrofit and too early to scrap (UNCTAD, 2023). Decisions on decarbonization measures are taken by the IMO and its members by formulating regulations after concerning with the member states.

In my thesis, the focus is on tanker ships because they will be the most impacted if oil demand is affected in future. By understanding the current and forecasted oil market, some analysis about the tanker market can be made. Tanker ships consist of mainly 3 types – crude oil, products and chemical tankers, as depicted in the flowchart below. Gas tankers like LNG, LPG, methane, ammonia carriers are outside the scope of this research, however all vessel types will be studied to see visible market trends and make comparisons.

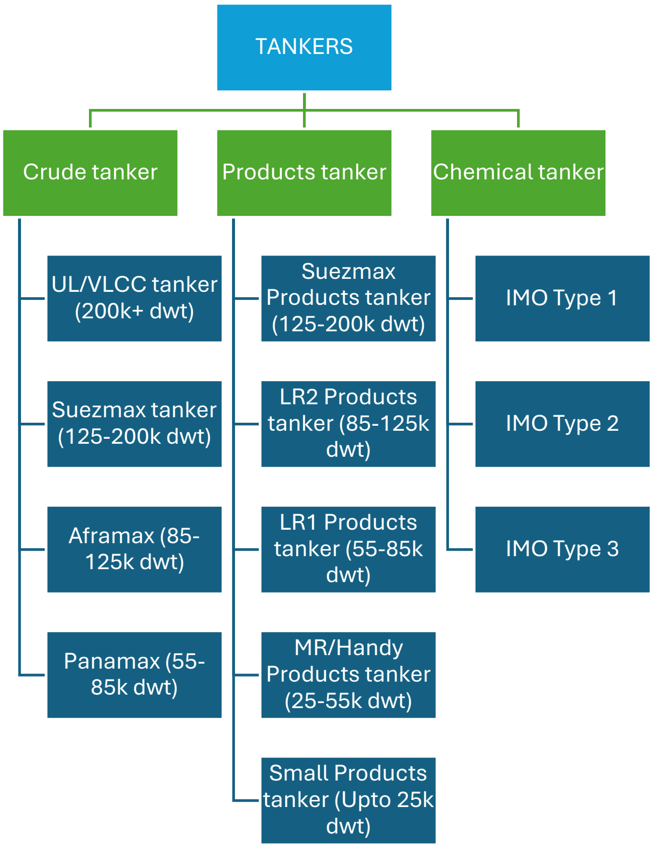

Figure 1: Structure of tankers

Source: Author, using R Studio

For the ease of understanding, “oil products” used in my work includes all products classified within the harmonized system code 27, representing all mineral fuels, mineral oils, and the products of their distillation.

Before diving into the shipping industry, an understanding of the countries most dependent on oil for their economy is important. For this, the countries who are top importers and exporters of oil is included. The sum of the imports and exports of a country in USD was compared to their Gross Domestic Product (GDP) values. The reference year is 2022 for these calculations. While one may believe that most of the gulf countries would only be affected by oil as they are the leading exporters of oil and petroleum products, this is not necessarily the case. As per 2022 Observatory of Economic Complexity (OEC) data, although Iraq ranks on top whose 98.5% of all export comes from oil products, followed by Azerbaijan with 95.7% and Libya at 94.6%, however their GDP’s are only 45% , 47% and 70% dependent on oil trade respectively (World Bank, 2023) (Observatory of Economic Complexity, 2022). Although the dependency on oil trade for these 3 countries is in no way any less and constitutes nearly half of their GDP (in case of Azerbaijan much more than that), there are some countries whose GDP is much more dependent on oil trade, particularly due to their oil imports. For e.g., as per 2022 OEC and World Bank data, Marshall Islands takes the top spot whose oil trade constitutes 1107% of their GDP. Their oil exports volume is very less (USD 95 M) but their oil Imports is massive (USD 2.77 B) and their GDP is only USD 259 M (OEC, 2022) (World Bank, 2022). The high volumes in oil imports comes since they are the fifth-largest non-Canadian destination for U.S. crude oil exports in 2016, averaging 14,000 barrels per day. With a population of just 50,000 the huge imports volume is clearly not for their own consumption and neither they have any refineries to create byproducts of crude oil. But rather is likely the location of ship-to-ship transfers for delivery to destinations in Asia, or a point at which a cargo of crude oil would await a buyer in Asia (Gloystein, 2016). The other nations, followed by Marshall Islands, dependent on oil trade are Togo, Liberia and Brunie constituting 159%, 108% and 101% respectively as oil Trade % of their GDP.

Hence, energy transition efforts around the world will have some impact on the oil demand for the transport industry apart from shipping sector who are transitioning towards EVs and alternate fuels (AF) and power industry moving towards solar, nuclear power. One must also not forget that crude oil serves a variety of other purposes apart from fuel, like production of lubricants, wax for candles, electricity, charcoal, polyester clothing etc. So, it needs to be studied. However, for the scope of this study, the focus will be mainly on decarbonization in shipping industry only as assessing the impacts of other industries will require to study them in detail individually.

1.2 Problem Statement

The maritime industry is one of the world's most important industries involved in the transportation of goods and products worldwide especially through the oil tanker but at the same time, it is also one of the largest emitters of GHG contributing to approximately 3% of total emissions. Given the growing concern with climate change, some organizations like the IMO have developed measures to address the carbon emissions in the maritime sector. However, the oil tanker industry has several challenges in achieving these regulatory standards. Older fleets, especially, may have difficulty in meeting new standards due to outdated technology and they do not have many economic incentives to update their fleets.

Despite the growing regulatory pressure, there is uncertainty about how effectively these decarbonization technologies can enhance operational efficiency, feasibility of upgrading older generation vessels, and preparedness of tanker companies to invest in these innovative solutions. This situation raises concern about the capability of this industry to meet the stipulated reduction in emissions and its sustainability. Hence, there is a need to establish the correlation between the implementation of decarbonization technologies and the operating efficiency, examine the effect of the age of the fleet on the level of compliance with regulations, and review the investment flows in emission reduction technologies in the oil tanker industry.

1.3 Research Objectives

While keeping the focus on tanker ships in mind and motivated by the problem statement discussed in the previous section, this thesis focuses on the following main research question:

"What will be the impact of global decarbonization efforts on the composition of the tanker fleet and the average operational lifespan of tankers?"

The aim of this study is to predict the demand of oil in future by analysing the new ship building markets, scrap markets, industry reports, oil production trends and crude oil prices which can help us analyse the impact on tanker ship market.

1.4 Research Questions

To adequately respond to the main research question, the following sub-research topics were formulated:

1. What regulations and policies are adopted to curb emissions in the maritime sector and how effective are these policies?
2. How efficient are alternate fuel vessels in controlling GHG emissions?
3. What are the economic implications for oil tankers transitioning to efficient fleet?
4. Which decarbonization technologies are being adopted by leading tanker companies?
5. How has decarbonization goals affected the demolition of tankers?

6. Is newbuilding or retrofitting existing tankers a better option for tanker companies towards their decarbonization goals?
7. What is the impact of global oil demand on oil tankers?
8. What is the impact of decarbonization on utilization rates of oil tankers?

1.5 Significance of the Study

This study is significant for several reasons:

Industry Relevance: The result of this research is expected to benefit various stakeholders in the shipping industry, particularly the oil tanker sector, policy makers and potential investors. By understanding the impact of various decarbonization technologies on economic performance of a vessel, stakeholders can make informed choices about their investments.

Policy Implications: This study will analyze the implications of the environmental regulations in the shipping industry and try to find out how effective are these policies in meeting their targets. The insights can help the organizations to understand the effectiveness of these policies they set and place them in a better position to implement such policies in future.

Environmental Contribution: In the era where emission of GHG is a global concern, this study is important to reveal the contribution of the shipping industry. Thus, addressing the issue of how regulation, technology and industry practice all interrelate, the study investigates how the decarbonization efforts in shipping can lead to broader environmental goals.

Economic Impact: The study also suggests, what might be the economic consequences of decarbonization for oil tanker shipping business. It gives a comprehensive understanding of how investment in green technologies may affect the financial viability of tanker companies so that it has a better perception of the risks that are likely to be encountered with immediate implementation of green technologies in the tanker industry.

Therefore, in addition to providing an overview of the problem field associated with decarbonization in the oil tanker market and proposed solutions, this work contributes to a broader understanding of how industries can adapt to stringent environmental regulations while maintaining economic viability.

2 LITERATURE REVIEW

2.1 Introduction

As the effects of climate change continue to worsen each year, the impact of GHG emissions on the environment has become a matter of concern across the world. Nations across the globe are creating short- and long-term policies aiming to reduce these emissions. As a result, maritime industry is under immense pressure to adopt to these changes.

With a change in the global regulatory policies, the industry is now faced with the dilemma of having to choose between environmental factors and economic feasibility. This literature review examines the complex nature of decarbonization in the oil tanker sector by responding to several sub-questions that help to define the overall effects of such processes on the composition of the tanker fleet and average operational life of tankers.

Firstly, it will be important to comprehend the legal requirements of the process of decarbonization. Many countries have established polices and regulations to reduce GHG emissions with focus on minimizing the use of fossil fuels. These regulations include the initiatives taken by IMO and their aim is to reduce emissions by a considerable amount. An analysis of these regulations and policies will help in understanding the extent to which they have been effective in the reduction of GHG emissions.

In transitioning to a more efficient fleet, there are environmental and economic implications. A process of decarbonization may involve significant capital expenditures, such as retrofitting of the existing fleet or ordering new ships that are designed to meet the current and future regulatory targets. This also has significant implications on the economic effects of such transitions especially on the cost, productivity and the disruption of the global oil supply chain.

Large tanker companies are the key players in complying with these decarbonization policies by adopting various measures while ensuring competitiveness. A study of how these companies are managing decarbonization targets will help us understand the real challenges and strategies being employed across the industry.

In addition, there are number of technological measures that are open to the shipping companies to decrease emissions; these options include technological changes to the design of ships, slow steaming, voyage optimization, vessel utilization, green bonds and the use of alternate fuels. Gaining a knowledge of which technologies are most deployed and how effective they are will give us a better understanding of the industry's path to decarbonization.

The policies that are driving decarbonization also have important consequences for the industry's older, less efficient ships. They may help to speed up the process of elimination of such vessels which can affect the general composition of the tanker fleet. It is still an open question whether new building or retrofitting is more effective for the tanker companies; the question of cost, the possibility of technological application, the infrastructure and the long-term approach are decisive in this case.

The age of a tanker depends on the current technology available, the pressure from the regulations and laws, efficiency of the vessel, the whole oil market and the economic factors. Awareness of these factors is important in forecasting the remaining practical service life of tankers in a low carbon environment.

Finally, OPEC and the demand of oil across the world has a great influence on the tanker industry. In the process of implementing the decarbonization strategy, changes in the production and consumption of oil are expected to affect the functioning of tankers and may cause changes in the composition of the fleet.

In these areas, the aim is to provide the reader with a clear understanding of how the decarbonization of the global economy is impacting the oil tanker market. Thus, by answering these sub-questions, the review will shed light on the possible future trends in the tanker fleet composition and tankers' operational life cycle, and thus, add to the global discussion on sustainability in marine shipping.

2.2 Decarbonization Policies

Decarbonization, in simple words mean all the measures taken to reduce GHG emissions- mainly carbon dioxide and methane. It can either be done by using renewable sources of energy like wind, solar, hydropower, geothermal and biomass or by carbon capturing, which means adapting technologies which can absorb the carbon footprints from the atmosphere. The natural means of carbon capturing is afforestation or plantation of trees. Trees, as we all know inhale carbon dioxide (CO_2) and release oxygen. This CO_2 absorbed by trees and plants remain there until they die after which it becomes part of the soil. In this section, we will discuss the various policies adopted with a focus on curbing GHG emissions.

2.2.1 Paris Agreement (adopted 12 Dec 2015)

The historical Paris Agreement which was adopted by 196 Parties at the UN Climate Change Conference (COP21) in Paris, France on 12 December 2015, aimed to hold the global average temperature to well below 2°C above pre-industrial levels" and pursue efforts "to limit the temperature increase to 1.5°C above pre-industrial levels. Copernicus, a component of EU's space program observing Earth, suggests that at the time of COP21 in 2015, the global temperature was 0.98°C above the pre-industrial average. It was then estimated that 1.5°C threshold would breach in 2045. However, a global average of 1.25°C was already reached in 2023 and is expected to be at 1.5°C over pre-industrial levels by 2034, indicating that the target is already 11 years behind schedule. (Copernicus, 2023).

2.2.2 IMO Initial Strategy 2018

Within the shipping industry, IMO has been taking various measures in the past with an aim to reduce GHG emissions and contribute to energy efficient shipping. These measures are adopted by IMO under its body The Marine Environment Protection Committee (MEPC) which addresses environmental concerns. In Apr 2018, IMO adopted an Initial Strategy with a vision to reduce GHG emissions from international shipping by 50% by 2050 and to phase them out as soon as possible in this century. CO_2 emissions alone were intended to reduce by at least 40% by 2030 and 70% by 2050, with initiatives like EEDI (discussed further in section 2.3) (IMO, 2018).

2.2.3 IMO 2020 (Sulphur Cap)

On 1 Jan 2020, IMO (also known as "IMO 2020") enforced a strict rule which limits the sulphur in the fuel oil used on board ships operating outside designated Emission Control Areas (ECA) to 0.50% m/m (mass by mass). The sulphur limit of fuel inside ECA was already strict at 0.10% m/m and no changes were made. The shipping companies were either forced to adopt more expensive fuel or retrofit their vessels with scrubber, also called Exhaust Gas Cleaning System (or EGCS) to comply with the IMO requirements. Ships faced challenges in the availability of low sulphur fuel. Many ports did not allow the use of scrubbers within their port limits.

2.2.4 IMO 2023 Strategy

In July 2023 (MEPC 80) IMO adopted more stringent measures as compared to 2018 Initial Strategy in the form of “2023 IMO Strategy on Reduction of GHG Emissions from ships” with a target:

(a) To reduce the total annual GHG emissions from international shipping by at least 20 per cent, striving for 30 per cent, by 2030, compared to 2008; (“SUSTAINABLE DEVELOPMENTS”)

(b) To reduce the total annual GHG emissions from international shipping by at least 70 per cent, striving for 80 per cent, by 2040, compared to 2008

(c) To achieve net-zero emissions by 2050

(IMO, 2023)

The process of decarbonizing the shipping industry is influenced by international regulations and market demands to reduce the GHG emissions. Oil tankers are crucial in the transportation of crude oil and other petroleum products; however, they are known to pollute the environment through the release of Volatile Organic Compounds (VOCs) during loading and carriage of cargo. VOCs are gases having high vapor pressure releasing from certain liquids. VOCs emitted into the atmosphere when the tank pressure reaches set levels not only leads to the loss of cargo but also has an adverse effect on the health and environment. The degree of vaporization is influenced by the volatility of the cargo, and some ports especially in Europe have incorporated the Vapor Emission Control Systems commonly known as VECS to capture the emissions by trapping the vapor from the ship and containing them in tanks.

Thus, in addition to VOCs, oil tankers do not have other more detrimental environmental impacts compared to other types of vessels. The shipping industry is gradually shifting to the use of other fuels like Liquefied Natural Gas (LNG) and methane with lower GHG emissions than the conventional marine fuels. However, the accessibility and the price of the abovementioned alternative fuels are still an issue, becoming a hindrance to their increased usage.

To meet these issues, this study will analyse the current and future trends in the oil tanker market by looking at the order books, demolition orders, forecast of oil demand, average age of a ship and the recent fleet composition. This analysis will offer an insight of how the industry is adjusting to these changing pressures and what this has in store for the composition and the service life of the oil tanker fleet in the future.

2.2.5 Long-Term Decarbonization Targets by Major Oil Exporters and Importers

In this section, policies in major oil-importing and exporting countries, particularly those focusing on the reduction of carbon emissions will be reviewed. The regulations imposed by bodies like the IMO, especially those related to reducing carbon emissions (e.g., IMO 2020) will also be examined. The costs associated with adhering to these regulations, including investments in cleaner technologies and fuels will further be analysed.

Before diving into the table, it is important to understand about the Global Methane Pledge (GMP). The GMP, launched in 2021, is a voluntary framework aiming to reduce methane emissions by 30% by 2030, potentially eliminating over 0.2˚C of warming by 2050. The GMP now has over 155 country participants, representing nearly 50% of global anthropogenic methane emissions (Climate and Clean Air Coalition, 2023). Methane is a powerful GHG and responsible for warming climate, only behind CO_2. It traps more heat than CO_2 but has a relatively short lifespan of 7 to 12 years in the atmosphere, while CO_2 can exist for hundreds of years in the atmosphere (NASA, 2024).

Table 1: Policies and Targets to curb emissions by major oil countries

COUNTRIES	POLICIES
	EXPORTERS
Saudi Arabia	Net zero emissions targets by 2060.
Russia	To reach net zero GHG emissions by 2060.
Canada	• Commitment to reach net zero GHG emissions target by 2050. • To reduce methane emissions from the oil and gas sector by 40-45% by 2025, and further by 75% by 2030 relative to 2012.
United States	• To reduce GHG emissions by 50-52% by 2030 (from 2005 levels) and national target to reach net zero GHG emissions by 2050. • Commitment to the Global Methane Pledge.
Iraq	Zero Routine Flaring by 2030 initiative
	IMPORTERS
China	• 20% non-fossil share of the energy mix by 2025, 25% by 2030. • Aim to peak CO_2 emissions before 2030. • Carbon neutrality target by 2060.
India	• To reduce national emissions intensity by 45% by 2030 from 2005 levels. • Commitment to reach net zero emissions by 2070.
South Korea	Carbon Neutrality and Green Growth Act for Climate Change committing to carbon neutrality by 2050.
Japan	• Climate neutrality target by 2050. • Reduce GHG emissions by 46% by 2030 from 2013 levels. • Commitment to the Global Methane Pledge.
European Union	• Net zero emissions target by 2050 embedded in the 2021 European Climate Law. • To eliminate the import of Russian natural gas supply to the European Union well before 2030.

Source: (IEA, 2023, pp. 307-309)

2.3 Impact on the Shipping Industry

Shipping is under growing pressure to achieve the set GHG emission reduction goals and standards with the sector responsible for 2.8% of global emissions. If no action is taken to reduce these emissions, they are expected to rise to 90-130% of 2008 levels in 2050. To achieve the goals set by the Paris Agreement of keeping the temperature increase to 1.5°C above pre-industrial levels, shipping needs to mainstream decarbonization goals. But present policies and commitment slash the temperature increase to 2.4°C - 2.6°C by 2100. There is a need to urgently increase the rate of mitigation and adaptation to climate impacts. It is apparent that the shipping industry needs a package of measures to fit the objectives of reducing GHG emissions. (Dickie, 2023)

As per UNCTAD 2023, GHG emissions vary with shipping activity levels, trade flows, ship type, size, age, and operational practices. UNCTAD further claims that emissions from container shipping per ton-mile are higher than those from dry and liquid bulk shipping, although the former should get credit for achieving the highest reduction from 16 grams per tonne nautical mile in 2012 to 12 gm/t.nm in 2023, followed by a reduction in Bulk and general cargo vessels from ~9 gm/t.nm in 2012 to 7 gm/t.nm in 2023. Tankers have seen relatively consistent carbon dioxide emissions for the same period at ~9 gm/t.nm. (UNCTAD, 2023, pp. 87-88)

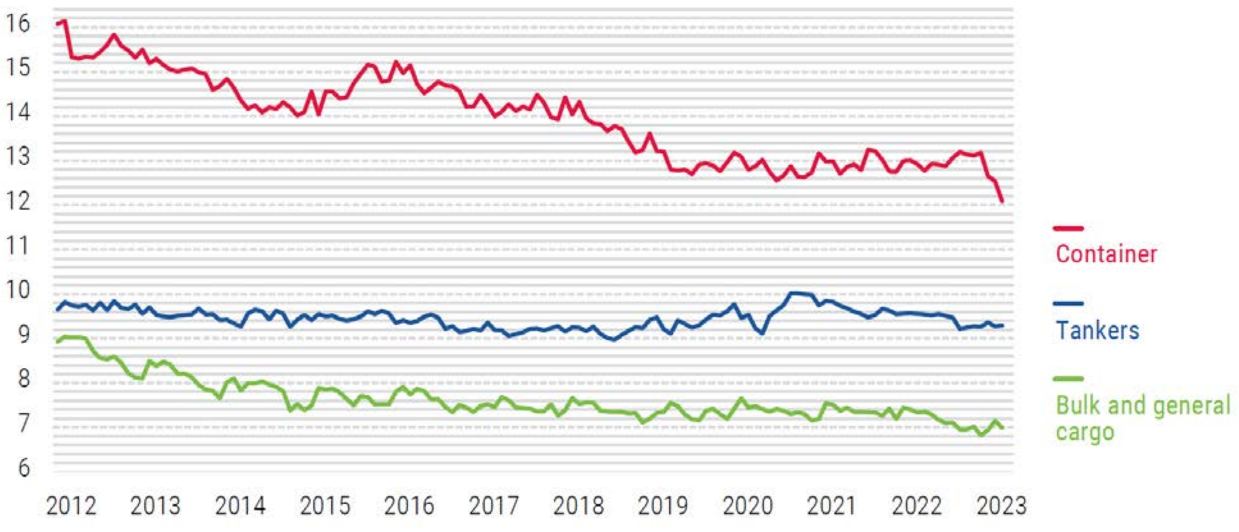

Figure 2: World feet, three main vessel types, carbon dioxide emissions per ton-mile (2012-2023)

Source: UNCTAD

Flag state of a ship is responsible to implement the IMO regulations pertaining to reduction of GHG emissions, while ship owners are responsible for important commercial and investment decisions like retrofitting, newbuild order, sale/purchase of vessel or sending the inefficient vessels for demolition usually with the help of brokers. Hence, shipowners play a key role in shaping the global shipping fleet's emission profile and meeting the IMO GHG emission targets, through their investments in the future fleet, fuels and onboard green technologies. In 2022, vessels sailing under the flags of Panama, Liberia and Marshall Islands accounted for over one-third of carbon emissions. (UNCTAD, 2023). Interestingly, these 3 flag state combined contribute to about 43% of world fleet (in GT, 2022).

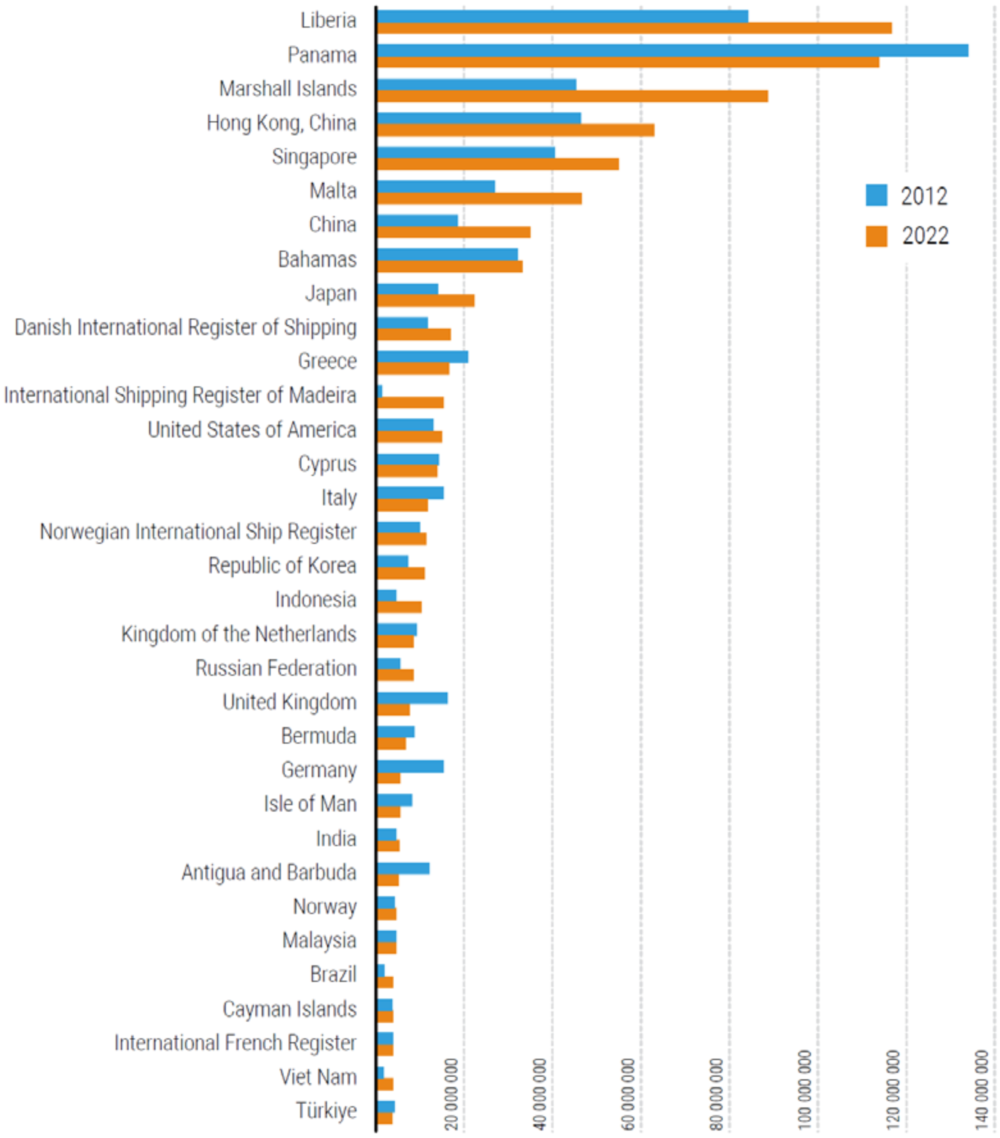

Figure 3: Carbon dioxide emissions by main flags of registration, tons, 2012 and 2022

Source: UNCTAD, Jan 2023.

With regards to ownership, vessels owned by China, Japan, and Greece accounts for the largest share of CO_2 emissions. Like flag states, these 3 countries own the largest share of vessels amounting to 43% (GT,2022). Hence, these flag states or owners should not be held responsible for high emissions. However, one can argue that since these owners own a huge share of world fleet and they are likely capable of making strong investments, they must lead the way forward in decarbonizing shipping.

2.4 Regulations on Decarbonization

The regulatory requirements introduced by IMO play a crucial role in decarbonizing and improving the energy efficiency of the shipping sector. IMO, through its amendments in "The International Convention for the Prevention of Pollution from ships" (MARPOL) Annex VI has adopted various short-term decarbonization measures, including the Energy Efficiency Design Index (EEXI) for existing ships and the Carbon Intensity Index (CII) rating scheme, implemented from 2023. This complements, earlier rules namely Energy Efficiency Design Index (EEDI) which focused on only newbuild ships, and Ship Energy Efficiency Management Plan (SEEMP).

2.4.1 Energy Efficiency Existing Ship Index (EEXI)

EEXI defines design parameters and structural efficiency by energy efficiency level per capacity mile which can be initially achieved through technical enhancements such as installing engine power limiters or shaft power limitation systems.

2.4.2 Carbon Intensity Index (CII)

The CII is an operational measure which directs the ships to calculate their attained CII. The CII ranks the vessel in the scale that ranges from A to E and is based on the Annual Efficiency Ratio (AER). However, concerns have been raised regarding CII over its structure (UNCTAD, 2023).

Figure 4: Calculation of CII

Source: (DNV, 2023)

In July 2024, BIMCO along with CLIA, ICS, INTERCARGO, INTERMANAGER and INTERTANKO issued a joint statement highlighting the shortcomings and loopholes with the CII scheme. The current CII metric penalises efficiently operated ships carrying cargo, while favouring empty ones. With the current CII metric, the ship with the best Annual Efficiency Ratio (AER) is a ship always trading in ballast condition without any cargo onboard. Furthermore, ships are penalised for time spent at ports even though the length of port calls is outside the control of the ship. The duration of port calls depends on the efficiency and limitations of the port and some ports and terminals suffer severe congestion. The current metric therefore penalises efficiently operated ships carrying cargo, while favouring empty ones (BIMCO, 2024). The IMO will evaluate the measures for the application of the CII and EEXI requirements by January 1, 2026, at the latest and will develop further modifications if needed.

CII compliance primarily rests with the shipowners, however, it can be delegated to the charterers if agreed to in a contract. The new BIMCO's CII Operations Clause for Time Charter Parties 2022, also transfers part of the responsibility for CII to charterers and emphasizes the principle of the good faith of the parties—shipowners and charterers in achieving the agreed CII score (BIMCO, 2022).

2.4.3 Monitoring, Reporting and Verification (MRV) Maritime Regulation

From January 2018, ships with gross tonnage of 5,000 or more loading or unloading cargo or passengers in the ports in the European Economic Area (EEA) were required to monitor and report the GHG emissions and other relevant information. Annual data is collected into an emissions report by the company that must monitor emissions, fuel consumption, distance travelled, time at sea and cargo carried per voyage and this data must be verified by a shipping MRV verifier. By the 30th of April 2025, an independent verification report of the emissions should be provided to the Commission and the flag States and by the 30th of June 2025, all ships should have a compliance certificate. (European Commission, 2024)

2.4.4 European Union Energy Taxation System (EU ETS)

Shipping emissions were added to the MRV regulation recently and this is the first time that it has fallen under the European Union Energy Taxation System (ETS). The European Union extended its Emissions Trading System (EU ETS) to cover the CO_2 emissions from all large ships that call at EU ports from January 2024. The system is designed to capture 50% of emissions from the voyages originating or terminating outside the EU and 100% if the voyage is completed within two EU ports. The limit of emissions from maritime transport is gradually lowered starting with 40% for verified emissions from 2024, 70% from 2025, and 100% from 2026 to achieve the climate goals of the EU. Carriers are required to buy and cancel emission allowances per each reported ton of CO_2. The first of the foregoing surrendering dates is September 2025 for emissions from January 2024 to December 2024. EU ETS has the target of cutting emissions by 62% by 2030 in sectors included in ETS, which concerns 100% of emissions from internal shipping and at the EU ports. These alterations may have a wide impact on the trade of European countries and between developed and developing counterparts, and other partners may push them to retaliate the same way (European Commission, 2024).

2.5 Technological Innovations in Shipping

Ships are designed with a view of next 15 to 20 years. What type and capacity of ships to order, what type of engine to use, what type of alternate fuel system to be installed depends on the financial state of the owner, supply and demand side of a commodity, geopolitical factors and how the stakeholders forecast the trends in shipping. With international pressure mounting on the industry to control emissions which is expected to be severe in future, modern ships need to be built efficiently considering future energy needs. In this section, various technologies being developed and adopted in the industry will be discussed, along with case studies aiming to reduce GHG emissions.

2.5.1 CO_2 Import Terminal

As discussed earlier, one of the ways to reduce carbon emissions is carbon capturing. Vopak has signed a Memorandum of Understanding (MoU) with Australia's Northern Territory Government to build CO_2 import terminal in Darwin. This terminal will be designed to manage the import, storage and distribution of carbon dioxide as a common user facility. The CO_2 once imported would be stored in large tanks before transferring to a permanent underground storage facility or for recycling for utilisation. (Shipping Australia, 2024)

2.5.2 Onboard Carbon Capture System (OCCS)

In a white paper released by DNV, “DNV Onboard Carbon Capture”, it talks about the possibility of decarbonization option in the form of “Onboard Carbon Capture Storage” (OCCS). This concept is based on a technology which captures carbon dioxide on board before it is released into the atmosphere through vents. It is gaining popularity because of carbon taxes, the limited availability and high prices of low-carbon fuels, amid decarbonization pressure by IMO. As depicted in the figure below, this technology is dependent on the establishment of Carbon Capture, Utilization and Storage (CCUS) value chain to lay the foundation of onboard carbon capture technology. This infrastructure is not yet designed. Also, it would require emission regulations to be established and approved by the class authorities. OCCS can be a gamechanger for shipowners because it provides the opportunity to continue operation on conventional fuels, while reducing GHG emissions. (Slotvik, Georgopoulou, Nakstad, & Sørhaug, 2024)This technology falls under one of the Energy-Saving Technologies (ESTs) available. More than 8,713 ships have been retrofit with ESTs, accounting for 33.5% of the global fleet by tonnage. Available ESTs range from propeller ducts and rudder bulbs to Flettner rotors, wind kites and Air-Lubrication Systems (ALS). Combined, ALS (493 ships) and wind-assisted propulsion (116 ships) have been fitted on more than 600 ships, while OCCS fitted on 31 vessels and 28 newbuilds (Snyder, Turning green: 20% of global fleet will be alternative-fuel capable by 2030, 2024). However, its technical and economic feasibility needs to be evaluated and compared against the expensive, limited availability of alternate green fuels.

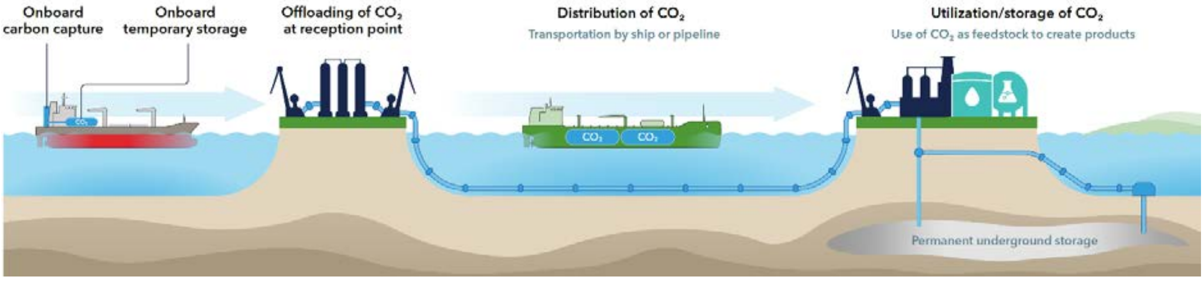

Figure 5: Stepwise process of the onboard carbon capture value chain

Source: (Slotvik, Georgopoulou, Nakstad, & Sørhaug, 2024, p. 3) (DNV)

2.5.3 Air Lubrication System (ALS)

ALS is intended to minimize energy demand by decreasing the drag between the hull of the ship and water. Skin friction is always the primary part of a vessel's resistance to moving through water and small reductions in skin friction affect fuel consumption. ALS use air along the flat bottom area of a ship in order to minimize the frictional drag. The reduction of frictional drag is related to the homogeneity of the air and seawater mixture and the air flow rate over the bottom. Some systems use more than one row of air release units in the ship's lengthwise direction while all these systems include more than one air release units in the width wise direction. To achieve the best result in the air outlets, several laboratory tests have been carried out using full-scale air release units. Full-scale measurements can be applied in order to assess the impact of the air lubrication technology and determine the actual increase in the vessel speed and the decrease of the engine power. Net power savings of an ALS are normally in the range of 4% to 7% at normal operating weather conditions. Air lubrication is growing more popular, especially in the container and gas carrier markets but is still in the early adopting stage. The future development will most likely increase the effectiveness of ALS, new types of hull coatings, the ALS control system, and its use. By June 2023, more than 347 vessels either equipped or retrofitted with an ALS have been reported as contracted or delivered. (DNV, 2023, pp. 33-34)

2.5.4 Wind-Assisted Propulsion

Japan's Mitsui OSK Lines (MOL) is set to launch the world's first LNG Carrier with wind assisted propulsion system, following in principle approval from classification society ClassNK. The 174,000-cu metre LNG carrier equipped with two Wind Challenger sails, a design developed by MOL in partnership with the University of Tokyo and Oshima shipbuilding, can enter LNG terminals worldwide. Interestingly, MOL had also launched "world's first" coal carrier equipped with the Wind Challenger hard sail wind propulsion system in 2022 and claims to achieve fuel savings by up to 17% and by 5 to 8% per voyage on average, thereby also reducing carbon emissions (Prevljak, 2024). The Japanese shipping company plans to launch 25 vessels equipped with the Wind Challenger by 2030 and 80 vessels by 2035 to meet its net zero GHG emissions by 2050. ("MOL delivers second Wind Challenger-equipped bulk carrier”). Wind-assisted propulsion has already delivered yearly fuel savings of between 5% and 9% for certain ships, and is claimed to have the potential to reach 25% (DNV, 2023, p. 31)

Figure 6: MOL vessel with wind assisted propulsion

Courtesy: MOL

2.5.5 Alternate Fuels

The most common trend in energy efficient ships is use of alternate fuels. For comparison, 1.8% of the current world fleet and 27.8% of orderbook of world fleet are alternate fuels capable whereas 0.6% of current world fleet and 10.8% of orderbook of world fleet are alternate fuels ready. (Clarksons World Fleet Monitor Vol 15 No 07 July 2024). In October 2023, “Laura Maersk” , world’s first green methanol container vessel started its operations which is a 172-meter-long vessel capable of carrying 2,136 twenty-foot containers (State of Green, 2023). Maersk plans to achieve net-zero GHG emissions by 2040 across the entire business and aims to transport a minimum of 25% of ocean cargo using green fuels by 2030. (“Maersk secures green methanol for maiden voyage of the world’s first ...”) Not only this, A.P. Moller Holding announced the establishment of the company C2X in September 2023, which will build its own large-scale green methanol production facilities around the world with the goal of having a production of three million tons per year by 2030. Maersk has further ordered 18 large methanol-enabled vessels, that will be delivered between 2024 and 2025 (MAERSK, 2024).

Further research was done on how various types of ships are adopting to alternate fuels where our main focus was to see the behaviour of tanker ships. By comparing the percentage of tanker vessels using alternate fuels against other types of vessels, some analysis on which ship type owners are investing the most for decarbonisation can be made. Based on the data collected from Clarksons SIN, the table below represents the industry average of current fleet as well as orderbook of different ship types using alternate fuels. The table also represents the average age of these ship types. However, it is unclear from Clarksons data whether this percentage includes only the alternate fuel capable vessels or alternate fuel ready vessels or both. Data as of Aug 2024.

Table 2: Average age and percentage of alternate fuel vessels

S No.	Type of Vessel	Alt. Fuels % (Current fleet)	Alt. Fuels % (Orderbook)	Average age
1	tankers	1.5	13	15
2	Container ships	2.3	55.5	13.9
3	Bulk Carriers	0.5	5.3	12.4
4	LNG	74.2	100	10.9
5	Car Carrier	5.9	86.8	15.9
6	Cruise	7.1	55.9	17.9
7	Total	6.6	34.6	18.5

Source: Author, based on data provided by Clarksons (Clarksons, 2024)

2.5.5.1 Current fleet using alternative fuels:

LNG Vessels led the market with 74.2% of the current fleet estimated to be running on alternative fuels whereas car carriers and cruise ships currently have a very low penetration rate of the current fleet using the various forms of alternative fuels, at 5.9% and 7.1% respectively. tankers, containers and bulk carriers have the least percentage of adoption in their current fleets ranging from 0.5% to 2.3%.

2.5.5.2 Orderbook (future fleet) using alternative fuels:

For the orderbook, LNG and car carriers are fully focused on alternative fuels, with 100% and 86.8% of their orderbooks to incorporate the use of the alternative fuel.

Container ships and cruise ships also have considerable dedication with 55.5% and 55.9% of their future fleets to be designed for, and built to run on, alternative fuels.

Tankers and bulk carriers once again are seen to be adopting the technology at a considerably lower pace with only 13% and 5.3% of their orderbooks, respectively, designed for alternative fuels.

2.5.5.3 Average age of the fleet:

LNG vessels have the youngest fleet with an average age of 10.9 years. Bulk carriers and container ships have a slightly younger fleet, around 12.4 and 13.9 years, respectively. Tankers and car carriers have older fleets, the average age of fleet being 15 and 15.9 years, respectively. Cruise ships have the oldest fleet with average of 17 years in the industry.

2.5.5.4 Comparative analysis of tankers with other ship types

- **Adoption in the Current Fleet:**

Tankers are placed at almost the bottom of the table, just ahead of bulk carriers, showing they are less adoptive in the use of alternate fuels, with only 1.5% of the fleet using alternative fuels compared to 74.2% for LNG vessels.

- **Focus on the Orderbook:**

Although tankers too have some orderbook improvement in place (13% future vessels designed for use of alternative fuels); however, it is still not as high as LNG at 100% or car carriers at 86.8% of their orderbooks for those catering for alternative fuels.

- **Fleet age and Modernization:**

Looking at the tanker fleet, the average age of this fleet is 15 years, which implies that there may be prospects of fleet replacement in the future hence leading to the adoption of other sources of energy. However, the current orderbook percentages show that this process might be slower than in other sectors.

2.5.5.5 Conclusion

LNG vessels are on the front line of the decarbonization process, both in terms of today’s fleet and tomorrow’s orderbook. **Tankers** are lagging with only a small proportion of their current and future fleet designed to run on alternate fuels. From the data, it is evident that the tanker companies are less sensitive or slow in adopting the new fuels, and this could be as a result of the following factors: age of the existing fleet, economic factors or technical factors arising from retrofitting or construction of new tankers with the new fuel type. **Car carriers and cruise ships** are also displaying a higher level of interest towards the use of new fuels in the future fleets and hence, the overall theme of decarbonization appears to be an industry-wide process, although at a different pace depending on the type of vessel.

2.6 Economic Impacts on Oil Markets – Forecast for 2045

As per OPEC World Oil Outlook 2045 (OPEC) , The primary energy demand of world is projected to increase from about 291 million barrels of oil equivalent per day (mboe/d) to approximately 359 mboe/d in 2045, mainly driven by non-OECD countries. The growth is expected to slow down from high short-term rates to more modest long-term increments. The fastest projected growth is seen in wind and solar, however, oil is considered the largest fuel in the energy mix. Demand for oil will grow strongly too, and despite the decrease of its proportion in the energy balance, oil will remain the most used fuel in 2045 by 29.5%. With coal expected to be the only energy to experience negative growth of 21.5% between 2024-2045, natural gas is estimated to replace coal as the second most demanded energy by 2030 with a share of 24.2% by 2045. Nuclear, Hydro and Biomass will all see a substantial increase in growth of 2%, 1.3% and 1.2% per annum respectively during the forecasted period. The proportion of other renewable sources in the energy consumption will increase from 2.7% in 2022 to 11.7% in 2045. Fossil fuels (oil, coal and gas) will reduce from above 80% in 2022 to about 69% in 2045 because of the reduction in coal energy. However, the total percentage of the oil and gas in the energy generation does not decrease and it is 54% in 2045 (OPEC, 2023).

When focusing on the long-term outlook in 2045 (see table below), the global oil demand is expected to increase even more to 116 mb/d, an increase of more than 16 mb/d from 2022. The long-term increase will be led mainly by non-OECD countries as they are expected to increase their demand by almost 26 mb/d while OECD demand is expected to decline by about 9 mb/d. India is expected to be one of the leading sources of this growth adding an extra 6.6 mb/d to oil demand by 2045. Among other players, oil demand is set to increase by other Asia (excludes India and China) at 4.6 mb/d, China at 4 mb/d, Africa at 3.8 mb/d and the Middle East at 3.6 mb/d (OPEC, 2023). The major industries driving this oil demand increase are road transportation, petrochemicals, and aviation industries. These sectors are expected to grow by 4.6 mb/d, 4.3 mb/d, and 4.1 mb/d, respectively. As for the refined products, major long-term demand is expected for jet/kerosene (4 mb/d) followed by ethane/liquefied petroleum gas (3.6 mb/d), diesel/gas oil (3.1 mb/d), naphtha (2.5 mb/d) and gasoline (2.5 mb/d). (OPEC, 2023)

Table 3: World primary energy demand by fuel type, 2022-2045

	Levels (mboe/d)						Growth (mboe/d)	Growth (% p.a.)	Fuel share (%)	
	2022	**2025**	**2030**	**2035**	**2040**	**2045**	**2022-2045**	**2022-2045**	**2022**	**2045**
Oil	90.7	96.4	102.0	104.3	105.3	106.1	15.4	0.7	31.2	29.5
Coal	75.9	74.6	71.1	65.9	60.0	54.4	-21.5	-1.4	26.1	15.1
Gas	67.1	69.6	75.0	80.2	84.4	87.0	20.0	1.1	23.1	24.2
Nuclear	15.0	15.9	17.4	19.4	21.7	23.8	8.8	2.0	5.2	6.6
Hydro	7.7	8.2	8.9	9.6	10.2	10.5	2.8	1.3	2.7	2.9
Biomass	26.6	27.9	30.2	32.3	34.1	35.2	8.6	1.2	9.1	9.8
Other renewables	7.9	11.2	18.5	26.7	35.8	42.2	34.3	7.5	2.7	11.7
Total	290.9	303.9	322.9	338.3	351.6	359.2	68.3	0.9	100.0	100.0

mboe/d, %

Source: (OPEC, 2023)

Table 4: Long-term oil demand by region (2022-2045)

	2022	2025	2030	2035	2040	2045	Growth 2022-2045
OECD Americas	25.0	25.5	25.8	24.8	23.2	21.5	-3.5
OECD Europe	13.5	13.5	13.1	12.0	10.8	9.8	-3.7
OECD Asia-Pacific	7.4	7.5	7.2	6.6	6.0	5.4	-2.0
OECD	45.9	46.5	46.0	43.4	40.0	36.7	-9.3
China	14.9	16.8	17.8	18.2	18.5	18.8	4.0
India	5.1	5.9	7.3	8.8	10.2	11.7	6.6
Other Asia	9.0	9.9	11.1	12.1	12.9	13.6	4.6
Latin America	6.4	6.9	7.8	8.4	8.7	9.0	2.5
Middle East	8.3	9.4	10.0	10.7	11.4	11.9	3.6
Africa	4.4	4.9	5.9	6.6	7.4	8.2	3.8
Russia	3.6	3.8	4.0	4.0	3.9	3.9	0.3
Other Eurasia	1.2	1.2	1.3	1.4	1.5	1.5	0.3
Other Europe	0.8	0.8	0.9	0.9	0.8	0.8	0.0
Non-OECD	53.6	59.6	66.0	71.0	75.4	79.4	25.7
World	99.6	106.1	112.0	114.4	115.4	116.0	16.4

Source: (OPEC, 2023)

2.7 Key Findings from Recent Research

The shipping sector is an important player in the sustainability debate, accounting for nearly 3% of global GHG emissions. Although shipping contributes relatively less GHG emissions as compared to other sectors like power and road transport, without further action, emissions from this sector would continue to rise. To achieve decarbonization and avoid dangerous levels of global warming, the sector must reach an agreement on regulatory frameworks and mitigation strategies. As per UNCTAD, decarbonization in shipping requires a shift in technology and operations and consuming low and zero emission fuels. This transition, would however, result in higher maritime logistic costs, shipping rates and voyage times. Shipping is a global business with ships involved in diverse national and international waters, making it challenging to implement differentiated rules i.e. by flag state or ownership, trade route, type of commodity or fleet profile. Delaying actions to mitigate GHG emissions would be costly as it will lead to more steeper emission reduction targets. Investments need to be made in new ship building related to design, engines, onboard technologies, propulsion system and alternate fuel capability. Bunkering infrastructure needs to be expanded for easy supply of alternate fuels.

As per Clarksons Research, newbuild contracts for alternate fuel types are going at a steady pace. In H1 2024, 310 alternative fuel-capable newbuilds (17.2M grt) accounting for 41% share of tonnage was ordered. This included 109 LNG dual-fuel ships (11.5 grt), 49 for methanol (2.7M grt), 42 for LPG (1.7M grt), 15 for ammonia and 4 for hydrogen. In 2023, shipowners invested in 578 such vessels accounting to about 40% share of tonnage while in 2022, newbuilds represented about 54% of the tonnage ordered. LNG was the most preferred alternate fuel in 2023 with 221 ships of 19.3M grt, followed by methanol (135 ships, 10.7M grt).

Earlier this year, an ultra-large 16,000-TEU container ship *Astrid Maersk,* running on methanol dual fuel was launched, which Maersk says, can sail 23,000 nautical miles (41,000 km) when fully bunkered. On the other hand, ship owners who are at the moment not ready to invest in alternative fuel-capable newbuild kept their options open by ordering fuel-ready ships. These are the ships designed with engines, systems and space in place, capable of being retrofitted to green fuels as and when owner decides. Around a fifth of all newbuilds — 169 orders, or 22% of tonnage comprises of these kinds of ships. Based on projected investment, 20% of global fleet will be alternative-fuel capable by 2030, says Steve Gordon, Global Head of Clarksons Research. However, all is not well with the port and bunkering infrastructure which continues to lag on the availability of “green” fuels. He further says Clarksons data shows 273 ports with LNG bunkering and 251 ports with shore-power connection in place or planned, but only 29 ports with methanol bunkering available and planned. This can be one of the reasons as LNG continues to be the preferred choice of alternate fuel among shipowners. Due to the limited availability of low- and zero-carbon fuels, existing ships must be retrofitted with ESTs in order to comply with the CII. But ship-repair capacity is limited, and so delivery times extend as long as 3.5 years for the latest orders. Overall, the global average fleet age has also increased to 12.8 years from 9.7 in 2013. In 2023, more than 30% of fleet capacity received a D or an E rating under CII. Clarksons believes that the current pace of investments by the shipowners in alternative fuel newbuilding and ESTs is not enough to bring the emissions below pre-pandemic levels. (Snyder, Turning green: 20% of global fleet will be alternative-fuel capable by 2030, 2024)

2.8 Conclusion

Literature review reveals a complex of issues and prospects of decarbonization of oil tanker transportation. Decarbonization is taking place due to the strict international requirements, for example, IMO and EU regulations, and due to the increased market requirements for sustainable practices. The shift towards more environmentally friendly shipping practices is therefore revolutionizing the industry by changing the characteristics of the fleet as well as the technologies used.

However, there is a growing pressure to increase the efficiency of the industry through such measures as EEXI and the CII, though there are fears about the way they will be implemented and their impact on the shipowners financially. Also, the fact that most of the leading tanker companies have not shifted from traditional fuel sources to the use of more sustainable fuels implies that more stringent measures will be required to bring the industry in line with the global climate change measures.

Wind-assisted propulsion and carbon capture systems are the modern solutions to the emissions problem, but their implementation is still in its initial stages. The economic implication of these decarbonization efforts is enormous, and the long-term projections of the global energy demand that would inform the oil tanker market going forward. However, as per OPEC forecast, the use of fossil fuels in the industry is expected to continue where oil and gas are going to be the dominating energy sources in the future.

In summary, the process of decarbonization of the sector of oil tankers is a challenging and long-term task that implies finding the right approach to the legal requirements, economic efficiency, and technological developments. Future configuration of tanker fleet and tankers’ operational life cycle will highly depend on these factors which underlines the importance of regular updates and preparedness among the industry’s stakeholders for the changes that are to occur in the future.

3 CONCEPTUAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

3.1 Introduction

After discussing various factors in the Literature Review, which affect the shipping Industry's efforts for decarbonization, a conceptual framework to understand the relationships between decarbonization policies, technological innovations, regulations, and their impact on the shipping industry, particularly focusing on the tanker sector will be developed. A specific hypothesis will also be developed to test our study. It is going to outline the connections between the major variables defined during the process of literature review. All the hypotheses will be based on the evidence and trends derived from credible sources as detailed out in the previous section and does not intend to criticize or favor any market.

3.2 Conceptual Framework

The conceptual framework will depict the key constructs and their relationships. With the help of a visual diagram (or conceptual model), the hypothesized relationships between the variables identified in the literature review will be identified. The analytical framework for analyzing the effects of global decarbonization initiatives on the oil tanker industry combines several related factors. It is a useful conceptual map that helps to examine the relations and consequences in the industry and lay a foundation for further research and forecasts.

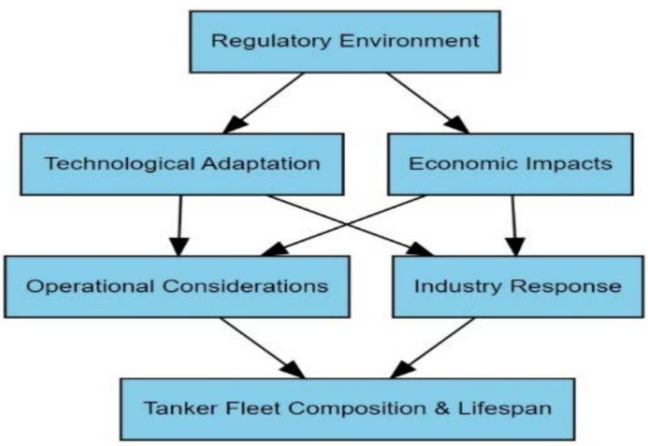

Figure 7: Conceptual Framework model

Source: Author, created using R Studio

3.2.1 Regulatory Environment

As discussed in section 2.2 and 2.4, the legal requirements play a very important role in influencing the decarbonization process in the oil tanker industry. The IMO has played an important role in developing very high standard of emission reduction targets of GHG from ships. It is an effort accompanied by key regulations in the form of EEXI and CII that apply not only to newbuilding but also the existing fleet.

International Regulations: It is evident from section 2.1 on decarbonization policies that IMO is becoming stricter with its regulations over time. These regulations affect the design of the ships, type of fuel used, and the practices adopted by the industry thus requiring it to be very responsive.

Regional Policies: Apart from IMO, several nations are designing the regulations concerning emissions as discussed in section 2.4. These policies also introduce another layer of regulation and establish market-based solutions for curbing emissions.

The legal framework therefore plays a role of a change agent that puts pressure on the oil tanker industry to seek for better ways of carrying out its operations in a more environmentally friendly manner.

3.2.2 Technological Adaptation

As earlier explained in section 2.5, this is an essential element that must be utilized to facilitate the international guidelines on decarbonization. Modern oil tanker industry is in the process of seeking for better operating efficiency as well as for reduction of emissions.

Ship Design: Modern ships are constructed based on some aspects of the future in mind to help in sustainability. This involves improving hull forms, improving propulsion, and installing energy-efficient devices and others like air cushioning and new generation engines. Another significant field of innovation is the modification of ships in order to meet the requirements of EEXI and CII.

Alternative Fuels: Among the innovations, the low-carbon and zero-carbon fuels are evident to form one of the most significant factors of the decarbonization program. While at present there are more users of LNG as an alternate fuel, there are other potential alternatives such as methanol, ammonia, and hydrogen. These fuels are solely determined by the accessibility of the fuel, the cost and suitability in the current or in newly designed ships.

Emission Reduction Technologies: Carbon capture systems, ship borne, and terminal are emerging as viable technologies for controlling CO_2 emissions. Another approach that has been recently put in practice is the wind assisted propulsion, for instance the Wind Challenger is among the innovative technologies in this category.

The technological adaptation is therefore an active component of the framework and has an impact on the probability and the price of achieving the decarbonization targets in the industry. However, it is still in its initial stages and its effectiveness can only be determined in future.

3.2.3 Economic Impacts

As elaborated in section 2.6, the economic consequences of decarbonisation are vast and affect the strategic management of shipowners, operators, and all the entities within the maritime sector.

Cost Implications: The transition to green technologies and fuels is capital-intensive since the change entails major capital expenditure. This encompasses expenses related to retrofitting of older generation ships, building new generation ships that conform to the new environmental standards as well as investing on new fuels. These costs may impact the revenues of the shipping firms, especially those with old vessels which may need major overhauls.

Market Dynamics: The global oil market is in the process of experiencing various changes because of the changes in the energy consumption patterns, and the shift to decarbonization and renewable energy sources. OPEC foresee increase in the demand for oil especially in the non-OECD countries and this will impact on the demand for oil tankers and their employment.

Economic factors are thus pivotal for explaining how the process of decarbonisation will affect the tanker industry in terms of fleet, life and competitiveness.

3.2.4 Operational Considerations

As highlighted in Section 2.4 and 2.5, the technological advancement and the existing and emerging regulatory policies have a great impact on the working factors of the shipping companies, especially concerning energy management, fuel selection, and meeting the decarbonization goals. There is every reason to assume that the process of decarbonization will lead to fundamental changes in the practical management of the oil tanker industry.

Fleet Composition: As the decarbonization policies are put in place, it is believed that the global tanker fleet will be transformed. It is also possible that older and less efficient ships may be phased out faster and new, technologically superior ships that meet the existing set of regulatory requirements are brought on line. This change will alter the distribution of tanker capacity globally and this has an impact on the market supply and demand.

Lifespan of Tankers: The life span of the tankers depends on factors such as environmental issues, technology and the market. Decarbonization may shorten the working life of some vessels that cannot be efficiently upgraded or modified to meet the new standards, therefore, early retirement and scrapping.

It is therefore useful to examine operational factors in order to predict the future organization and behavior of the tanker industry in the context of decarbonization.

3.2.5 Industry Response

As previously briefed in section 2.7, the actions of leading tanker firms in relation to decarbonization pressures define the direction of the industry's development.

Corporate Strategies: Current strategies being implemented by leading tanker companies include ordering newbuilds designed to operate on decarbonization fuels and improving the energy efficiency of tankers. The attitudes and capabilities of such companies to adapt and commit to the change towards sustainable business models will determine the rate and level of decarbonization in the sector.

Adoption of Innovations: The speed at which the industry implements new technologies like carbon capture systems and other types of fuels differ significantly. Some of them are more active, declaring themselves as pioneers in the shift towards environmentally friendly shipping industry, while others can be passive, which may lead to non-compliance with the new rules and loss of market share. The industry's reaction, therefore, in response to the external and internal forces that shape it will define the global efforts to reduce carbon emissions in the oil tanker industry.

3.2.6 Conclusion

The conceptual framework provided in this paper provides a broad range of factors by which the impact of worldwide decarbonization efforts on the oil tanker industry can be measured. In this respect, the present framework offers a structured approach for studying the regulatory factors, technological advancement, economic impacts, organizational changes and industry trends in order to determine the future direction of the tanker fleet and the entire maritime sector. This is a very important perspective for the stakeholders who wish to address the issues and challenges and benefits of the transition towards sustainability in shipping.

3.3 Hypothesis Development

Hypothesis 1: ***The adoption of decarbonization technologies is positively correlated with the operational efficiency of oil tankers.***

Rationale: As oil tankers adopt decarbonization technologies such as energy-efficient engines, alternative fuels, or emission reduction technologies, their operational efficiency may improve due to reduced fuel consumption and compliance with environmental regulations. This hypothesis will be tested by analysing data on the implementation of these technologies and their impact on tanker earnings and transport costs.

Hypothesis 2: ***There is a negative correlation between the age of oil tankers and adoption of decarbonization technologies.***

Rationale: Older oil tankers are likely to face challenges in meeting the stringent decarbonization regulations due to outdated technology and higher emissions levels. It will be not a wise decision for them to invest heavily in retrofitting when their remaining lifespan is very short. As such, they will try to comply with the bare minimum compliance requirements. This hypothesis will be evaluated by examining fleet age data alongside compliance with emission standards and the adoption of retrofitting measures.

Hypothesis 3: *Strict enforcement of IMO decarbonization regulations will lead to a significant increase in investment by tanker companies in emission reduction technologies.*

Rationale: Increasing pressure to decarbonization from various organizations especially IMO will force the tanker companies to adopt technologies which could help in reducing the emissions. This could be adoption of alternate fuels, installation of scrubbers and other structural changes. This hypothesis will be evaluated by analysing the investment trends in emission reduction technologies before and after the implementation of these regulations. The orderbook of tankers will also be studied to forecast the future outlook of these technologies.

4 RESEARCH METHODOLOGY

4.1 Introduction

This research methodology explains the scientific method that has been used to analyze the effects of decarbonization in the oil tanker industry. This study is based on a comprehensive quantitative analysis and for this purpose secondary data was collected from reliable sources. The approach was developed to provide a rigorous analysis of the given data and to facilitate the understanding of the trends and relationships existing in the shipping industry and especially concerning oil tankers.

4.2 Research Design

This research uses quantitative research approach with an emphasis on descriptive and exploratory research. The work builds on the existing theoretical and empirical knowledge to identify the effects of decarbonization measures, industry standards, and innovations on oil tankers. Due to the nature of the topic, the focus is made on data collection, data analysis, and statistical evaluation to identify trends and relationships that are important for the answers to the research questions.

4.3 Data Collection Methods

The study is purely based on secondary data which is collected from standard and reliable sources. Datasets were collected from Clarksons Research and OPEC whereas UNCTAD, DNV and IMO gave important industry analysis reports.

- **Clarksons Shipping Intelligence Network**: This was the primary source of quantitative data which offered reports including the oil and tanker trades outlook, world fleet composition, company, orderbook data and more. Clarksons datasets ranges from 2005 and covers data up to July 2024. Various tabs on the Clarksons Research Shipping Intelligence Network (SIN) website like “Reports”, “Timeseries and Graphs”, “Fleet” and “Companies” were accessed. The data was then collected from various yearly reports and combined into a table representing different time periods. Some data in the form of reports were downloaded whereas some were accessed directly from the website. The direct links for each dataset is provided in the Bibliography at the end of this paper. Anybody with access to Clarksons SIN can get access to these datasets. Key data collected included:

a) Fleet lists by type of ship and orderbook for newbuilding.
b) Conversion to ‘green’ technologies and related information.
c) Scrap prices, values and the number of idle tankers.
d) Tanker specific emission data and the fleet composition of the different companies including their eco profile.
e) Economic performance indicators including profits, cost of transport, and age of the fleets.

- **IMO:** The policy and regulatory sources were identified from the IMO’s documentation including the reduction of emissions policies and the strategy on the route to decarbonization of the shipping sector.
- **UNCTAD**: Presented emission data for other vessel types which allows to put tanker emissions into context of the entire shipping industry.
- **DNV Energy Transition Outlook**: Provided a brief on new technologies for emissions cuts in shipping to supplement the Clarksons data by focusing on the future technologies.
- **OPEC World oil Outlook**: The recently published OPEC World oil Outlook 2023 (WOO) on 9 Oct 2023 provides a comprehensive analysis and prognosis of the medium and long-term outlook for the world’s oil and energy demands upto 2045. It helped to understand the future market environment of oil tankers

The data was collected, sorted and incorporated into tables to form a basis of the next step of analysis.

4.4 Data Analysis Methods

The data was analyzed through descriptive statistical analysis and correlation analysis, and this was made easier by the R Studio.

- **Trend Analysis**: Historical, current and forecasted data were employed to analyze the trends in the fleet structure, decarbonization technologies, emissions and the economic efficiency of oil tanker industry. This involved coming up with custom tables that would help in compiling information from various sources with an aim of capturing some of the important trends.

- **Correlation Analysis:** To establish the correlation between factors such as age of the fleet, environmentally friendly technologies, emissions, transport cost and income, descriptive statistics tests were done. The correlation coefficients were also determined using R Studio which provided a confirmation on the nature and strength of these relations.
- **Visualization**: Graphs and charts were created in R Studio to visually represent trends and relations. These visualizations were used as a way of making data relationships easy to understand and helped in the assessment of the results.

4.5 Validity and Reliability

To increase confidence in the research, data was only collected from established and reputable journals only. The reliability of the findings was further enhanced by cross checking information from other sources for example, comparing the Clarksons fleet composition data with emission data from UNCTAD. The use of proper statistical analysis in R Studio further augmented the validity of the results arrived at.

4.6 Ethical Considerations

Due to the fact that the research was conducted using only secondary data there were few issues of ethics that came up. All the information gathered from different sources were acknowledged to give credit to the original authors and organizations. No type of confidential or sensitive information was used and the study was done in accordance with the principles of academic integrity. Permission was taken by Clarksons directly to use the Clarksons SIN data provided to us by university on behalf of Clarksons.

4.7 Limitations

The first limitation of this study is that the data used in this study is secondary data and this may contain some bias and inaccuracy since the data is collected from other sources. For e.g., OPEC may be biased towards forecast of oil demand. Shipping market is continuously evolving and there can be around 50 newbuild orders every week which can affect our data and analysis. There can be some confidential data like spot rates or latest data involving technological advancements in shipping which may still not be available in the open domain. The impact of policies on oil tankers can also be affected by various geopolitical events like US-China trade war of 2018, COVID-19 pandemic of 2019, Russia-Ukraine war of 2022 which can influence the oil market and our interpretation about the data. Also, the regulations like CII and EU ETS have recently been enforced and it will be unfair to analyze its impacts and early to reach to a conclusion. Additionally, there is no primary data collection such as surveys or interviews in the current research which may affect the depth of the qualitative study. Since the experts have a vast industry knowledge and they can better interpret the findings of research, hence the external validation of my findings could not be achieved. However, the application of multiple and reliable data sources minimizes some of these limitations to some extent.

4.8 Conclusion

The method used in this study was developed in such a manner that information would be collected, processed and analysed scientifically concerning the effects of decarbonisation on oil tankers. This minimizes the likelihood of arriving at a sample that is influenced by random variation and thus the results achieved are suitable for the current and the future trends of the shipping industry.

5 RESULTS

5.1 Overview of the Impact of Decarbonization on the Tanker Fleet

Decarbonization in shipping Industry is growing at a quicker pace. While IMO is responsible for designing policies which could help reach the decarbonization targets, there are regional regulations also coming up from especially developed regions like the European Union. Stricter regulations like CII and EU ETS have recently been introduced. Since these regulations are relatively new, its effects on reducing the GHG emissions will only be visible in the future. Shipping companies are still in the transition phase, trying to figure out what will be most efficient and economical option for them in the future, as is evident from the different technologies they are trying. A majority of the vessels are being designed as alternate fuel capable vessels, with the option to retrofit in the future. The orderbook of tankers show promising growth of alternate fuel vessels and this will contribute significantly to curb GHG emissions.

To understand the pattern as to how oil tankers are adopting to various technologies for reducing emissions, a comparison of the last 5 years percentages of total Crude tankers and Product tankers fleet running on Electronic Engines, fitted with Sulphur Oxides (SOx) Scrubber and capable of running on alternate fuels was made. Before moving further with the analysis, it is important to first understand these terms.

- **"ECO" Fleet –** Ships fitted with better engines, hull forms, propellers and design modifications to reduce fuel consumption and save operational costs.
- **SOx Scrubber -** Scrubbers or EGCS is a structure fitted on board to prevent harmful SOx and Nitrogen Oxides (NOx) from the exhaust gasses generated as a result of combustion processes in marine engines from releasing into the atmosphere. This system gained popularity especially after IMO 2020 as the ships fitted with scrubber were permitted to carry fuels with sulphur content up to 3.5% as against the regulation of 0.5%.

Table 5: Overview of decarbonization technologies adopted by tankers

Year	"ECO" Fleet (% m dwt)		SOx Scrubber (% m dwt)		Alt. Fuel Capable (% m dwt)		% change in Avg GHG emission per vessel from previous year
	Crude	Product	Crude	Product	Crude	Product	
2020	28.5	29	27.1	14.1	0.4	0.0	-4.18
2021	31.9	32.3	34.2	16	0.6	0.4	-4.55
2022	35.6	34.5	37.4	16.6	1.2	1.3	-0.13
2023	37	36.1	43	18.6	2.3	1.9	-0.98
07/2024	37.2	36.7	44.7	19.7	2.5	2.2	+2.27

Source: Author, based on data provided by (Clarksons Research, 2020-2024, p. 2)

The steady growth in crude tankers in the "ECO" fleet from 28.5% in 2020 to 37.2% by mid-2024 and product tankers from 29% to 36.7% during the same period reflects the industry's gradual shift toward adopting more energy-efficient technologies. However, the growth has slowed down after 2022, indicating that the adoption rate might be reaching a saturation point.

The adoption of SOx scrubbers among crude tankers increased significantly, from 27.1% in 2020 to 44.7% by mid-2024 while the product tankers witnessed a lower adoption rate possibly due to differences in operational areas or the economics of installing scrubbers on these vessels. However, both types of tankers show continuous uptrend in growth suggesting a strong response to the IMO 2020 regulation that limits sulphur content in fuel.

The percentage of crude tankers capable of running on alternate fuels increased from a mere 0.4% in 2020 to 2.5% by mid-2024. Product tankers are catching up with the crude tankers with alternate fuel capable vessels reaching 2.2% of their total fleet. Although still a small percentage of the total fleet in both the cases, this growth indicates a growing interest in future-proofing vessels against stricter emissions regulations. The marginal increase suggests that alternate fuel technology is still emerging within the tanker sector, and broader adoption may require more time and technological advancements.

To conclude, the table illustrates the gradual adoption of emission reduction technologies in the oil tanker sector over the past five years. The slow growth in the

“ECO” fleet in the past couple of years suggests that the reduction in fuel consumption did not meet the expectations of owners. In case of SOx scrubbers, the higher adoption rate in Crude tankers, especially Very Large Crude Carriers (VLCCs) is likely because they are known to sail longer voyages, whereas product tankers spend much of their time in cargo operations. Most of the ports do not allow use of scrubbers within their port limits and therefore tankers spending most of their time in open seas gets advantage of this technology. The adoption of alternate fuels remains in its early stages, highlighting the challenges and costs associated with transitioning to greener technologies. In conclusion, continuous steady growth in all the 3 technologies within tankers reflect the industry's response to tightening environmental regulations, particularly the IMO 2020 and relatively new regulations like the CII and EU ETS, however the relatively slow adoption of alternate fuels suggests that the industry still has a long way to go to meet the IMO's ambitious decarbonization targets.

5.2 Analysis of Decarbonization Policies and Their Effectiveness

As discussed in section 2.1, policies such as the Paris Agreement and IMO regulations are leading to changes in the maritime industry. These policies exert external pressure on shipping companies to adapt and innovate. In section 2.3, some important regulations like CII and EU ETS, initiated by IMO and European Union respectively was discussed. Since these policies and regulations are closely linked to each other and focus on the primary goal of reducing GHG emissions from ship directly or indirectly, they have been combined in this section. The question arises how effective these policies are in meeting their targets.

IMO’s strategies of 2018 and 2023 focused on long term targets to reduce GHG emissions in shipping but did not make any mandatory requirements whereas IMO’s Sulphur Cap was a compliance requirement which directly dealt with GHG emissions reduction whereas the recent CII and EU ETS regulations are indirectly responsible for controlling the emissions from shipping, discussed further below. To understand which policy or regulation contributed to the most efficient shipping operations and to what extent, the trends of GHG emissions from shipping need to be observed. Since the first IMO Strategy was adopted in 2018, the data was collected from 2015 to understand about the past trends. Total GHG emissions emitted from the world shipping fleet over the last decade were taken. Since the world fleet is changing every year, it would be unfair to reach a conclusion by only looking at the total GHG emissions. Hence, a comparison was made with the total world fleet including all ship types in terms of number of vessels over the same period which could give us the average GHG emission per vessel. This way, a reasonable conclusion can be reached to see how the efficiency of vessels have evolved over time. The year-wise percentage change is also shown in the table to quickly notice the impact of a particular emission on vessel efficiency.

Based on the data collected from Clarksons research, the table below depicts the global GHG emissions from shipping, year wise in the last 10 years along with world shipping fleet in terms of number of vessels (Clarksons Research, 2024).

Table 6: GHG emissions of world shipping fleet (2015-2024)

Year	World shipping Fleet GHG Emissions, Well-to-Wake, CO_2 Eqv. Million tons	% change from previous year	World Fleet (No. of Vessels)	change in world fleet from previous year (%)	Avg GHG from vsl (in tons of CO_2-eq per vessel)	% change in Avg GHG emission per vessel from previous year
2015	995.4	NA	93,683	NA	10,626	NA
2016	987.2	-0.82	94,917	1.3	10,401	-2.12
2017	995.4	+0.83	96,091	1.2	10,358	-0.41
2018	1007.8	+1.25	97,236	1.2	10,364	+0.06
2019	1015.6	+0.77	98,823	1.6	10,276	-0.85
2020	1017.5	+0.19	103,337	1.4	9,847	-4.18
2021	986.6	-3.04	104,944	1.6	9,400	-4.55
2022	1002.7	+1.63	106,847	1.8	9,388	-0.13
2023	1012.9	+1.02	108,935	2.0	9,296	-0.98
2024[1]	1045.5	+3.2	109,940	0.9	9,507	+2.27

Source: Author, based on data provided by (Clarksons Research, 2024)

[1] Data as of July 2024 starting

1. **Trends of Global Shipping Emissions**

As shown in the graph below from the data in the above table, the period from 2015-2020 witnessed a consistent increase trend in global shipping fleet emissions with exception in 2016. A significant drop to 986.6 million tonnes was seen in 2021, a 3.04% reduction from previous year which is likely due to the impacts of the COVID-19 pandemic. The outbreak of COVID-19 impacted the global trade and supply chain significantly. In 2020 and 2021, several countries implemented lockdowns and restrictions on traveling, which affected the shipping demand and events that caused fewer voyages. Therefore, the total distance of the global fleet of ships could have been reduced, and this may have led to the reduction of global emissions irrespective of the increase in the number of ships. After the dip in 2021, the emissions increased significantly reaching to 1045.5 in the first half of 2024. On the other hand, fleet growth has been fairly consistent with recent years showing strong uptrend of upto 2%, suggesting a robust shipping market. While the fleet has grown by 14.8% from 2015-2024, total emissions have increased by only 4.8% which is a positive sign for the industry.

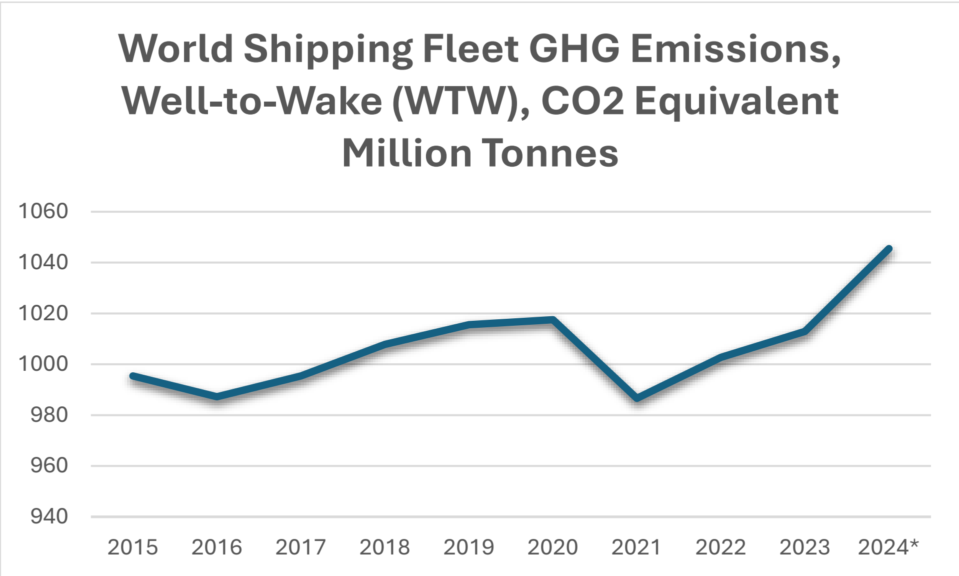

Figure 8: World shipping fleet GHG emissions (2015-2024)

Source: Author, using Excel, based on data provided by Clarksons

2. Impact of Major IMO Regulations on Decarbonization:

The graph below depicts a different picture when it comes to Average GHG emissions from vessel. The emissions show a continous downward trend with exception after 2023. This shows that the continous growth in the world shipping fleet is contributing to higher emissions while the increasing efficiency of the vessels is contributing to reduced emissions.

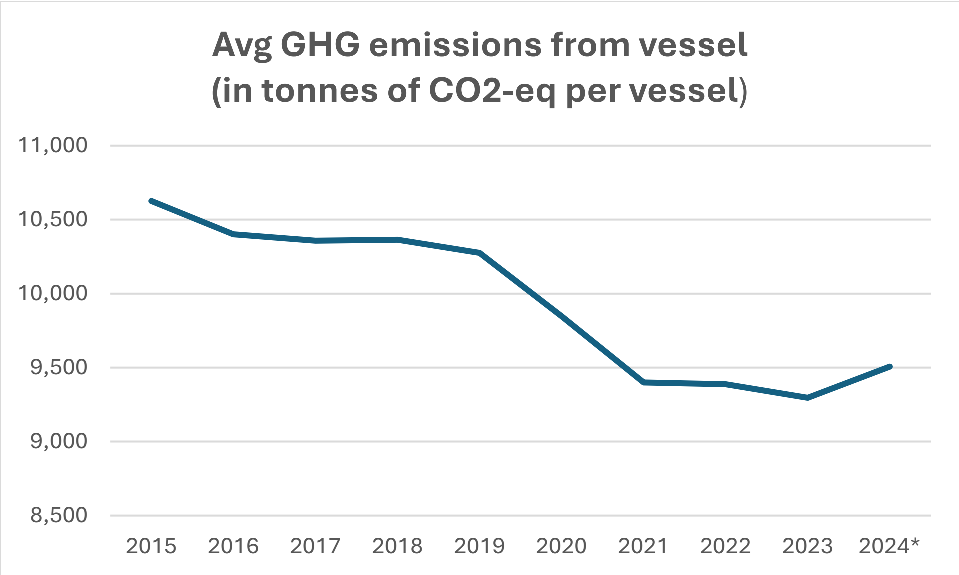

Figure 9: Average GHG emissions from vessel (2015-2024)

Source: Author, using Excel, based on data provided by Clarksons

- **IMO Initial Strategy (Adopted in April 2018):**

Policy Overview: The strategy aims to cut GHG emissions by 50% by 2050 and reduce CO_2 emissions by at least 40% by 2030.

Impact on Emissions:

Post-2018 Trends: The data from 2018 to 2020 shows a mixed impact. While GHG emissions continued to rise slightly from 2018-2020, the rate of increase in emissions and the average emissions per vessel started to decline post 2018. This suggests that while total emissions were difficult to control due to continuous fleet growth, the policy's focus on improving vessel's efficiency especially newbuilds through EEDI was creating desired results.

- **IMO 2020 Sulphur Cap (Effective January 2020):**

Policy Overview: This rule made it mandatory for ships to use marine fuel with sulphur content of not more than 0.5%, a significant reduction from previous limit of 3.5%. Consequently, it pushed the industry to use cleaner alternative fuels like VLSFO and LNG.

Impact on Emissions:

A slight increase of 0.19% was observed in total GHG emissions in 2020 but a significant 4.18% decrease in average emissions per vessel. This suggests that while the overall fleet size continued to grow, the switch to cleaner and low-sulphur fuels had a positive impact on emissions per vessel, indicating early success in decarbonization efforts.

There was a remarkable decrease in total emissions (-3.04%) and a further reduction in per-vessel emissions (-4.55%) in 2021. This could be due to the ongoing adoption of new fuel standards and the broader impact of IMO 2020, indicating that the policy was moving in the right direction and effectively contributing to reducing emissions. However, the effect of COVID pandemic, where global trade was impacted, and fewer vessels were in operation could also be a contributing factor in these reductions.

- **2023 IMO Strategy on GHG Emissions (Adopted July 2023):**

Policy Overview: The strategy introduces more ambitious targets, aiming for a 20-30% reduction in annual GHG emissions by 2030 and 70-80% by 2040.

Preliminary Impact:

While the total emissions increased slightly by 1.02% in 2023 as a result of a robust fleet growth of 2%, the average emission per vessel reduced almost by the same amount, thereby balancing the impact. However, a significant increase of 3.2% in total emissions and a 2.27% increase in average emissions per vessel, as compared to 2023 has already reached in the first half of 2024. This major increase could be the sign of transition pains of the new 2023 strategy as industries adjust to new measures such as the CII and the EU ETS. These measures are expected to encourage more decrease in the future years, but the initial implementation period is somewhat variable as the industry stabilizes.

- **CII and EU ETS (Effective January 2024):**

Policy Overview: CII measures and rates the operational carbon intensity of vessels, while EU ETS introduces a carbon market for shipping within the EU.

Expected Future Impact:

2024 Onwards: As the emissions indicate a gradual rise in early 2024, these regulations will likely enforce stricter compliance, leading to operational adjustments and potentially accelerating the scrapping of less efficient vessels. Given the positive outlook of newbuild vessels powered by alternate fuels, a more pronounced reductions in both total and per-vessel emissions in the subsequent years can be expected, as the industry aligns more closely with the new regulatory frameworks.

Conclusion:

The findings show that the process of decarbonisation in the shipping industry is slow and dynamic. The key takeaway is once you make a regulation and mandate a shipping company to comply with it, the results will be significant and immediate, while policies which require construction changes without pushing the industry to specific compliance requirements will yield results only in the long term. One of the most significant IMO policies has been the IMO 2020 which has been observed to have made significant impacts, especially in terms of the GHG emissions per vessel. IMO 2020 was the most effective due to its mandatory compliance. Shipping companies were left with no choice but to either adopt low sulphur fuels or to install scrubber on their ships. But this has been sometimes counterbalanced by an increase in the overall fleet size and therefore there are variations in the total emissions.

The minor rise in emissions seen in early 2024 indicates that, while policies such as CII and EU ETS are important, their effects will become more apparent in the future as also evident by efficient newbuilds orderbook. This means that constant monitoring and even more vigorous implementation of these rules will be required to make sure that they will achieve the desired cuts in international shipping emissions as dictated by the goals set for the year 2030 and beyond.

5.3 Effectiveness of Alternate Fuel Vessels on Curbing GHG Emissions

The following section will try to answer our 2nd research question, *"How efficient are alternate fuel vessels in controlling GHG emissions?".* The maritime industry is making efforts and looking for various technologies for transitioning toward decarbonization goals and meet the IMO's emissions reduction targets. Since the average age of a vessel is between 22.6 years (Clarksons Research, 2024, p. 3), a ship needs to be built efficient today amid increasing regulations and pressures from concerned organizations and in the long run to meet the 2050 net zero emission targets of IMO. Before shifting our focus on oil tankers, it is important to know how the broader shipping industry has evolved over the past decade and adopted technological advancements in efficient shipping. Although there are various ESTs like Fuel Cells, OCCS, hull modifications, scrubbers or EGCS, Eco Electronic Engines, wind-assisted propulsion, high efficiency propellers, ALS, waste heat recovery, EcoEGR, speed optimization and alternate fuels which focuses on efficient vessel operations, there is not enough data available to compare these various technologies, due to which a comparison with alternate fuel capable vessels will be made as this is the most commonly adopted technology today.

The table below gives an overview of the global shipping fleet tendencies for 2015-2024 with the focus on the trends of the use of alternative fuels and their impact on GHG emissions. In the last column, GHG Intensity (GT-based) was added to determine if there's a reduction in emissions intensity as alternate fuel-capable vessels become more prevalent. It is obtained by dividing the world shipping fleet GHG Emissions (as listed earlier) by total world shipping fleet in GT.

$$GHG\ Intensity\ (GT - based) = \frac{\text{World shipping fleet GHG emissions (CO2 equivalent)}}{\text{Total World shipping fleet (GT)}}$$

Gross Tonnage (GT) is an indicator that can be used to evaluate the fleet capacity in terms of the size of a vessel and its fuel consumption and, therefore, its GHG emissions. It explains the heterogeneity of the world's shipping fleet with regards to the type and size. For instance, two fleets with equal number of vessels may have a significant difference in their emissions if one of the fleets has larger vessels and these will emit more emissions. GT is also more suitable for regulatory authorities and the shipping industry because the CII regulation and the EU ETS pay attention to carbon intensity and total emissions more than to the number of vessels.

Table 7: Relationship between alternate fuel vessels and GHG emissions

Year	Total World Fleet (GT million)	Total Alt. Fuels Capable Fleet (GT million)	Percentage of Alternate Fuels Capable Fleet (%)	Total Alt. Fuels Capable Orderbook (GT million)	Percentage change in Alt. Fuels Capable Orderbook (%)	GHG Emissions Intensity (CO_2 Eq./GT)
2015	1184.4	21.93	1.85	19.88	NA	0.8403
2016	1228.62	25.71	2.09	21.73	+9.31	0.8037
2017	1267.12	30.56	2.41	18.37	-15.46	0.7854
2018	1310.6	34.61	2.64	22.17	+20.69	0.7692
2019	1350.66	42.11	3.12	25.99	+17.23	0.7517
2020	1404.53	48.45	3.45	33.89	+30.4	0.7246
2021	1444.72	55.45	3.84	39.85	+17.59	0.6829
2022	1491.95	68.42	4.59	61.55	+54.45	0.6724
2023	1541.0	80.86	5.25	94.51	+53.55	0.6572
2024[2]	1598.7	99.52	6.23	110.03	+16.42	0.6540

Source: Author, based on data provided by (Clarksons Research, 2024)

The percentage of alternate fuel-capable vessels increased continuously from 1.85% in 2015 to 6.23% in 2024. The GHG emissions intensity has decreased over the years from 0.8403 CO_2 Eq./GT in 2015 to 0.6540 CO_2 Eq./GT in 2024.

```
> print(correlation)
[1] -0.9419681
```

Using R Studio, correlation between the percentage of the alternate fuel-capable fleet and the GHG emissions intensity was calculated. The Pearsson correlation coefficient of **-0.942** suggests that as the percentage of

[2] Figures up to August 2024

alternate fuel-capable vessels increases, the GHG emissions intensity tends to decrease significantly.

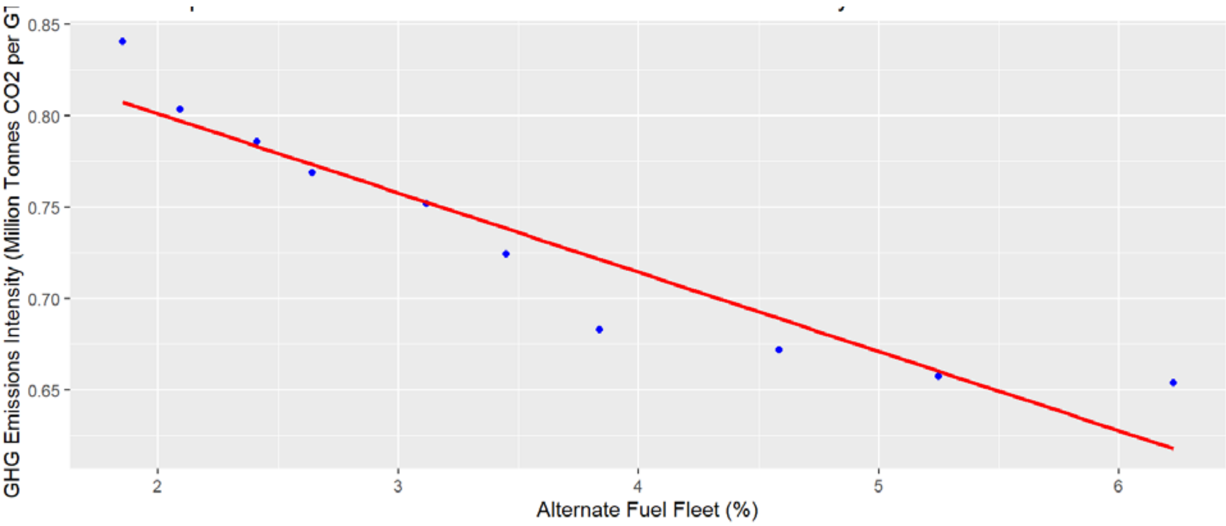

Figure 10: Graph representing relationship between alternate fuel vessel and GHG emissions intensity

Source: Author, using R Studio

A linear regression analysis was performed to examine the relationship between the alternate fuel percentage and GHG emissions intensity.

```
Residuals:
      Min        1Q    Median        3Q       Max 
-0.038551 -0.011476 -0.001916  0.005394  0.035939 

Coefficients:
                     Estimate Std. Error t value Pr(>|t|)    
(Intercept)          0.887748   0.020736  42.813 9.77e-11 ***
Alt_Fuel_Percentage -0.043328   0.005459  -7.936 4.62e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.02349 on 8 degrees of freedom
Multiple R-squared:  0.8873,	Adjusted R-squared:  0.8732 
F-statistic: 62.99 on 1 and 8 DF,  p-value: 4.625e-05
```

Figure 11: Linear regression analysis between AF vessel % and GHG emissions intensity

Source: Author, using R Studio

The coefficient estimate of Intercept **0.887748** suggests that without any alternate fuel-capable vessels, the GHG intensity would be approximately 0.8877 million tons of CO_2 per GT of the fleet. Alternate fuel percentage estimate of **-0.043328** or the slope (negative) of the regression line suggests that as the percentage of the fleet using alternate fuels increases, the GHG intensity decreases. In this case, for each

1% increase in the alternate fuel-capable fleet, the GHG intensity decreases by about 0.0433 million tons of CO_2 per GT. The p-value **4.625e-05** for the percentage of the alternate fuel-capable fleet is extremely small, indicating that the relationship between the percentage of the alternate fuel-capable fleet and GHG intensity is statistically significant. In other words, the decrease in GHG intensity with an increasing alternate fuel-capable fleet is not due to random chance.

Interpretation:

The regression analysis also indicates a strong probability that, the greater the percentage of the alternate fuel capable fleet, the lower the GHG intensity. This means that the vessels that are designed to operate on other fuels are playing a significant role in the process of decreasing the level of GHG emissions per unit of the fleet GT. This relationship is quite strong, and the coefficients are significant, the R-squared value is also high which means the model is a good fit.

5.4 Economic Implications of Decarbonization for the Oil Tanker Industry

To understand the economic impacts of decarbonization on oil tankers industry and answer our 3rd research question, *"What are the economic implications for oil tankers transitioning to efficient fleet?",* a comparison of the spot earnings per day of different types of tankers – Aframax, VLCC and Product tankers in 3 scenarios – 1) Eco vessel, 2) Fitted with scrubber and 3) Eco vessel fitted with scrubber was made. This comparison could show us the earning potential of the tankers if they adopt to decarbonization technologies which leads to their efficient operation.

Table 8: Comparison of Aframax tanker earnings in 3 scenarios (2021-2024)

	Avg Aframax Earnings ($/day)	**2021**	**2022**	**2023**	**06/2024**
Baseline	Spot	8,242	55,967	55,428	50,852
Scenario 1	Scrubber Fitted	11,229	63,830	59,529	54,439
Scenario 2	Eco	11,767	60,450	58,784	54,385
Scenario 3	Eco Scrubber Fitted	13,921	66,765	62,101	57,244

Source: Author, using data provided by (Clarksons Research, 2024)

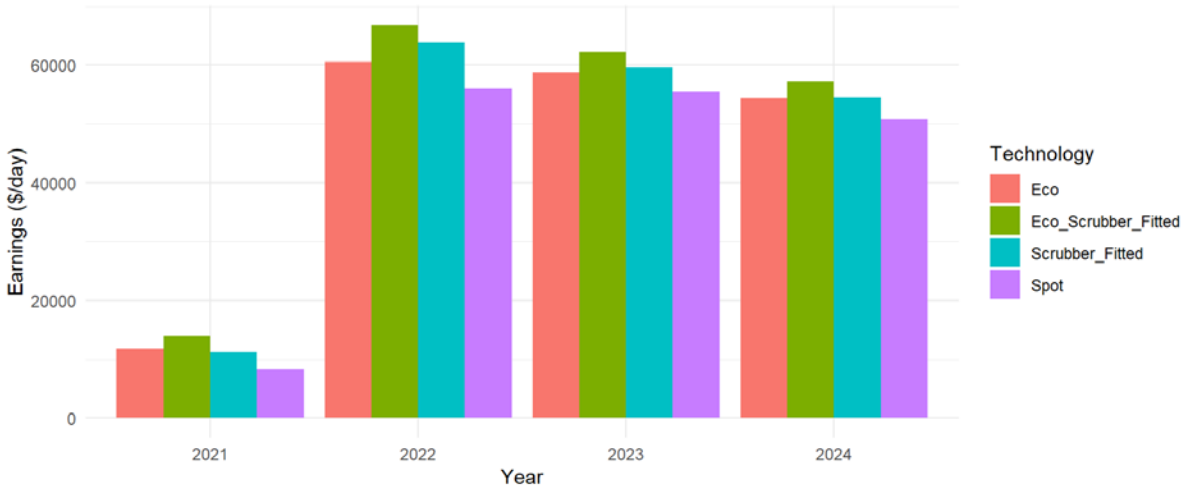

Figure 12: Comparison of Aframax tanker earnings in 3 scenarios (2021-2024)

Table 9: Comparison of VLCC tanker earnings in 3 scenarios (2021-2024)

	Avg VLCC Earnings ($/day)	**2021**	**2022**	**2023**	06/**2024**
Baseline	Spot	3,218	23,885	43,206	38,000
Scenario 1	Scrubber Fitted	8,342	37,335	50,610	43,826
Scenario 2	Eco	10,383	34,616	51,484	46,643
Scenario 3	Eco Scrubber Fitted	13,954	44,458	56,826	50,588

Source: Author, using data provided by (Clarksons Research, 2024)

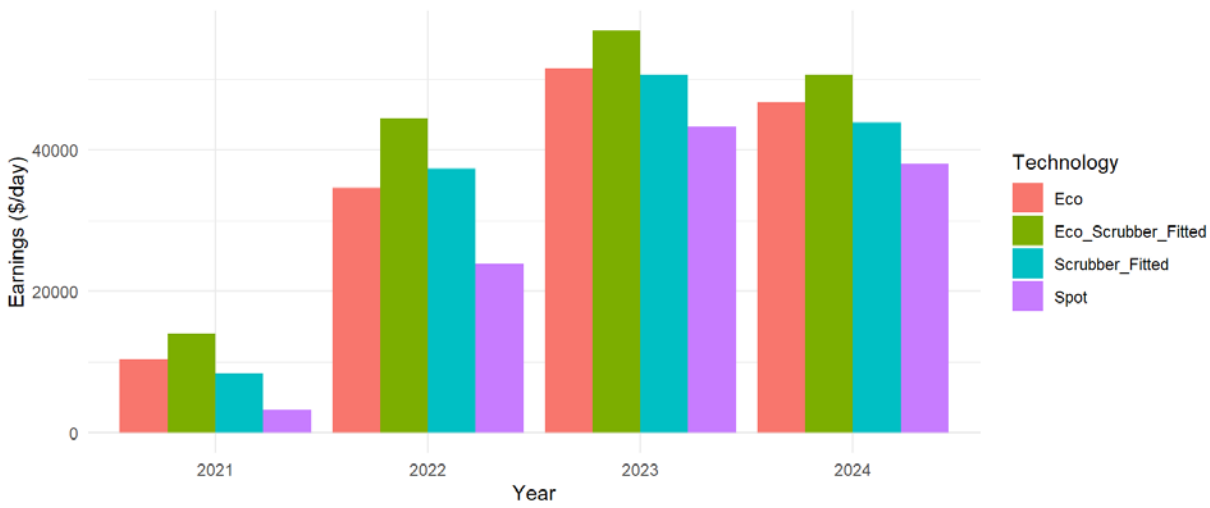

Figure 13: Comparison of VLCC tanker earnings in 3 scenarios (2021-2024)

Table 10: Comparison of Product tanker earnings in 3 scenarios (2021-2024)

	Avg Product tanker Earnings ($/day)	2021	2022	2023	06/2024
Baseline	Spot	6,740	31,775	26,948	32,047
Scenario 1	Scrubber Fitted	9,166	37,406	30,094	34,765
Scenario 2	Eco	10,593	37,584	31,489	36,200
Scenario 3	Eco Scrubber Fitted	12,153	41,353	33,549	38,029

Source: Author, using data provided by (Clarksons Research, 2024)

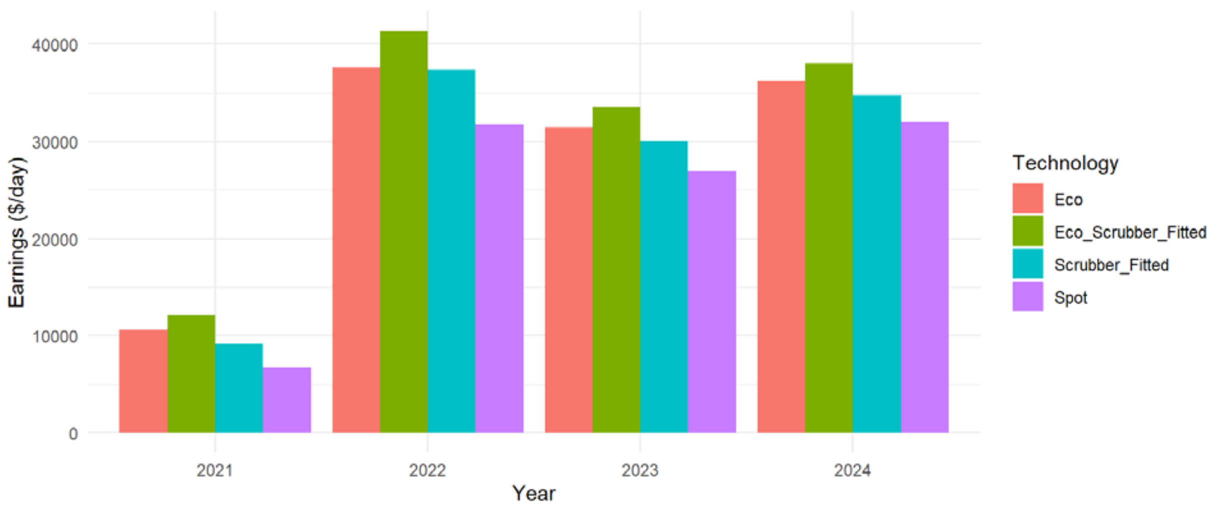

Figure 14: Comparison of Product tanker earnings in 3 scenarios (2021-2024)

Technological advancements: Scrubbers and Eco designs are evident to have a positive effect on tanker earnings across all vessels from Aframax and VLCC to product tankers as seen from the data and visualizations.

Yearly growth: For the period of 2021-2024, an increase in earnings is observed in all the cases with Eco scrubber fitted vessels earning the highest earnings. This trend implies that to obtain greater returns one must invest in new technologies for the tankers.

Strategic implications: Concerning the shipping companies, this analysis will justify the decisions to invest in Eco and scrubber technologies to increase their earnings in a new and competitive environment.

The table below shows the average crude oil transport costs across three types of tankers, namely VLCC, Suezmax and Aframax from year 2015 to 2024. These costs are in $ per thousand barrels per mile ($ ‘000bbl/mile).

Table 11: Average crude oil transport costs ($ per '000bbl/mile)

Tanker type	2015	2016	2017	2018	2019	2020	2021	2022	2023	06/2024
VLCC	0.32	0.22	0.17	0.19	0.28	0.31	0.32	0.16	0.32	0.33
Suezmax	0.63	0.43	0.36	0.42	0.56	0.48	0.50	0.34	0.82	0.84
Aframax	1.12	0.91	0.78	0.79	0.94	0.85	0.86	0.73	1.83	1.77

Source: Author, based on data provided by (Clarksons Research, 2024)

The data reveals that after a period of decline in crude oil transport costs from 2015-2017, the market was relatively stable until 2022, showing signs of small recovery and weakness both. The spike after 2022 and till date may suggest some changes in the market including increased demand, high fuel costs, longer sailing distances or other factors such as geopolitical tensions affecting the oil transportation industry. Tanker owners may be recovering the cost of heavy investments in retrofitting and expensive fuel oil with the transportation costs in the form of freight rates.

5.5 Technological Options and Adoption in the Tanker Industry

To address the 4th research question, *“Which decarbonization technologies are being adopted by leading tanker Companies?”,* the adoption rates of eco-friendly technologies among top 20 tanker companies were checked in order to highlight tanker specific leaders, followers and laggards. This helped to analyse the priority of different tanker companies towards emission targets. Thereafter, a comparison of this analysis was made with the overall average shipping industry rate for all types of vessels. This assisted in situating the tanker industry in the broader maritime sector to get more information about how tankers have evolved compared to other types of vessels.

Using data collected from Clarksons SIN, a list of top 20 tanker companies as per the number of vessels in their fleet was chosen. Each company’s eco profile was looked to find out the percentage of tanker vessels in their fleet equipped with scrubber, alternate fuels, ESTs and their average age.

Table 12: Current ECO profile of top 20 tanker companies (by no. of vessels)

TOP 20 TANKER COMPANIES	FLEET			
	SOx Scrubber Fitted (%)	Alt. Fuels (%)	EST Fitted (%)	Avg Age
China COSCO shipping	7	0.6	0	12.9
China Merchants	22.5	0	0	11.9
Mitsui OSK Lines	23.3	4.5	0	11.1
Fredriksen Group	59.8	1	0	6.3
Pertamina	7.2	0	0	23.8
BW Group	15.4	0	0	9.4
Sinokor Merchant	47.7	9.4	0	8
Scorpio Group	78.1	0	0	8.6
Dynacom	46.2	0	0	11.8
Eastern Pacific Shpg	44.4	6.4	0	7.2
TORM A/S	78.7	0	0	11.6
SCF Group	0	5	0	15.2
Intl Seaways	15.8	4	0	12.4
Junzheng Energy	0	0	0	12.4
Tsakos Group	18.5	9.2	0	11.3
Nissen Kaiun	55.2	0	0	4.6
Bahri	26	0	0	10.7
Stolt-Nielsen	12.3	0	0	16.5
Union Maritime	22.2	0	0	11.5
Angelicoussis Group	90.6	7.6	0	8.5

Source: Author, based on data provided by (Clarksons Research, 2024)

Table 13: Comparison of ECO profile of tankers vs other vessel types

TYPE	FLEET - INDUSTRY AVERAGE			
	SOx Scrubber Fitted (%)	Alt. Fuels (%)	EST Fitted (%)	Avg Age
TANKERS	13.4	1.5	0	15
ALL TYPES	9	6.7	0	18.5

Source: Author, based on data provided by (Clarksons Research, 2024)

Industry average data was also collected from Clarksons to compare the performance in terms of efficiency / environment friendly of top 20 tanker companies with i) the whole tanker fleet and ii) the whole shipping fleet.

Based on the above data, a final score was calculated for all 20 tanker companies as follows. First, a comparison was done with tanker fleet. Tanker industry's average scrubber and alternate fuel percentage was subtracted from the company's scrubber and AF percentage respectively because more percentage means better efficiency whereas company's average age was subtracted from industry's average age because lesser age means better efficiency. Then a sum was calculated of these 3 figures. Similar calculation was done with whole shipping fleet. Lastly, the sum of both the results was calculated to get the final score, called efficiency score (self-termed).

For e.g., efficiency score of China Cosco shipping was calculated as:

Comparison with tanker fleet = (7-13.4) + (0.6-1.5) + (15-12.9) = -5.2

Comparison with all fleet = (7-9) + (0.6-6.7) + (18.5-12.9) = -2.5

Efficiency score = (-5.2 + (-2.5)) = -7.7

Based on these calculations, a ranking was assigned to all top 20 tanker companies based on their efficiency score, with the higher the score, the better the ranking. These rankings are shown in the table below, along with their respective efficiency scores. Please note that these rankings are solely based on the data from the top 20 tanker companies listed in the table above as provided by Clarksons, and no claims should be made based on this calculation. There is no intention of describing a company as more or less efficient. Several other factors contribute to the vessel's efficiency which are out of the scope of this paper.

Table 14: Top 20 tanker companies as per efficiency (based on author's calculations)

Rank	Companies	Score	Rank	Companies	Score
1	Angelicoussis Group	182.3	11	Bahri	33.5
2	Scorpio Group	141.9	12	Union Maritime	24.3
3	TORM A/S	137.1	13	China Merchants	24.1
4	Fredriksen Group	111.9	14	Intl Seaways	17.7
5	Nissen Kaiun	104.1	15	BW Group	14.9
6	Sinokor Merchant	101.1	16	Stolt-Nielsen	-5.5
7	Eastern Pacific Shpg	90.1	17	China COSCO shipping	-7.7
8	Dynacom	71.7	18	SCF Group	-17.5
9	Mitsui OSK Lines	36.3	19	Junzheng Energy	-21.9
10	Tsakos Group	35.7	20	Pertamina	-30.3

Source: Author

Table 15: Orderbook ECO profile of top 20 tanker companies

TOP 20 TANKER COMPANIES (by no. of vessels)	**ORDERBOOK**			
	SOx Scrubber Fitted (%)	**Alt. Fuels (%)**	**EST Fitted (%)**	**Vsl Ordered**
China COSCO shipping	0	23.1	0	13
China Merchants	71.4	4.8	0	21
Mitsui OSK Lines	11.1	77.8	0	9
Fredriksen Group	71.4	0	0	
Pertamina	0	0	0	15
BW Group	0	100	0	4
Sinokor Merchant	NO TANKER VESSELS ORDERED			
Scorpio Group	NO TANKER VESSELS ORDERED			
Dynacom	10	0	0	40
Eastern Pacific Shpg	19.4	48.4	0	31
TORM A/S	NO TANKER VESSELS ORDERED			
SCF Group	0	100	0	3
Intl Seaways	100	0	0	6
Junzheng Energy	0	0	0	15
Tsakos Group	62.5	0	0	8
Nissen Kaiun	59.1	0	0	44
Bahri	NO TANKER VESSELS ORDERED			
Stolt-Nielsen	0	0	0	6
Union Maritime	15	15	0	40
Angelicoussis Group	0	72.7	0	11

Source: Author, based on data provided by (Clarksons Research, 2024)

Table 16: Comparison of Orderbook ECO profile of tankers vs other vessel types

TYPE	**ORDERBOOK – INDUSTRY AVERAGE**		
	SOx Scrubber Fitted (%)	**Alt. Fuels (%)**	**EST Fitted (%)**
TANKERS	27.4	12.8	0
ALL TYPES	13.9	38.5	0

Source: Author, based on data provided by (Clarksons Research, 2024)

Analysis of the top 20 tanker companies compared to industry averages

1. **Adoption of SOx scrubbers:**

Fleet Data: The average percentage of SOx scrubbers fitted in the tankers amongst the top 20 tanker companies is 13.4% compared to an overall industry average of 9 percent.

- **Leaders**: Some of the key carriers, namely Angelicoussis Group, Scorpio Group, and TORM A/S have 90.6%, 78.1% and 78.7% compliance respectively with SOx scrubber technology which signifies a high level of compliance with sulphur emission regulations.
- **Laggards**: Some of the companies such as China COSCO shipping (7%), Pertamina (7.2%), and Junzheng Energy (0%) have low or no SOx scrubber adoption that may mean regulatory compliance issues or other methods of sulphur control.

Orderbook Data:

The orderbook data reveal an upturn in the intended use of SOx scrubbers. New tanker orders including scrubbers stood at 27.4% while the industry average was at 13.9%.

- **Leaders**: Companies such as China Merchants with 71.4% of its new orders and Tsakos Group with 62.5% are installing scrubber technology as an indication of their commitment to meet the rules and curb fuel expenses.
- **Laggards**: Some carriers such as Mitsui OSK Lines (11.1%) and Dynacom (10%) have relatively low adoption rates in their orderbooks and may try to rely on other compliance mechanisms.

2. **Adoption of Alternative Fuels:**

Fleet Data: Currently, there is a very low level of adoption of the alternative fuels in the current tanker fleet, which is at 1.5% compared to an industry average of 6.7% for non-tankers.

- **Leaders**: Among them, Sinokor Merchant takes the top spot with 9.4% of their current fleet running on alternate fuels, followed by Tsakos Group with 9.2% and Angelicoussis Group with 7.6%.
- **Laggards**: Most of the tanker owning companies such as China COSCO shipping, China Merchants and Fredriksen Group have low or no penetration of AFVs in their fleets.

Orderbook Data:

The orderbook for tankers has also improved to 12.8% in the adoption of alternative fuels which implies that in the future more green technologies will be adopted, even though it is lower than the sampled industry average of 38.5%.

- **Leaders**: BW Group with all 4 of their newbuilds while Mitsui OSK Lines with 7 out of 9 vessels capable of running on AF show their commitment towards new technologies and can be regarded as distinguished leaders.
- **Laggards**: Some companies such as China Merchants has a low, or in the case of Dynacom, no utilisation of AF in their new order, suggesting that they may be using conventional fuel types.

3. **Average Age of Fleet:**

Among the top 20 companies, the average age of the tanker fleet is 15 years, which is less than the average age of 18.5 years in the whole industry.

- **Younger Fleets**: Nissen Kaiun’s average age of fleet is 4.6 years; Fredriksen Group is 6.3 years and Angelicoussis Group is 8.5 years, which is relatively younger that could mean that they have higher operational efficiencies and are capable of following the newer regulations.
- **Older Fleets**: Pertamina has a fleet age of 23.8 years, while Stolt-Nielsen has a fleet age of 16.5 years, which implies that the former’s fleet may be incurring higher operational costs and is more likely to be regulated than the latter.

Comparison to Overall Shipping Industry:

1. **SOx Scrubber Adoption**: The overall tanker industry has a higher penetration of SOx scrubber both in the current fleet as well as in the orderbook as compared to the overall industry average. This shows that the

tanker industry has been keen in implementing the sulphur emission standards probably due to the high sulphur content of the bunker fuel used in tankers.

2. **Alternative Fuels Adoption:** The development of AFs in the tanker industry is still behind the overall development of the global shipping industry. This means that although more tankers are installing scrubbers to meet today's environmental standards, they remain slow in converting to low-sulphur bunkers, perhaps because of the technical issues and expenses involved in modifying or constructing large carriers suitable for use with other fuels.

3. **Fleet Age**: Concerning the age distribution of the fleets, it can be observed that the tanker's industry is comparatively younger than the whole shipping industry. This could mean that the tanker industry has been more proactive in replacing its fleet, maybe due to fresh regulations or in a bid to improve efficiency. This is also a drawback as the industry may not be able to upgrade to the latest green technology as is possible because newer vessels are expected to have longer life spans than the older ones.

Conclusion:

This shows that although the ship owners are moving towards decarbonisation, but they are reluctant to invest in alternate fuels yet. Many small companies may not want to become industry leaders in decarbonization yet and monitor the performance of other companies' vessels or their own fleet running on alternate fuels. They will probably make their decisions after few years when the regulations become more clearer, efficiency of AF powered vessels is analysed and lastly, the availability and pricing of green fuels does not remain an issue.

According to the data, it is observed that most of the leading tanker companies are not giving much importance to decarbonization in their fleets. This could pose a challenge to these companies as the global climate regulations tighten and demand for greener shipping grows. The few companies that are investing in alternate-fuel capable vessels may get a strategic advantage eventually as they position themselves as leaders in decarbonization industry. This could potentially give them a competitive advantage as regulations tighten and markets demand more environmentally friendly shipping solutions. However, the overall trend shows that the tanker segment is falling behind in the global push for decarbonization.

Compared to other industries in the overall market, the tanker industry is more progressive in having scrubbers while it lags in other fuels. This could be because scrubbers are the immediate solutions to compliance while the alternate fuels may require more time because the changes required operationally and financially are large scale. The average age of the fleets has also been lowering in tankers due to which the owners may not find it viable to invest heavily in retrofitting for alternate fuels. This puts the industry in a good position to undertake future upgrades in a bid to meet the new environmental standards. However, the industry requires a faster adoption of AFs to match industry trends of decarbonizing shipping.

5.6 Impact on Inefficient Tanker Vessels

To address our 5th research question: *"How have decarbonization goals affected the demolition of tankers?"*, an attempt was made to determine how older and less efficient tanker vessels are being phased out or retrofitted. Tanker demolition data was collected between 2005 and 2024 using Clarksons SIN. Table 1 depicts the average age of crude oil tankers going for demolition and total number of tankers (10,000+ dwt) going for demolition which further subdivided into tanker types and total volume of tankers (10,000+ dwt). Table 2 represents the scrap values and scrap prices of all these tanker types. The graph below depicts the relationship between scrap price and the number of tankers scheduled for demolition. The data was examined to determine the relationship between decarbonization policies and tankers scheduled for demolition. Data representing all types of tankers was collected to determine which tankers were affected by these policies over the course of the period. Except average age, tankers here include crude and product tankers.

Table 17: Average age and volume of demolition of tankers (2005-2024)

YEAR	Total Crude tanker Demolition Avg. Age (Years)	Total tanker 10k+ DWT Demolition (No.)	Handy size	Panamax	Aframax	Suezmax	VLCC	Total tanker 10k+ DWT Demolition (DWT million)
2005	25.46	114	75	21	14	3	1	5.61
2006	25.58	121	103	8	10	0	0	4.52
2007	26.49	142	125	8	9	0	0	5.2
2008	25.25	107	72	20	10	2	3	5.18
2009	22.81	198	150	15	18	6	9	10.61
2010	23.15	310	229	35	20	13	13	16.59
2011	21.34	172	112	15	26	7	12	11.39
2012	20.63	190	95	29	36	20	10	14.73
2013	19.75	162	95	15	29	6	17	13.13
2014	21.81	131	75	19	22	7	8	9.05
2015	21.53	77	61	11	3	0	2	3.2
2016	23.65	62	51	2	6	1	2	3.31
2017	21.78	135	59	10	40	13	13	12.96
2018	20.18	232	110	19	50	22	31	22.88
2019	21.31	75	63	1	1	6	4	4.32
2020	23.4	69	47	3	13	2	4	4.41
2021	21.75	259	176	14	42	13	14	17.14
2022	21.69	93	61	5	17	7	3	6.23
2023	24.61	23	20	0	2	1	0	1.07
2024[3]	22.64	5	2	0	1	1	1	0.64

Source: Author, based on data provided by (Clarksons Research, 2024)

[3] Data as of July 2024

Table 18: Scrap value and price of demolition of tankers (2005-2023)

	SCRAP VALUES (USD million)					**SCRAP PRICE INDIA ($/ldt)**		
YEAR	Handy	Panamax	Aframax	Suezmax	VLCC	(Handy / Panamax)	(Aframax / Suezmax)	VLCC
2005	3.19	4.82	6.38	9.52	14.13	330	330	305
2006	3.85	5.61	7.52	11.26	17.53	410	410	410
2007	4.72	6.69	8.8	13.25	19.95	525	525	510
2008	2.65	3.87	4.87	7.61	11.64	285	285	285
2009	3.30	4.95	6.12	9.41	13.16	340	340	340
2010	4.38	6.84	8.34	12.98	19.61	495	495	490
2011	4.57	7.27	8.38	12.08	20.97	485	485	480
2012	3.76	5.99	7.17	9.11	17.26	430	430	420
2013	3.69	6.41	7.24	9.41	18.31	440	440	435
2014	3.88	6.81	7.47	9.97	19.12	460	460	450
2015	2.42	4.09	5.03	6.48	12.17	305	305	290
2016	2.34	3.95	4.87	6.7	12.57	290	290	290
2017	3.43	6	7.42	9.47	17.37	435	435	415
2018	3.36	5.87	7.24	9.59	17.58	425	425	415
2019	3.08	5.38	6.64	9.02	16.56	360	360	365
2020	3.27	5.73	7.07	9.48	17.48	405	405	400
2021	4.78	8.35	10.3	13.6	25.05	565	565	560
2022	4.17	7.31	9.01	12.19	21.84	535	530	520
2023	4.17	7.18	8.84	11.96	21.42	510	505	495

Source: Author, based on data provided (Clarksons Research, 2024)

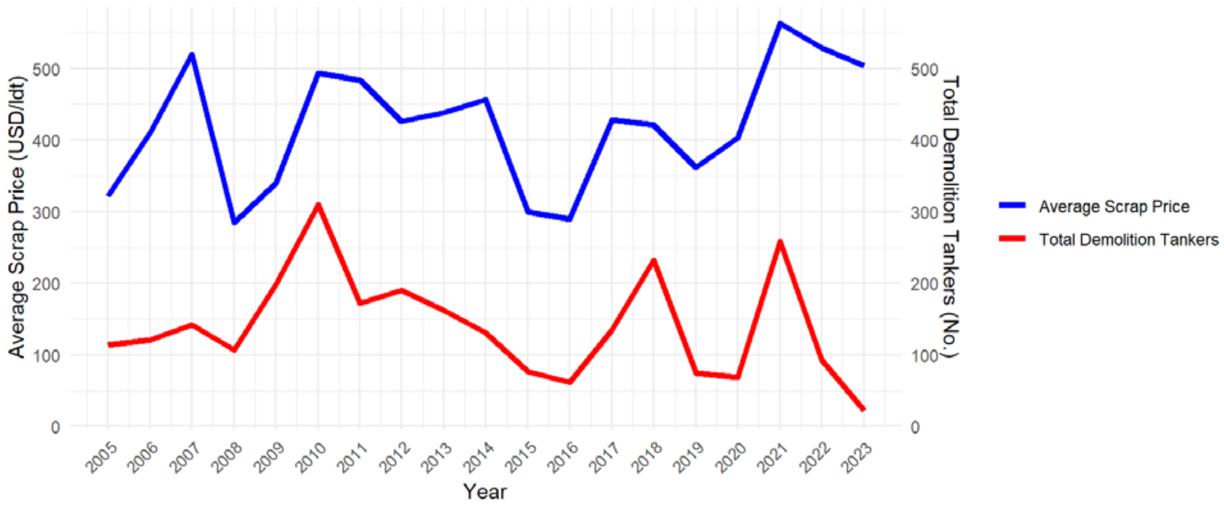

Figure 15: Average scrap prices vs total demolition tankers (2005-2023)

Source: Author, using R Studio based on data from above table

The data provided details the number and volume of tankers scrapped between 2005 and 2024, categorized into five types: Handysize, Panamax, Aframax, Suezmax and VLCC. The second table provides scrap prices in India and the scrap value of these tankers from 2005 to 2023. Tankers here represents both crude and product tankers. The purpose of this data was to analyse the impact of decarbonization on scrapping trends of inefficient tankers.

Trend in Tanker Demolitions:

The overall pattern of such tanker demolitions has not been consistent but has rather fluctuated in the course of the years. Global financial crisis led to a significant rise of scrapping especially in the period 2009-2010. The most recent rates of demolition (2023 and 2024) may, however, indicate that the majority of substandard ships have already been removed from the fleet or that the tanker fleet has been renewed.

Demolition by Vessel Type:

Handysize tankers: They have consistently remained the largest contributor to the demolitions peaking in 2010 and 2021 with 229 and 176 Handysize tanker vessels being demolished. The consistent removal of Handysize tankers suggests that such older and smaller vessels are more vulnerable to the market headwinds and decarbonization efforts.

Panamax, Aframax, Suezmax, and VLCCs: The scrapping of larger vessels has gone up significantly between the periods 2010-2013 and 2017-2018, correlating with the increase in scrap prices showcasing a direct connection.

Impact of Decarbonization:

Economic Pressure: 2021 and 2022 data reveal an even steeper slope for scrapping of larger vessels which suggests that the pressure to decarbonize is not only affecting small, old vessels but also large vessels that are costly to retrofit.

Market Dynamics: Other factors that have rendered it almost impossible to sustain the old and inefficient tankers include economic downturns such as the 2008 financial crisis and the current COVID-19 pandemic, coupled with the rising costs of fuel and the push towards decarbonization. The trade war between the US and China may also have lowered demand for big ships, which may have helped increase scrapping in 2017-2018.

Scrap Prices and Values: As evident from the graph, the number of tankers demolished relates closely with the scrap price. Higher the scrap price, larger the number of tankers going for demolition. The trend of scrap prices and values of ships after the year 2021 depict that there is a decreasing trend in the market for these old age vessels, which can be attributed to a number of factors such as oversupply of scrapped ships and the phase out of large number of inefficient vessels during COVID, resulting in relatively younger fleet of tankers. IMO 2020 alongwith COVID-19 in 2021 led to the highest number of vessel demolitions since 2010 due to operational inefficiencies during the lockdown period and a surge in scrap prices in 2021. The next decline in scrap prices shows that, as the market gradually shifts towards decarbonization, tankers are retrofitting with scrubbers to comply with the fuel requirements and as such there is reduced interest in scrapping.

5.7 Newbuilds vs. Retrofitting: Strategic Choices for Decarbonization

To address our 6th research question, *"Is newbuilding or retrofitting existing tankers a better option for tanker companies towards their decarbonization goals?"*, the pros and cons of retrofitting and newbuild ships, along with the costs associated with transitioning to alternate fuels were examined. The table below shows the estimated retrofitting costs (in USD million) for ships transitioning from one type of fuel to other. The data highlights significant cost variations depending on the type of retrofit:

from/to	VLSFO ship	LNG ship	LPG ship	Methanol ship	Ammonia ship	LH2 ship
VLSFO ship	0.0	9.3	9.3	6.0	15.0	24.6
LNG ship	3.5	0.0	2.5	6.7	11.3	22.6
LPG ship	4.0	7.8	0.0	6.7	8.2	22.6
Methanol ship	1.0	9.3	9.3	0.0	15.0	24.6
Ammonia ship					0.0	22.6
LH2 ship					6.7	0.0

Figure 16: Retrofit costs (in USD Million). Green: low cost, Red: high cost

Source: (Lindstad, Lagemann, Fagerholt, Rialland, & Erikstad, 2022) 102. 103145. 10.1016/j.trd.2021.103145

Overall, while some retrofit options are cost-effective, transitioning to more advanced fuels like ammonia and LH2 generally incurs high costs, which might diminish the attractiveness of retrofitting in these scenarios.

- **Pros of New Builds:**

1. The vessels built today are equipped with state-of-the-art technologies that enhance the efficient operation of the ship.

2. Newer ships also have lower maintenance and reliability issues than older ships hence the operating costs are low.

3. Designed as per the current and anticipated requirements so as to eliminate the need to retrofit later.

4. They have adopted modern technology including the navigational assistance and the automated equipment.

- **Cons of New Builds:**

1. Substantially higher initial costs than in the case of retrofitting.

2. Market risks that include fluctuations may have an impact on the profitability of vessels.

3. Building and delivery of new ships normally takes around 2 to 3 years.

- **Pros of Retrofitting:**

1. Normally, less initial cash requirement as compared to the newly constructed vessel.

2. Enables older ships to stay in the market thereby protecting over capacity of fleet.

3. Retrofitting of existing ships normally takes 2 to 3 months, saving time.

- **Cons of Retrofitting:**

1. One may find that the physical and design constraints may limit the level of enhancements.

2. A lot of retrofitting can create a vacuum of fleet, resulting in under capacity.

3. The older generation ships, however, might continue to be less efficient than newer constructed ships even after retrofitting.

Source: (Ship Universe, 2024)

Given the high costs associated with retrofitting older vessels to use more efficient and relatively new fuels in the shipping industry like ammonia and LH2, along with the physical limitations and potential inefficiencies of older ships, newbuilding may be a more attractive long-term strategy for tanker companies who wants to capitalize on their own and industry's decarbonization targets. New vessels are better suited to meet stringent environmental regulations and are likely to offer higher operational efficiency due to their technological advancements and lower maintenance costs over their lifespan.

However, for companies with limited capital, older vessels or those looking for quicker solutions to comply with short to medium term regulations, retrofitting could still be viable, especially when converting to lower-cost fuel options such as methanol. Retrofitting is particularly beneficial when the cost is relatively low (e.g., LPG to Methanol) and the fleet's remaining operational life is sufficient to justify the investment.

5.8 Impact of Oil demand on Oil Tanker Market

To understand our 7th research question, *"What is the impact of global oil demand on oil tankers?"*, the current demand for oil in regions that are major importers needs to be known. The forecast of oil demand was already discussed in section 2.6, where OPEC's estimate indicates that global oil demand is expected to increase at a rate of 0.7% per annum from 2022 to 2045. The table below gives information on oil demand of major oil consumers in million barrels per day (mbpd) for the period of 2015 to 2023. The emphasis will be made on the trends, the influence of such factors as COVID-19, and the comparison of the demand in different regions.

Table 19: Global oil demand by region (2015-2023)

Oil demand (mbpd)	2015	2016	2017	2018	2019	2020	2021	2022	2023
United States	19.8	20.0	20.3	20.6	20.6	18.4	20.0	20.2	20.3
China	11.6	12.0	12.5	13.6	14.2	14.3	15.1	14.7	16.1
India	3.8	4.2	4.3	4.8	4.9	4.5	4.7	5.0	5.2
Japan	4.1	4.0	3.9	3.9	3.8	3.4	3.4	3.4	3.3
Canada	2.5	2.5	2.4	2.5	2.5	2.2	2.3	2.3	2.4
OECD Europe	13.8	13.9	14.3	14.2	14.2	12.3	13.0	13.4	13.3
Global Total	**95.0**	**96.0**	**98.0**	**100.2**	**100.9**	**91.6**	**97.3**	**99.0**	**101.3**

Source: Author, based on data provided by (Clarksons Research, 2024)

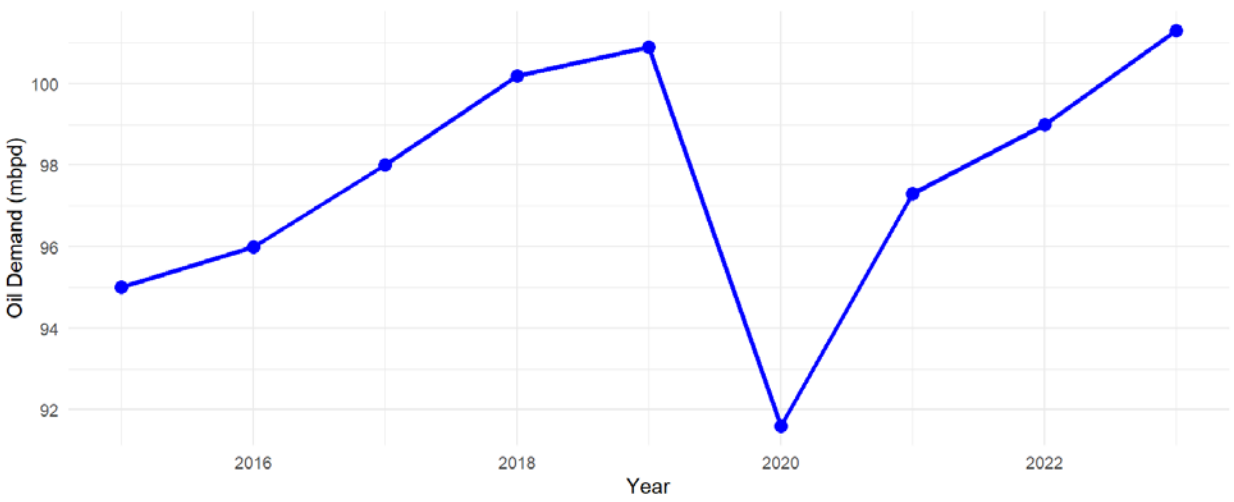

Figure 17: Global oil demand (2015-2023)

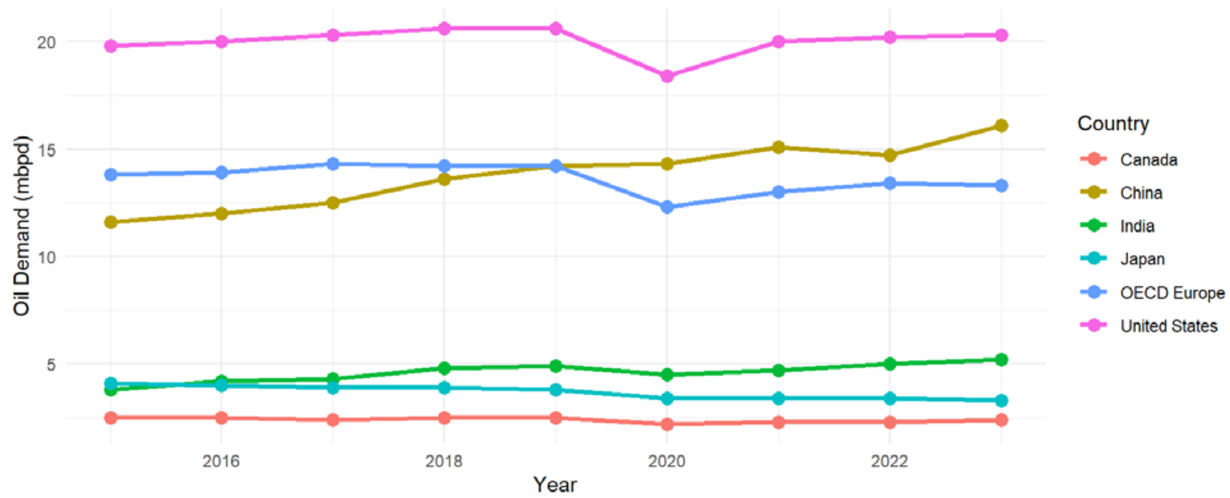

Figure 18: oil demand by region (2015-2023)

Source: Author, using R Studio, based on data provided by Clarksons Research

The world's demand for oil has normally risen over the years from 95 mbpd in 2015 to 101.3 mbpd in 2023. It reached the peak of 100.9 mbpd in 2019 before a steep decline to 91.6 mbpd in 2020, majorly because of the COVID-19 outbreak.

The pandemic influenced the reduction of oil demand in 2020, decreasing the world's total to 100.9 mbpd in 2019 and took 4 years to recover the demand to surpass the pre-covid levels in 2023. This reduction is clearly seen in all the main world areas.

- **Analysis by Regions:**

United States: The largest consumer with relatively stable demand, has its demand peak at 20.6 mbpd in 2018 with current demand at 2017 levels.

China: A continuous rise in demand is evident, which has risen from 11.6 mbpd in 2015 to 16.1 mbpd in 2023 reflecting China's industrialisation coupled with economic growth. Also, the only country whose demand remained unaffected by COVID.

India: Steady increase from 3.8 in 2015 to 5. 2 mbpd in 2023, proving the increasing industrial and transportation demand.

OECD Europe: Moderate and somewhat predictable with a significant decline in 2020 and only a partial rebound in 2023.

Japan and Canada: Both have experienced a steady or slightly declining demand, Japan being the one that has seen a steady decline from 2015 to 2023.

The data shows that the developing nations such as China and India are leading towards the demand of oil and there is not much change in the developed nations. COVID-19 had a significant impact on the global oil demand but the subsequent rebound shows that the global economy is fairly durable and is coming back to normal. OPEC forecasts an increasing demand of oil as earlier discussed in section 2.6 and is also evident from the continuous increase in demand in the last 3 years.

These trends call for energy companies and policymakers, to pay attention to the increasing energy demands of the developing nations as well as the susceptibilities to external threats such as pandemics.

5.9 Impact of Decarbonization on Utilisation Rates of Oil Tankers

To gain a deeper understanding of decarbonization policies on the financial condition of oil tankers and answer our 8th research question, *"What is the impact of decarbonization on utilization rates of oil tankers?"*, the proportion of oil tankers that are not in service over the years will be studied. Carbon emission reduction regulations by IMO and regional authorities will either require retrofitting of vessels or adoption of low sulphur expensive fuels. In this section, it will be shown how these policies are affecting the utilization rate of tankers. The following table displays information on the idle oil tankers of MR (Medium Range) class and above from the year 2014 to 2024.

Table 20: Idle oil tankers (2014-2024)

YEAR	Oil tankers MR and above - Idle No.[4]	Oil tankers MR and above - % Idle No.[5]	Oil tankers MR and above - Idle DWT million[6]	Oil tankers MR and above - % Idle DWT million[7]
2014	178	4.9	20.25	4.5
2015	202	5.4	24.01	5.2
2016	200	5.2	21.55	4.6
2017	191	4.7	22.33	4.5
2018	198	4.7	23.32	4.4
2019	188	4.4	20.60	3.9
2020	177	3.9	21.03	3.7
2021	148	3.2	16.09	2.8
2022	148	3.2	18.36	3.1
2023	165	3.4	22.00	3.6
2024[8]	237	4.8	35.52	5.7

Source: Author, based on data provided by (Clarksons Research, 2024)

The proportion of idle tankers kept on reducing after reaching its highest level of 5.4% in 2015. The last couple of years have seen the percentage rising rapidly. In 2014, 178 tankers comprising 4.9% were idle whereas in 2024, although the percentage reduced slightly to 4.8%, the number of idle tankers was 237 implying over supply in the oil market. The sharp rise of idle deadweight in 2024 points to the fact that large tankers were possibly idle in the year than in the other years. The variation in the number of idle tanker and their tonnage could be associated with oil demand, economic conditions, geo-political events or shifts in trading patterns. New policies for instance the IMO 2020 may have resulted to scrapping of older and less efficient tankers. The rise in idle numbers and percentages in 2024 may imply certain market or operational problems, such as overcapacity, demand decline or new environmental regulation. Such a sharp increase in 2024 might be explained and

[4] The aggregate of the number of tankers that are not in service.
[5] The percentage of the total fleet of tankers that are idle.
[6] The total amount of deadweight tonnage of the idle tankers
[7] The percentage of the total deadweight tonnage comprising of idle tankers.
[8] As of August 2024

might need a more detailed examination of the factors that need to be considered in order to forecast the tendencies in the tanker market for further periods.

5.10 Hypothesis Evaluation

Based on the results, the outcomes of 3 hypothesis as discussed in section 3.3 will be discussed here.

Hypothesis 1: *The adoption of decarbonization technologies is positively correlated with the operational efficiency of oil tankers.*

Evaluation: The first hypothesis is, to a certain extent, true. As discussed in the previous section 5.4, for instance, the tankers that bear technologies such as Eco Scrubbers have recorded highest earnings, thus implying a correlation between the decarbonization technologies and operational efficiency. However, the hypothesis does not hold true entirely regarding transport cost which have also been observed to have gone up. This discrepancy could be attributed to external factors beyond the costs associated with new technologies, as discussed in Section 5.4. It is also necessary to note that these costs may also decline in the future as the technologies themselves are becoming more popular and developed.

Hypothesis 2: *There is a negative correlation between the age of oil tankers and adoption of decarbonization technologies.*

Evaluation: The second hypothesis is validated. As detailed in section 5.5, the evaluation of the 20 largest tanker companies by efficiency that considers the age of the fleet and the adoption of decarbonization technologies show that companies with older fleets have lower efficiency score. For instance, Pertamina, Stolt-Nielsen and SCF Group which operate some of the oldest fleet, rank poorly in efficiency, with rankings of 20, 16, and 18 respectively. This supports our assumption that older tankers struggle to comply with stringent decarbonization regulations and that they only meet the minimum standards.

Hypothesis 3: *Strict enforcement of IMO decarbonization regulations will lead to a significant increase in investment by tanker companies in emission reduction technologies.*

Evaluation: The third hypothesis can only be partially supported. As was mentioned in Section 5.1, there has been a noticeable shift in the tanker orderbook to invest in low emission technologies such as the adoption of Eco designs, scrubbers and alternative fuels. But the rate of adoption, though rising steadily is still not as fast as what has been estimated. In addition, as highlighted in section 5.5, while tankers have a higher adoption of scrubber technologies than the industry average, it is low in adopting alternative fuels. Such a mixed picture indicates that although the IMO's regulatory pressure has stimulated investment to a certain extent, it has not led to the implementation of the latest decarbonization technologies.

5.11 Discussion on the Implications for the Future

The study shows that the decarbonization technologies have been implemented in the tanker sector gradually but steadily, with focus on the ECO fleets, SOx scrubbers, and ships designed for the use of other fuels. However, the growth rate has reduced significantly after 2022, and this could be attributed to the fact that the market has become saturated, and the implementation of new technologies is very expensive. However, it seems that Eco fleets have reached a certain level of maturity, while the use of SOx scrubbers and alternate fuels is growing, but at a very slow pace. This implies that though a number of tankers and bulk carriers are now adhering to emission standards, their uptake of other fuels is still low as compared to that of the container ships and car carriers. This could be attributed to a difference in the nature of transport of container vessels that always have fixed schedules for their transport hence making it easier to plan for fuel bunkering as compared to tankers which have more diverse routes and trades on spot market fixtures.

The COVID-19 and the IMO 2020 affected the shipping industry and resulted in the decrease of emissions. The pandemic impacted the global economy and thus affected the global trade significantly, while the sulphur cap ensured the utilization of low-sulphur fuels. However, the effects of recent policies like CII and EU ETS can only be observed in the future.

Economic assessment shows that the implementation of decarbonization technologies, especially Eco designs and scrubbers, significantly improves the profitability of the tanker ships. However, the analysis reveals that scrubbers' uptake is higher across the industry than that of alternate fuels, especially in the tanker segment. This is evident in the current fleet as well as in the orderbook, which indicates that tanker companies are reluctant to invest in new technologies and focus on the bare minimum requirements to meet the sulphur regulations. This might be so because of the different trading behaviours of the tankers and the volatility of the oil market. The companies with older fleets are especially less inclined to invest in these technologies, considering the costs, and the fact that there relative operational life span is not practical to do heavy investments.

The average demolition age of tankers is more than 20 years, and the current fleet age is 15 years which shows that the scrap market in the near future is not very strong. However, there is a tendency that demolition activity escalates when scrap prices go up, the latter of which happens in cycles of 2-3 years. This cyclical pattern indicates that although the current market does not show a high rate of demolitions, future high scrap prices may lead to higher demolitions.

The current overcapacity in the tanker market is manifested by the tendency towards the growth of idle fleet share during the last three years, which may result in the deterioration of demand, decrease of freight rates, and the increase in the rate of scrapping. This overcapacity could also mean that there is scope for second- hand modification of inefficient tankers if required. Apart from the aforementioned challenges, the global oil demand is expected to grow in the future especially due to India and China which implies a consistent growth market for tankers.

6 CONCLUSION

This research attempts to answer the following research question: “What will be the impact of global decarbonization efforts on the composition of the tanker fleet and the average operational lifespan of tankers?”

Before coming to an answer on the main RQ, eight sub questions were posed. The first sub question was about the regulations and policies adopted to curb emissions in the maritime sector and their effectiveness. The oil tanker sector has gradually adopted emission reduction technologies over the past five years. Crude tankers, particularly VLCCs, have a higher adoption rate of SOx scrubbers due to longer voyages and less port calls. Nevertheless, the use of alternate fuels is not very widespread, which can be regarded as evidence of the difficulties and additional expenses of the transition to environmentally friendly technologies.

The second research question was finding about the efficiency of alternate fuel vessels in controlling GHG emissions. The world fleet has been growing steadily and with the growth of the number of vessels capable of using alternate fuels, the GHG intensity has been decreasing over the research period indicating the connection between the alternate fuel vessels and the GHG. In other words, as the proportion of alternate fuel capable vessels rises, the emissions of GHG declines, hence a positive correlation.

The third research question concerns with the economic implications for oil tankers transitioning to efficient fleet. This shows that scrubbers and eco designs have a positive effect on tanker earnings among all vessel types. In the period of 2021-2024, Eco scrubber fitted vessels recorded the highest earnings, implying that the shipping companies require new technologies for efficient operations.

The fourth research question was about the adoption of decarbonization technologies by leading tanker companies. Ship owners are moving towards decarbonisation but are hesitant to invest in alternate fuels. Most of the leading tanker companies are not giving much importance to decarbonization in their fleets, which could pose a challenge as global climate regulations tighten and demand for greener shipping grows. The tanker segment is falling behind in the global push for decarbonization, with scrubbers being the immediate solution to compliance.

The fifth research question discusses the impact of decarbonization targets on tankers demolition. Decarbonization along with other economic factors have influenced the tanker market especially in terms of scrapping out older and less efficient vessels. The analysis of the data reveals a definite trend of phasing out such vessels, most of them observed after 2010 with more emphasis placed on the larger carriers. Since the process of decarbonisation continues to progress, more pressure is anticipated to push up the demolition rates and affect the scrap rates in the market.

The sixth research question was between the choice of newbuilding and retrofitting for the decarbonization goals of tankers. Newbuilding may be a more attractive option for the tanker companies in the long run to take advantage of the decarbonization targets and meet the environmental standards. New vessels have better operational efficiency and require less amount for maintenance as compared to old vessels. However, retrofitting may still be viable for companies with limited capital, older vessels, or those seeking quick compliance with short to medium term regulations, especially when the cost is low.

The seventh research question was about the impact of global oil demand on oil tankers. The data indicates that developing nations like China and India are leading in oil demand while the developed countries have remained stagnant. COVID-19 significantly reduced oil demand but the bounce back shows that there is a sustainable global economy. Therefore, the oil demand should not be a cause of concern for oil tankers.

The eighth research question was concerning the effect of decarbonization process on the average oil tanker utilization rates. The above trends indicate that there is an increase in the number of idle oil tankers especially the large ones in the past couple of years. This can be attributed to lower oil demand, excess capacity, shorter voyages and geo-political reasons which would need more investigation.

The shipping industry and especially the tanker segment is slowly moving towards decarbonization due to the regulatory push and cost factors. The slow adoption of alternate fuels is another issue that has been brought out despite there being improvements in the uptake of Eco designs and scrubbers. The slow rate of adoption of new technologies especially among the older fleets indicates that many of the tanker operators are more concerned with meeting the current set standards than they are with embracing new technologies.

The overcapacity situation in the market along with the fluctuating nature of scrap prices indicate future prospects of increased demolition. On the other hand, the prospects of the global oil demand especially from the emerging markets offer a balance to these challenges.

To summarize, the paper points to the fact that the process of transition to a low-carbon economy is already underway in the tanker industry; however, the rate of change is not consistent, and the application of various technological solutions differs quite sharply. The transition will be continuous and will need constant review and adjustment especially with the new regulations that are being implemented and the constantly changing market environment. To achieve the industry’s long-term decarbonization objectives, there will be a need to step up the pace of embracing new technologies and other fuels in addition to investing in fleet modernization and updating.

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