Erasmus University Rotterdam

MSc in Maritime Economics and Logistics

2021/2022

[The Impact of Fit For 55 on the European Shipping Industry]

by

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ACKNOWLEDGMENTS

My greatest thanks go out to Roy van den Berg, my thesis advisor, for assisting me with my project. Roy's insightful advice, professional background, and perspective as a researcher with Ce Delft were motivating and encouraged me to reach my objectives for this research.

My parents Sheela and Cecil, as well as my in-laws Glenn and Anjali, deserve my gratitude. I am appreciative of their continuous encouragement, love, patience, and prayers throughout my year at MEL. A special thanks to my wife Shelly Mascarenhas for her unwavering support, her faith in me, her insistence that I follow a schedule, and for holding the fort when I most needed it.

My warmest gratitude to Renee, Felicia, and Martha from the MEL team. Keeping the course functioning during the pandemic has been a difficult challenge, and I will add that they deserve praise for their tenacious execution of their responsibilities during these trying times. I would like to thank all the professors for their constant support and guidance.

I also want to express my sincere thanks to my close friends and classmates for their continual support and constructive criticism as I worked on my thesis, especially to Surendran Venkatakrishnan and Floyd Alfonso for motivating me. A better cohort could not have been desired.

ABSTRACT

The shipping industry places a vital role in churning the economic wheels of the world. Every product that we see in our homes, supermarkets, shopping malls, boutiques are directly or indirectly linked to shipping. Around 90 % of the world's trade volumes are shipped by vessels. The statistics of cargo being shipped is mind boggling. All this comes at a price. As the demand of goods goes up and continues to go up, the demand for ships and larger ships would also go up. This has created a concern for the amount of CO_2 emitted by the shipping industry and eventually increasing the GHG emissions. Over the years the awareness of the shipping industry being a polluter of air has increased.

If the emissions continued as usual unchecked, then soon the world would reach a point of no return where the temperature of the globe would keep rising and lead to more natural calamities. Therefore, to curtail the rise of the global temperature, European commission came up with its own plan. The plan known as 'fit for 55' where it aims at reducing the net greenhouse emission to 55% by 2030. This paper has made an effort to address all the aspects of 'fit for 55' relevant to the maritime sector. We have divided the maritime aspect of 'fit for 55' into two angles; 1. The cost impact of the fit for 55 maritime directives and 2nd the alternate fuel mixes which would help reduce the total cost of shipping.

To answer our objectives, we have made use of a new technoeconomic model 'MSF455' and taken input of three segments of commercial cargo ships mainly Bulk, tanker container vessels. The model takes inputs from the total cost of shipping (TCS), percentage fuel costs to the TCS, using the fuel consumptions to generate the required energy and the inputs from the maritime directives of 'fit for 55' like the EU-ETS, ETD, CBAM, Fuel EU maritime, trade volumes within and outside Europe, future costs of fossil and Biofuels to give a percent increase in the TCS which is cumulative figure of the increase carbon taxes.

We observed that the additional taxes for vessels making voyages within the EU is very high. For the Intra-EU vessels, the percentage increase in the total cost of shipping has increased from 5% in 2023 to 100% by 2030. The total annual carbon tax for CO_2 emission e.g., for a Container Feeder (1000 – 2000) TEU increased from 2945 €/ ton in 2023 to 39361 €/ton in 2030 for a fuel mix of LNG + MGO leading to percentage total cost of shipping to 126%. This can have a detrimental effect on the flow of goods and the Intra- EU trade can lose its competitive advantage and also lead to losses of EU-ETS and carbon slippage. Using the model to the above scenario with a fuel mix of LNG + Green Methanol, we arrived to the percentage total cost of shipping reduction of 22%.

Therefore, to conclude our findings we feel the incorporation of EU-ETS and other maritime directives into the shipping sector is for a good cause, however the policy makers have an uphill task to make the right decisions to make the 'fit for 55' maritime directives conducive for the shipping sector which would be discussed in detail in the paper.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Abbreviations and acronyms

EU - European Union
MW – Mega Watt
H2 – Hydrogen
NH3 – Ammonia
ETS - Emissions Trading System
ETD - Energy Taxation Directive
IMO - International Maritime Organization
HFO – Heavy Fuel Oil
LNG - Liquified Natural Gas
DWT – Deadweight
CII - Carbon Intensity Indicator
GHG - Greenhouse Gas
TCS - Total Cost of Shipping
SDG – Sustainable Development Goals
TEN-T - Trans-European Transport Network
Opex - Operational Expense
AFIR - Alternative fuels infrastructure regulation
MEPC - Marine Environment Protection Committee
EEXI - Energy Efficiency Existing Ship Index
MARPOL – Marine Pollution Convention
SEEMP – Ship Energy Efficiency Management Plan
ICCT – International Council Clean Transportation
CBAM – Carbon Border Adjustment Management
Intra EU – Within EU
Extra EU – Outside EU
SBCC – Ship Based Carbon Capture

1. INTRODUCTION

1.1 Background

With the advent of climate change and decarbonization looming over the shipping industry, the requirement to restrict the use of fossil fuels in shipping in order to considerably reduce carbon dioxide (CO_2) and other greenhouse gas emissions, as well as the associated International Maritime Organization regulations and instruments (IMO,2021). The policy objective is to cut carbon emissions to 50% by 2050 compared to 2008 levels; this target is also characterized by a decrease in CO_2 emissions per transport work of at least 40% by 2030 on average across all international shipping segments.
The IMO decarbonization goals are in place to tackle the growing GHG emissions from the shipping industry. On similar line, in order to achieve complete EU decarbonization by 2050, the European Commission introduced its Fit for 55 packages of measures, which aims to cut the EU's overall GHG emissions by 55 percent by 2030 (DNV,2021). The Council's and the European Parliament's approval of the package is projected by 2023. There are eight existing directives in the EU fit for 55 bundle, and a few new ones were added pertinent to the maritime sector. Certain existing directives were amended to make it relevant to the energy transition. The directives pertaining to the maritime sector are:

1. The revision to the European Emissions Trading System (ETS) Directive
2. The revision to the Energy Taxation Directive (ETD)
3. The revision to the alternative fuels infrastructure regulation (AFIR)
4. The new Proposal on greening European shipping (Fuel EU Maritime).

1. The revised European Emissions Trading System (ETS) Directive:
The current ETS will be expanded to include the maritime industry. This relates to energy use at ports, energy use while traveling between EU ports, and 50% of energy use while traveling between EU ports and ports in third countries for ships above 5,000 gross tons. About two thirds of emissions from maritime transport are affected by this. In addition to become more acquainted with them as well as be responsible for reporting a percentage of them, with that portion rising each year, shipping companies will therefore need to start monitoring their emissions as of 2023. In a recent development dated 22nd June 2022, with regard to the revamping of the EU Emissions Trading System, the European Parliament adopted a position (EU ETS) for the maritime sector. As a result, the Port Authority supports the legislative actions taken by the Parliament to reduce the incentive for ships to avoid the EU ETS, including the inclusion of non-EU ports within a 300 nautical mile radius and the coverage of 100% of emissions on extra-EU routes beginning in 2027. Furthermore, the European Parliament mandates that 75% of the proceeds from the competitive bidding of marine allowances be placed in an "Ocean Fund" to aid in the conversion of the EU maritime industry to one that is climate resilient and energy efficient (PoR,2021). Port of Rotterdam feels this will encourage accelerate the shift to sustainable shipping.

2. The Energy Taxation Directive (ETD)

The ETD sets the minimum tax rates for fuels, which are now determined by energy content rather than by liters. The minimum rate will be adjusted under the proposal to a level of 0.33 euros per liter in 2030, which is similar to about 130 euros per ton of CO_2 for airlines. On similar lines, with a transitional period of ten years (2023–2033), minimum fuel and electricity tax rates (measured in euros per gigajoule) will be implemented for intra-EU shipping for passenger services, freight, and fisheries, with a zero rate for sustainable alternative fuels and electricity for intra-EU shipping. If the port of entry or departure is outside the Union, EU Member States may levy the same tax rates on extra-EU shipping as they do on intra-EU shipping or they may offer exemptions. EU members may completely or partially exclude energy supplied to ships from shore from taxes.

3. The new proposal on greening European Shipping (Fuel EU Maritime)

To reduce greenhouse gas emissions by 6 percent in 2030 and by 75 percent in 2050 compared to 2020, ships docking at European ports must use less energy. This relates to energy consumption in ports, energy use while traveling between EU ports, and half of the energy used by ships exceeding 5,000 gross tons while traveling between EU ports and ports in a third country. This law, which is slated to go into effect in 2025, requires all ships with a gross tonnage of 5000 gross tonnage or over to reduce the amount of greenhouse gases they emit when using onboard energy while also tracking for all emissions. The shipping companies are subject to the requirement. The plan necessitates shipping companies to a thorough monitoring, reporting, and verification system.

4. The revision to the alternative fuels infrastructure regulation (AFIR)

The Alternative Fuels Infrastructure Directive (AFID) is a program intended to expand access to alternative fuels throughout the EU and more environmentally friendly electrical power sources at ports. The AFID, which has officially been in effect since 2014, was created to promote a sufficient infrastructure network for the refueling and charging of ships with alternative fuels while they are berthed, as well as to provide substitutes for engines now fueled by fossil fuels.

This becomes a regulation under the Fit For 55 package proposal, making it legally binding. In order to comply with the maritime-related amendment suggestions to AFIR, EU member states must strengthen the supply of hydrogen and LNG as well as the onshore power supply for ships at ports. Therefore, these measures do not specifically apply to shipping firms, but they do guarantee that the infrastructure will be in place to meet the Fuel EU Maritime regulation's requirements for the changeover to alternative fuels and shore power supply at port stays.

1.2 Problem Statement

For each of the initiatives in the fit for 55 package, the European Commission has released an Impact Assessment, which includes the impact on shipping and port expenses or from which that impact can be deduced. Though the Fit for 55 is initiated for a bold cause to reduce the greenhouse gas emissions, however 'fit for 55', provides neither the legal framework nor the technical solutions have been fully established yet; for instance, the existing set of applicable rules and regulations do not take into account the technologies and fuels advocated as technical answers. In accordance with the aforementioned policy directives, it is also necessary to replace fleet components that are not expected to conform to the new regulations; new ships that emit fewer GHGs per transport task will take the place of older ones that are nearing the end of their economic lives or for which the cost of retrofitting may not financially viable. A significant proportion of current ships will need to upgrade certain components of their propulsion systems or install new technology in order to adhere to the more stringent environmental regulations. To add to it, the recent revision of the EU-ETS to incorporate the maritime sector for the first time to comply with the fit for 55 will also add to the woes of the ship and cargo owners as it will incur additional costs. Therefore, at this juncture the insights on the costs for the shipping industry is important to be addressed to give a holistic view of the implications of these new regulations and directives.

The following section briefly discusses the flow of the research paper: Section 2 presents the topic, specifies the research questions, and establishes the framework for the research using the history of the identified issue as a starting point. Section 3, to demonstrate the gap in the literature that this study attempted to fill, a section summarizing relevant works and literature is included. In section 4, the model assumptions and underlying technique are presented. The section 5 examines the datasets as well as the model's input parameters and the results from the interview. The section 5 of the paper would contain the results of the data obtained from section 4. This work is completed, analyzed, and the paper's main conclusions and potential consequences are highlighted in the last part of the paper in section 6.

1.3 Objective

The objective of this paper is to foresee the cost impact and the challenges in place for European shipping industry for "Fit for 55" maritime directives and their direct implication on the carbon taxes over the years until 2030. Based on the scenarios developed using the MSF455 model, we look at the output to analyze to signify the implication that could have due to the incorporation of shipping in the EU-ETS. In addition, we also look at the various scenarios in which the future fuel mix with fossil fuels and Biofuels to give a good indication of the total cost of shipping impact and suggest a suitable fuel mix for the future to come.

1.4 Research Question

Consequently, the following main research question has been addressed in this thesis:

> ***"What would it cost the European shipping industry to comply with the fit for 55 directives?"***

The main focus of this study is to see how the 'fit for 55' maritime directives will impact the flow of cargo, CO_2 cost impact on the vessels within EU and sea going vessels visiting Europe. will these new changes make the ship owners switch to greener fuels and who will bear the cost of it. The four main directives addressed towards the maritime industry would be the mostly discussed to answer the main research question. By enabling a fair, competitive, and environmentally sustainable transition by 2030 and beyond, the "Fit for 55" package, which consists of a number of connected policies, seeks to meet the EU's higher carbon reduction target. In addition, to answer the research question, we will understand IMO's decarbonization goals (GHG emissions) and the initiatives taken to reduce CO_2 emission along with the EU's "Fit for 55" initiative impacting the shipping industry.
The quantitative and qualitative phases of the research setup that are required to respond to the research question produced from the problem analysis are discussed in the next chapter.

2. RESEARCH DESIGN

2.1 Introduction

This kind of research would combine quantitative and qualitative methodologies that might be categorized as sequential mixed methods research. This strategy has been applied at various levels of research. It combined information from interviews with philosophical suppositions.
The applied research setup made it possible to better comprehend the subject and its context than either qualitative or quantitative research could.

2.2 Problem Definition

The cost impact of reducing greenhouse gas emissions is a hefty challenge for the shipping companies and port authorities. The primary objective of the research study is to determine how much it would cost to implement the EU directive for the maritime industry. As fuel plays a vital role in the transition, we will look at the various alternative fuel options available and the cost impact of the new directive of Fuel EU and AFIR in inland and sea going vessels within the Netherlands. Consequently, the following sub-questions arise.

How much amount of CO_2 emission generated in the world by vessels and the shipping in the Netherlands?
What alternative fuel options there are to support the decarbonization goal and the incentives provided by the EU policy makers to make fit for 55 conducive?
What elements do we need to include in a model to compute emissions from shipping using various fuel mixes and connect that to fit for 55 maritime directive that helps shipowners make commercial decision?
What are the challenges fit for 55 faces in terms of cargo volumes and avoidance of EU-ETS?

2.3 Methodology

Qualitative research
A methodology that has been utilized to investigate the study problem is qualitative research. The objective of the qualitative research was to comprehend the individuals' situation by actively visiting the content matter and acquiring the necessary data. The goal of qualitative study was to directly gather facts and meaning as first-hand knowledge from shipping industry specialists. The knowledge obtained from the qualitative research was used as a basis for quantitative research.

Quantitative research

The quantitative research is mainly based on the four literatures: literature review, literature study, literature analysis and literature synthesis. The literature review is performed to identify the key issues and trends in build up to the fit for 55 directives towards the maritime sector. The link between variables has been investigated using quantitative research methods, for example the data used for calculating the EU ETS for the CO_2 emissions and Fuel EU.

Case study

The relevant case study related to the EU ETS and vessel's voyage data would be used to represent the research paper. For this specific study the case paper: The competitiveness of European Short-sea freight Shipping compared with road and rail transport published by the European Commission DG environment written by Delhaye et al., 2010 was used. The cost structure of the various scenarios of voyage within Eu and ocean passage was used to develop the fuel mix scenarios. The cost structure used for the scenario development is attached in the appendix 4.

2.4 Relevance

This study's objective is to enlighten the reader about the recently developments in the European Union's initiative to include shipping sector in their quest for carbon free emissions, explain how it will affect the shipping sector, and assess the advantages and downsides. We will briefly look at the four major directives related to the maritime industry that have been revised or added newly to the fit for 55. The major focus of the study would be on the two directive Fuel EU maritime and AFIR (Alternative fuel infrastructure regulation) and input the alternative fuel including Biofuel options available for the transition. In addition, using the MSF455 model in the methodology, we will look at the new angle at reviewing the total cost of shipping (TCS) and how it can be reduced by analyzing the fuel mixture for the future to make the fit for 55 cost impact conducive.

3. LITERATURE REVIEW

3.1 Introduction

Approximately 80% of all trade is accounted for by the shipping industry, which is predicted to continue growing. Both a significant driver of climate change and a comparatively low-carbon source of freight transportation is the shipping industry. Additionally, the industry accounts for around 3% of all CO_2 emissions, which, if unregulated, may more than double by the year 2050.

3.2 IMO's Decarbonization Goal

The IMO supports the UN Sustainable Development Goal (SDG) 13 and takes immediate action to combat climate change and its effects as a special organization and the United (UN).

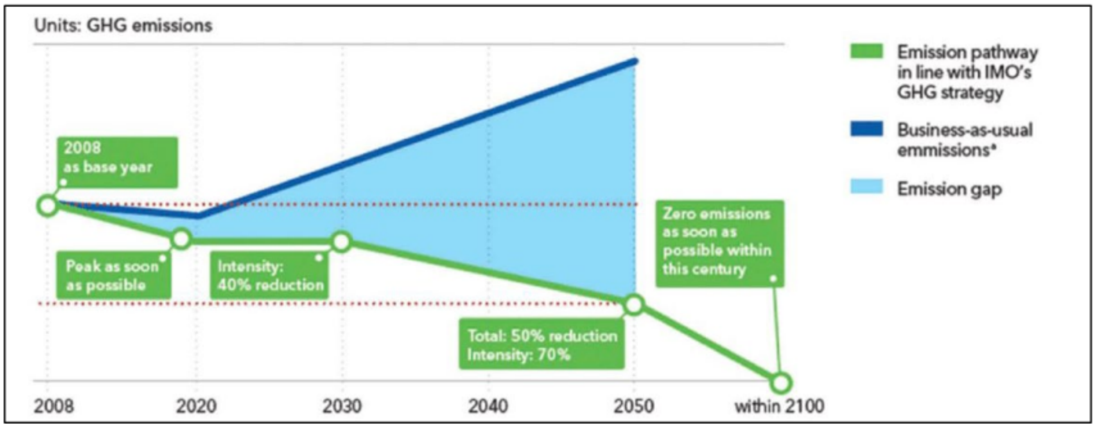


Figure 3.1 IMO GHG STRATEGY AND BAU EMISSIONS (DNV-GL 2019) | Source: DNV website/ IMO decarbonization strategy

Given 2008 levels as the benchmark, the IMO's initial GHG objective proposes a reduction in CO_2 emissions per transport work of at least 40% across all international shipping segments by 2030 and a goal of 70% by 2050 ((Øyvind Endresen & Magnus S. Eide, 2019). The Marine Environment Protection Committee (MEPC) 75 (2020) of the IMO recommended a reduction in the carbon intensity of emissions from all vessels over 400 GRT. Under the IMO's pollution prevention convention (MARPOL), three key factors make up the list of short-term actions that the IMO agreed to in June 2021:

1. EEXI: An existing ship technical measure (Technical approach).
2. CII: To assess the performance of operational energy efficiency, use a carbon intensity indicator (CII), (Operational approach).
3. Vessel rating system: A segmentation method in which vessels are awarded the designations based on the efficiency as A, B, C, D, and E.

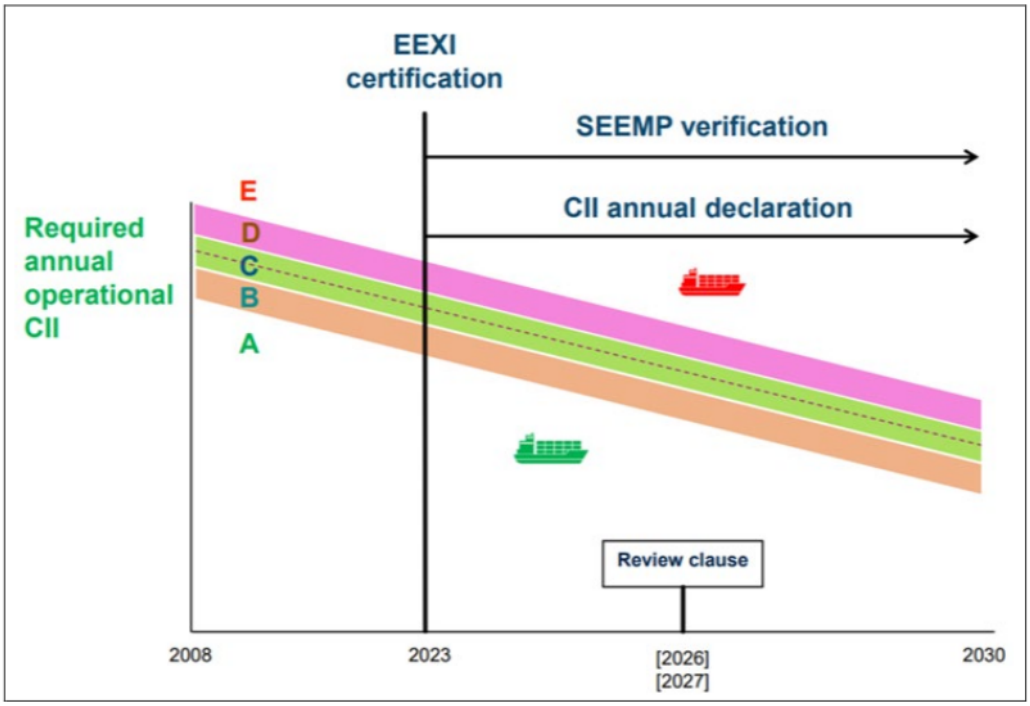


Figure 3.2 EEXI and CII implementation plan. Source: DNV

IMO's GHG Strategy

The short-term measures to achieve the IMO 2030 target can be split into Technical Approach – EEXI (Energy Efficiency Existing Ship Index) and Operational Approach – CII (Carbon Intensity Index)

At its 76th meeting in June 2021, the Marine Environment Protection Committee (MEPC) agreed changes to MARPOL Annex VI that make the Energy Efficiency Existing Ship Index (EEXI) guideline mandatory. Vessels with a gross tonnage of 400 or more and a ship type that fits into one or more of the categories* mentioned in regulation 2 of MARPOL Annex VI are subject to the EEXI regulation (Class NK, 2021).
(*All segments of cargo vessels, *Ro-ro passenger ship, LNG carrier having conventional and non-conventional propulsion i.e., diesel-electric propulsion, turbine propulsion, hybrid propulsion systems, etc. and cruise passenger ship.)*

The Carbon Intensity Indicator (CII), which is expressed in grams of CO_2 emitted per cargo-carrying capacity and nautical mile, gauges how effectively a ship transports cargo or passengers. The ship is then given an annual grade between A and E, with the rating thresholds getting tougher as we get closer to 2030. All cargo, passenger, and cruise ships over 5,000 GT are subject to the CII (DNV,2022). The ship is rated from A to E according to the annual CII, which is determined using recorded IMO DCS data. A corrective action plan must be created as part of the SEEMP and authorized for ships that receive a D assessment for three consecutive years or an E assessment in one year. The vessel has to maintain its attained CII in band A, B or C.

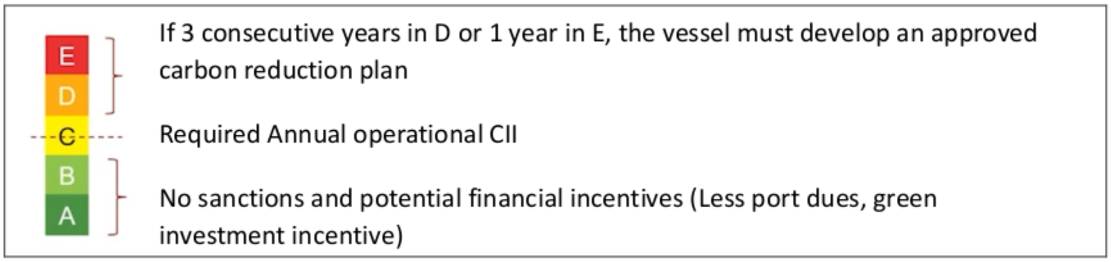


Figure 3.3 CII Assessment for Vessels. Source: Author

The calculation for the CII can be carried as follows:

$$CII = \frac{Annual\ CO2\ mass}{Distance\ x\ Deadweight}$$

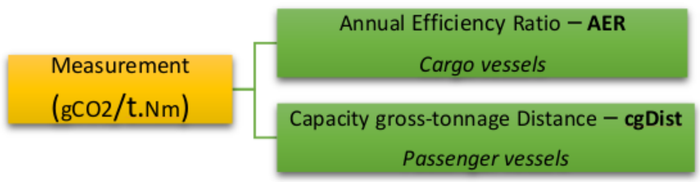


Figure 3.4 Calculation for CII. Source: Author

A vessel can lessen its carbon intensity by undertaking a variety of actions such as:
1. Reduction in speed
2. Optimizing fuel measurement
3. Alternative fuel usage
4. Social Measures
5. Engine Power Management

The quickest way to reduce CII would be by achieving economics of scale and a slow steamed voyage. Alternately, the CII can be reduced by optimizing the fuel measurement system. As CII is dependent heavily on the fuel measurement, any faulty reading from the fuel meters onboard the vessel can give erroneous readings thereby give wrong CII indicators. Therefore, regular calibration of the fuel measurement systems should be carried out. The choice of fuel for the vessel is prudent in reducing the CO_2 emissions, therefore an alternative fuel with lesser CO_2 emission should be considered to achieve the CII target. Social measures need to be considered like, training the crew to switch off unnecessary lights on the ship like cabin and store lights off when not needed to reduce the energy consumption. Engine power management is vital to the success of the CII indicator. This can be achieved by running the vessel at optimal power which is economical and viable for the voyage. This will not only help in reducing CII but also reduce the wear and tear on the engine.

3.3 Fit for 55 – European Union's plan for green transition

Despite the fact that an international strategy to reduce greenhouse gas emissions from international shipping, led by the International Maritime Organization (IMO), would be the most efficient and thus preferred solution, the IMO's relatively slow progress has prompted the EU to act and make new proposals to ensure that maritime transport plays a part in achieving climate neutrality in Europe by 2050. The EU's goal of reducing net greenhouse gas emissions by at least 55 percent by 2030 is known as "Fit for 55." The proposed package intends to align EU law with the 2030 target. The set of recommendations attempts to provide a comprehensive and fair framework for achieving the EU's climate goals. We will focus in detail the directives which would impact the shipping industry.

3.4 Revision to the EU emissions trading system

The largest adjustment of the emissions trading system (ETS) in the European Union since its inception in 2005 took place on January 1, 2018. With the reform, the ETS will be able to respond to economic development and reduce greenhouse gas emissions more effectively. A revamped allocation method that will give more weight to emission reductions attained through investment in low-carbon technologies is one of the most significant changes. Another is a new market stability reserve that will aid in managing volatility in carbon prices. Shipping companies will have greater options to exchange carbon allowances and participate in renewable energy projects thanks to the updated ETS. An overall decrease in emissions in the impacted sectors of 61 percent by 2030 compared to 2005 is what the Commission has suggested for the current EU emissions pricing scheme (EU ETS). The EU Council agreed to integrated maritime shipping emissions under the scope of the EU ETS as of 2024 on June 29, 2022, when it adopted its negotiating positions (general approaches) on significant legislative measures in the Fit for 55 packages. The EU Council decided to redistribute 3.5% of the auctioned allowance cap to the member states most adversely affected by maritime transport because of their strong dependence on it. To put the Emissions covered by EU ETS in perspective, as of 2024, EU ETS will cover 100% of the emissions from ships traveling on intra-European routes with a gross tonnage of 5,000 tons or greater as well as 50% of those traveling on international routes to and from the EU (extra-European). 100 percent of the emissions shall be factored into the computation of annual emissions if the voyage is less than 300 nautical miles to and from an EU port. Emissions from both intra- and extra-European routes are covered by the EU ETS as of 2027, with the option of derogations to 50% for non-EU countries under tight criteria, should third nations take responsibility for such emissions or a so-called "IMO market-based approach" be in place. As of this date, the ship's gross tonnage has been reduced to 400 gross tons and above (Brunner,2022). According to the amended proposal, the shipping firm shall be the entity in charge of ensuring compliance with the EU ETS. A binding clause should be included in such agreements for the purpose of passing on the costs since the shipping company isn't always in charge of buying the fuel or making operational decisions that have an impact on the ship's GGE and can be assumed by another party under a contractual arrangement. According to the modification proposal, the shipping firm shall be the entity in charge of ensuring compliance with the EU ETS. In this way, the party ultimately in charge of making decisions that have an impact on the GGE of the ship will be held accountable for paying the shipping company's compliance fees. An Ocean Fund will be created in accordance with the new regulations to assist projects and initiatives. According to the concept, the Ocean Fund shall get 75% of the proceeds from the auctioning of entitlements. Funds given under the Ocean Fund will help the transition to an energy-efficient and climate-resilient maritime industry in the European Union. The Ocean Fund will be centrally managed by an EU entity (Zero2050Redaction, 2021) .

EU Emissions Trading System (Maritime sector) - Key Takeaways	
1	The MRV reporting system serves as the foundation for the ETS. It is applicable to any ships with more than 5,000 GT that conduct commercial operations in Europe, regardless of flag of registration.
2	The price of EUAs is influenced by the market mechanism and the quantity of EUAs issued.
3	The system will gradually incorporate the maritime industry. Starting in 2023, with 20% of total emissions, it will rise gradually to 100% starting in 2026.
4	Ships are accountable for 50% of their CO_2 emissions when entering or departing the EU and for 100% of them while in EU ports and while transiting between them. In addition, 100 percent of emissions at a berth in a port under a Member State's sovereignty.
5	Pay-as-you-go is not applicable in this system. Before April 30 of the following year, ship operators must deliver the previous year's emission rights.
6	Failure to comply has a high price; in in addition to submitting the required EUAs, a €100/t penalty will be assessed. A vessel prohibition in EU seas could be imposed after two years in a row of noncompliance.
7	Holders are permitted to purchase EUAs from other shipping companies, during yearly EU auctions, or on the open market.

3.5 The Energy Taxation Directive (ETD)

Since 2003, the Energy Tax Directive has been unifying fuel and power tariffs in the European internal market. The directive will now be equipped to regulate taxes on maritime fuels thanks to the revisions provided in Fit for 55. In addition to aviation fuel which was already part of the ETD, Fuel usage will now incorporate maritime transport (including fishing) and inland waterway transport and shall be subject to taxation at the EU's harmonized minimum rates for intracommunity activities under this directive. The idea behind taxing fuel is by supporting a switch to cleaner energy, more sustainable industries, and more environmentally friendly choices as part of a socially just green transition, taxation initiatives at both the EU and Member State level can help us achieve our climate policy goals (European Commission, no date). However, the present ETD raises a number of difficulties related to its separation from climate and energy efficiency goals as well as its flaws in terms of the internal market's functionality. Few of the drawbacks in the ETD are, primarily the directive falls short in its efforts to encourage energy efficiency, the use of alternative fuels, and a decrease in greenhouse gas emissions (renewable hydrogen, synthetic fuels, advanced biofuels, etc.). This is because there is no specific rate for new, less-carbon-intensive fuels because they are taxed at the same rate as their fossil equivalent if they were developed after the previous ETD was adopted in 2003. In the case of biofuels, because of the volume-based taxing, biofuels suffer (rates expressed per liter) because while paying the same tax rate, one liter of biofuel often contains less energy than one liter of the competitor fossil fuel. Thus, indicating ETD does not give sufficient incentive for investing in cleaner technological improvements. Additionally, the ETD notionally is in favor of fossil fuels because of the divergent national rates and wide range of tax exemptions, reductions provided to fossil fuels. In two ways, the new plan would aid in lowering the usage of fossil fuels. The relative pricing advantage of fossil fuels over fewer polluting alternatives is reduced, firstly, by setting higher rates for fossil fuels and lower rates for renewable products. By looking at potential tax exemptions and reductions, which now lower the taxation of fossil fuels, as a second step. These include gas oil used in agriculture and households use to warm and fossil fuels used in energy strenuous industries. This is where the mandatory exemption will impact the maritime industry especially impacting the shipping industries and the fishing sectors. Thirdly, because the minimum tax rates no longer have a convergent effect on national tax rates, the ETD is no longer helping the internal markets operate properly. Although national rates are typically substantially higher than the ETD minima, minimum rates are low because they haven't been altered since 2003. All of this contributes to the internal market's fragmentation and, in particular, affects the equitable playing field throughout the concerned economic sectors by existing exclusions and cutbacks (European Commission, 2021). The FUEL EU Marine effort and the EU ETS initiative, both of which aim to increase the demand for renewable and low-carbon fuels in the shipping industry, both support taxing traditional fossil fuels used in maritime transport inside the EEA. The ETD's reduced tax rates on the sustainable and low-carbon fuels that this effort promotes would gradually reduce the cost disparity between traditional and sustainable fuels by stimulating fuel switching (Zero2050 RedAction, 2021). Additionally, there are parts of the ETD that are unclear, irrelevant, and inconsistent, which raises legal ambiguity. These include, among other things, the classification of taxable goods and uses that fall outside the purview of the Directive, as well as how the exemption relating to the use of motor fuels for maritime navigation should be interpreted.

EU Energy Taxation Directive (Maritime sector) - Key Takeaways	
1	Fuels purchased within the European Economic Area and used for intra-EEA travel will no longer be tax-free.
2	The tax on diesel and heavy fuel will be similar to around € 37 per ton, and the cost on LNG will be slightly less.
3	A 10-year waiver will be given to low-carbon fuels.
4	Rather than volume, taxes would be based on energy content and environmental performance.
5	International bunkers will continue to be exempt from taxes, however Member States may do so unilaterally—although it is improbable that they will.

3.6 Fuel EU Maritime – New Proposal on greening European Shipping

One of the directives, along with four others, is the FuelEU Maritime legislation due to come into force by 2025, which aims to decarbonize the EU maritime industry. The proposal will mandate that all ships with a gross tonnage of 5,000 GT or more begin lowering the GHG intensity of the energy they use on board. The European Commission suggests limiting the carbon intensity of the energy used on board ships in order to encourage the adoption of environmentally friendly maritime fuels. As a response, the framework proposes a mandate for the most polluting ship types to use onshore electricity when at berth and specifies a fuel standard for ships. To comply with this directive, the onus of responsibility is entrusted to the shipping companies. The regulations that result from this proposal will be closely related to the regulations that are also being suggested in alternative fuel infrastructure, energy taxation, renewable energy, and involving the maritime industry in the EU carbon trading system (Pape,2022). The framework suggests that ships must reduce their yearly average GHG intensity of their onboard energy by 2% by 2025. The total quantity will rise in five-year increments until 2050, when all ships' carbon intensity must match by 75 % that of the base year 2020 (Elina,2022). The breakup of the percentage reduction in GHG per five year is as follows; 2% by 2025, 6 % by 2030, 13% by 2035, 26% by 2040, 59% by 2045, and 75% by 2050. Shipping companies who do not comply with the regulations by May 1 of the following year will be penalized, with the fine going into a green fuel fund. The proposal outlines a methodology for fuel lifecycle analysis as well as standard guidelines for monitoring, reporting, verifying, and accrediting fuels. Starting in January 2030, all freight (especially container vessels) and passenger ships docked in EU ports for longer than two hours will be required to connect to an onshore power supply (OPS) and use it for all of their energy requirements while berthed, unless they are using zero-emission technologies or are in an emergency. Additionally, given that all of the ships in the pool are certified by the same verifier, the plan permits ship owners of various ships to pool their resources to assist one another with compliance. Based on the proposal, if one ship in a pool exceeds the previous year's compliance standards while another does not, the first ship may transfer its excess credits to the second ship. The proposal is ambiguous as to how exactly this occurs, but it implies that if two ships are controlled by separate ship owners, one company may sell its credits to the other (UK P&I,2021). The Fuel EU directive has not gone down well with the ship owners as for multiple reasons the onus of responsibility is put on the ship owner, for e.g. The European Shipowners (ECSA) notes that under the Fuel EU Maritime proposal, the calculation of carbon reductions for gasoline purchased outside the EU would be reliant on papers from non-EU fuel suppliers. Additionally, they advocate holding EU fuel suppliers accountable for adhering to the fuel regulations rather than shipping companies. Transport and Environment cautions that ports still run the risk of becoming locked into fossil fuels despite their electrification efforts. They emphasize how crucially connected the Fuel EU Maritime concept is to the updated proposal on alternative fuels infrastructure and believe that the Commission is "betting on the wrong horse" by boosting LNG (Delphine, 2021). This raises the issue of use of Biofuels. As mandated by the IMO SOLAS Convention, the Maritime Safety Committee (MSC) of the IMO urged ISO to create standards for methyl/ethyl alcohol as a fuel for ships with a flashpoint below 60 deg C in 2018. In order to establish an international standard for ships utilizing such fuels, the IMO MSC issued interim rules for the safety of ships using methyl/ethyl alcohol as fuel in November 2020. Regarding the nature of the fuels used, the IMO standards include measures for the arrangement, installation, management, and monitoring of machinery, equipment, and systems using methyl/ethyl alcohol as fuel in order to minimize the danger to the ship, its crew, and the environment. The use of biofuels should only be taken into consideration for obligatory enforcement by the European Union if fuel suppliers are legally required to ensure that the biofuel blends, when combined with fossil fuels, are safe and suitable for their intended usage in accordance with IMO regulations.

EU FuelEU Maritime (Maritime sector) - Key Takeaways	
1	Primary objective, by placing restrictions on the amount of energy consumed on board ships, its major goal is to encourage the adoption of low-carbon fuels. Over time, the needs are rising.
2	The system also has a time averaging and grouping feature for ships and organizations to give some flexibility.
3	Regarding the FuelEU Maritime plan, the ECSA notes that the calculation of carbon reductions for fuels purchased outside the EU would be relied on credentials from non-EU fuel suppliers.

4	Unlike in EU ETS, this rule determines CO_2 equivalency from a life cycle perspective (from well to wake), while also taking methane and nitrous oxides into account.
5	The regulation specifies that container and passenger ships must be connected to shore power if they spend more than two hours in EU ports by 2030.
6	Similar to the EU ETS, there are consequences for non-compliance, such as the potential for access into EU waters to be barred after two years of non-compliance.

3.7 The revision to the alternative fuels infrastructure regulation (AFIR)

Through this directive, a comprehensive and extensive network of infrastructure for alternative fuels will be made available and made simple to use across the EU. The primary goal of the proposed legislation is to guarantee that the general public has access to a suitable infrastructure network for refueling or charging alternative fuel-powered ships or vehicles on land. Additionally, it seeks to offer alternate options so that docked ships and grounded airplanes won't need to keep running their engines. It ensures that sufficient shore power supplies will be installed in ports to fulfill the need for carbon free gases as well as to provide electricity for container ships, ro-ro passenger ships, high-speed passenger ships, and cruise ships while they are moored. The salient features of the directive are channelized towards the development of infrastructure for providing electricity and LNG (Zero2050 RedAction, 2021).

The Regulation's Article 9 outlines the goals for the provision of electricity on land and at seaports that the member states shall ensure by January 1, 2030;

a. The seaports of the basic TEN-T and the global TEN-T have enough electricity on land to meet at least 90% of that demand on an annual basis for container ship calls of more than 5,000 gross tons over the past three years.

b. The seaports of the basic TEN-T and the global TEN-T have enough power on the ground to meet at least 90% of that demand for ro-ro passenger ships and high-speed passenger ships with annual mean calls of more than 5,000 gross tons during the past three years, over 40.

c. The marine ports of the TEN-T and TEN-T that have seen an average of over 25 passenger ships, excluding ro-ro passenger ships and high-speed passenger craft, call annually over the past three years have enough electricity on the ground to meet at least 90% of the aforesaid demand.

The Regulation specifies the goals for the supply of LNG in seaports in its article 11. 1. In order for seagoing vessels to move freely within the TEN-T core network, Member States shall see to it that a suitable number of LNG refueling facilities are created in the TEN-T core seaports listed in table 2 of the AFIR directive (attached in appendix 1) prior to

January 1, 2025. When necessary, member nations will work together to guarantee that the TEN-T core network is adequately covered .

2. The TEN-T key maritime ports that will give access to the LNG refueling sites indicated in the above section shall be designated by the member states in their national political frameworks while also taking into account the actual needs and market evolution.

In order to comply with the maritime-related adjustment suggestions to AFIR, EU member states must expand the supply of hydrogen and LNG as well as the onshore power supply for vessels in ports. Therefore, these requirements do not specifically apply to shipping firms, but they do guarantee that the infrastructure will be in place to meet the Fuel EU Maritime regulation's requirements for the migration to alternative fuels and onshore power supply while port stays (Elina, 2022).

EU AFIR (Maritime sector) - Key Takeaways	
1	The Alternative Fuel Infrastructure Directive is being reviewed by the Commission in order to enhance LNG and onshore power supply facilities in the major EU ports, soon this will become a legislation.
2	According to this assessment, EU nations must invest adequately in the fuel supply, LNG availability by 2025, and land-based energy installations by 2030.
3	The objective of this Rule is to make it easier to comply with the FUEL EU regulation for maritime transport's onshore energy requirements.

3.8 Optimizing vessel efficiency to reduce CO_2 emissions

On ships, there are several energy loads and losses, places where energy is lost, consumed, or dispersed (Bucknall et al., 2014). These mainly take place in the engine room near the point of combustion of the fuel, thermodynamics, losses through exhaust energies. It is also crucial to account for mechanical and friction losses while transferring engine torque and speed to the propeller. To move the ship through the water and the air, propeller thrust energy must outweigh the prevailing hydrodynamic and aerodynamic factors. There are numerous solutions available to decrease the weights on each vessel and internal losses to cut down on fuel use and CO_2 emissions (ICCT, 2011). The image below indicates the various options by which a vessel can improve its efficiency and reduce fuel consumption, in the bargain reducing CO_2 emissions. Reducing vessel speed represents the single largest chance to cut fuel consumption and CO_2 emissions, besides it can simultaneously improve engine efficiency and decrease thermodynamic loads of the vessel.

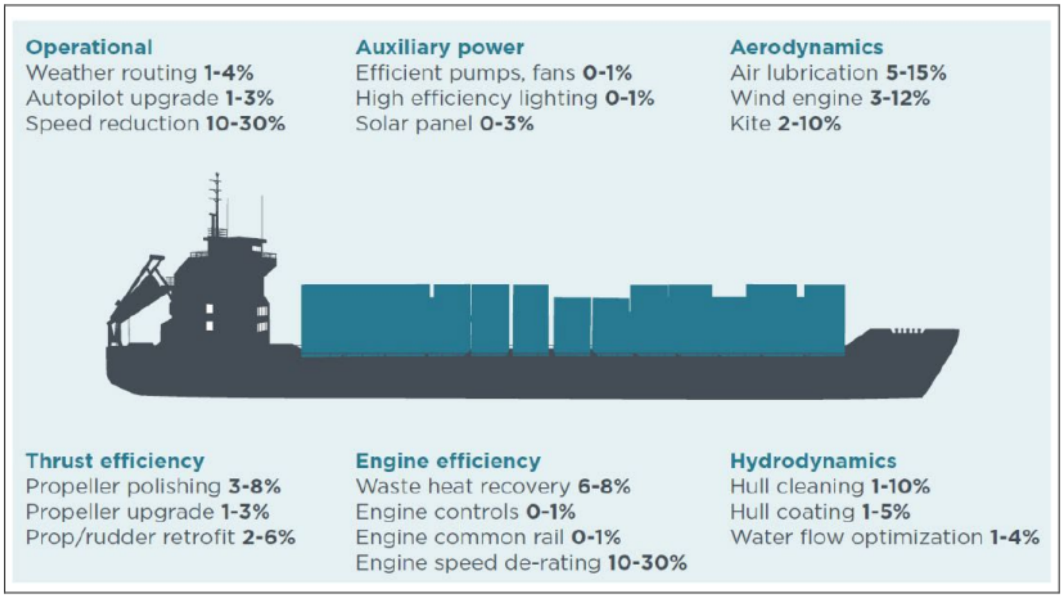


Figure 3.5 Synopsis of strategies for improving the effectiveness of commercial vessels. Source: ICCT Publication

Wang and Lutsey provided a comprehensive summary of the alternative strategies for the improvement of commercial vessels, as seen in Figure above (Haifeng et al.,2013). The percentages displayed pertain to possible fuel consumption reductions as indicated in ICCT 2011, which have an effect on GHG emissions.

3.9 Alternative fuel options in The Netherlands- Biofuels

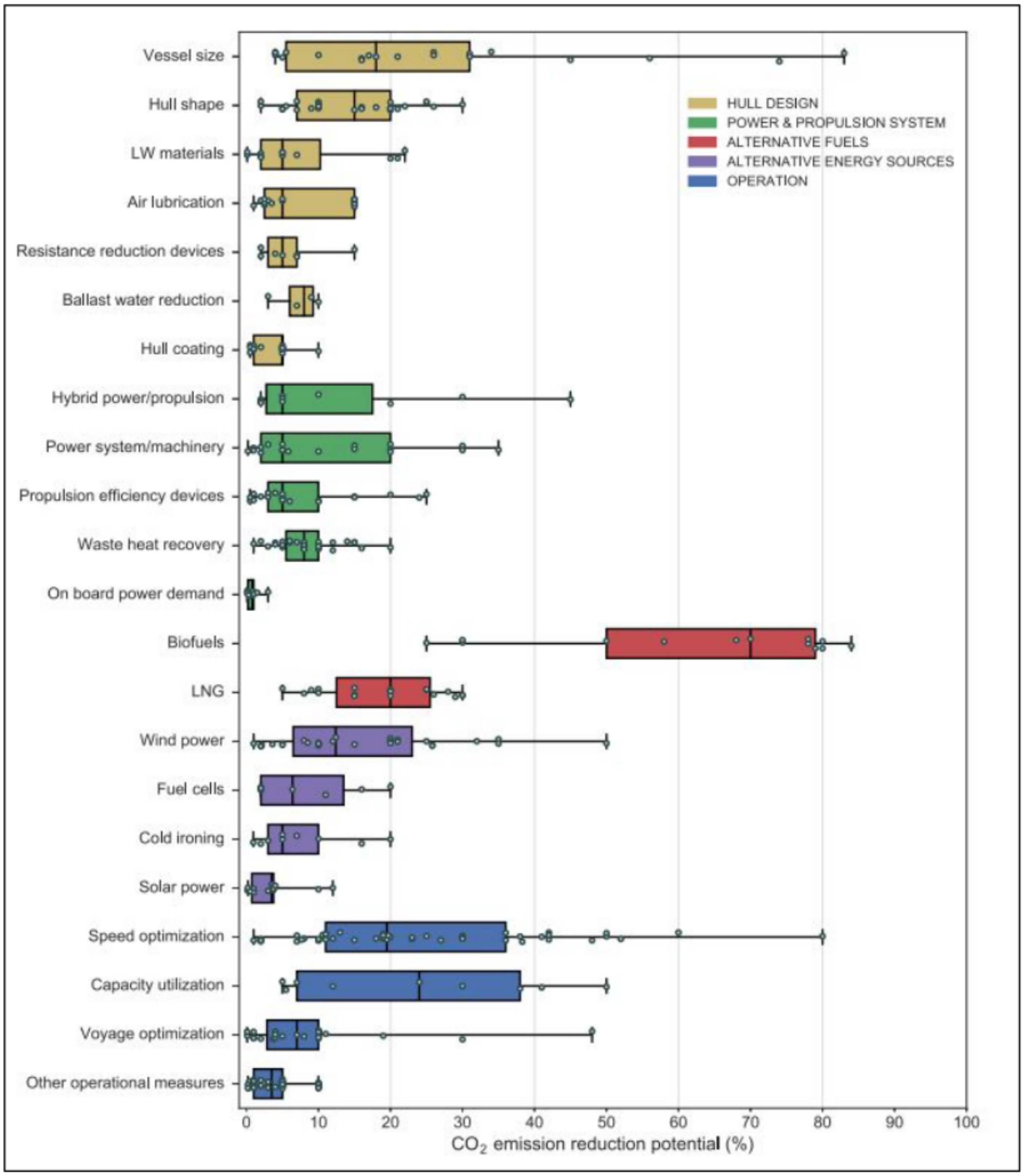


Figure 3.6 Alternative fuel options. Source: E.A. Bouman et al. / Transportation Research Part D

A comprehensive study of almost 150 research by Bouman sought to give a thorough overview of the potentials and strategies for reducing CO_2 emissions in shipping (Evert A et al., 2017). Based on Bouman et al study, CO_2 reduction can be achieved by 22 measures. Leveraging economies of scale and lowering operating resistance are the main goals of hull design measures. The findings of the above table suggest that new hull design can significantly reduce CO_2 emissions. Increased vessel size lowers emissions per unit of transported goods, while hull form optimization can considerably lower power usage and emissions as a result. Light-weighting, hull coating, and lubrication are other strategies that can help hulls perform even better, but their effectiveness as a stand-alone strategy is constrained. The power and propulsion system has a significant reduction of CO_2 emissions. However, the challenge to have a successful hybrid technologically advanced vessel is yet to be established as many shipping companies and engine manufactures are still experimenting to attain the best output. LNG was considered as the fuel of the future to reduce GHG emissions, though LNG has proven better than the other fossil fuels such as HFO, the biggest drawback with LNG is the potential of LNG slip or leakage. LNG slippage when occurs has detrimental effect and can severely damage the environment by increased amount of pure CH4 being released to the environment thereby adding to the GHG emissions. A possible short-term solution to prevent the slippage of LNG would be to install (SBCC) ship-based carbon capture (Jasper A et al., 2022). Wind power has strong reduction potentials and solar power modest reduction potentials for the initiatives focusing on alternative energy sources. The application of solar cells, sails, and kites to harness these extra energy sources heavily depends on the type of ship being used. Due to the surface area required for each of these measures, the total quantity of energy that can be generated by these measures on-board is limited. As a result, these measures are most effective for smaller ship sizes on selected routes with high solar exposure and wind capacity.

The above image demonstrates that the usage of biofuels has the most potential to reduce CO_2 emissions. The decrease of greenhouse gas emissions would benefit from the extensive usage of biofuels. The ability of biofuels to reduce atmospheric CO_2 is primarily influenced by two aspects. First, the types, qualities, and processing methods of the bio feedstock vary. Variations in feedstock, methods of production, efficiency, etc. affect CO_2 reduction potential. The second aspect has to do with how reduction potential is computed. Emissions from biological sources are typically seen to be carbon-neutral because biofuel is a renewable source and carbon is captured throughout the growth of the biomass. Nevertheless, the carbon-neutrality concept is highly dependent on the source crop's rotation periods, where it is grown, and both direct and indirect albedo changes brought on by harvesting, all of which have an impact on the climate.

	HVO (Renewable Biodiesel)	SVO (Straight Vegetable Oils)	FAME (Product of Fat and Oil)	Bio-Ethanol	Bio - Methanol	Bio-Dimethyl ether (DME)	Bio-Methane
Blending Possible	Yes	Yes	Yes	Yes	Yes	Yes	
Production Cost	14 – 25 €/ GJ	17 – 24 € / GJ	20 – 28 €/ GJ	19 – 29 €/ GJ	16 – 25 €/ GJ	Not available yet	12 – 35€ / GJ
Compatibility with HFO, DO	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Low Speed Engine – Deep Sea vessels	Yes	Yes	Yes	Yes	Yes	Yes	No
Diesel Engine – Inland and Short Sea Vessels	Yes	Not	Yes	Yes	Yes	Yes	Yes
Well to tank GHG Reduction	Up to 88 %	Up to 58%	Up to 80%	32 – 87 %	Up to 95%	Up to 94%	71 – 82 %
Availability Today to 2030	Yes	Yes	Yes	Yes	Moderate	Moderate	Yes

Table 3.1 **-** *Biofuel Options in the NL From today until 2030. Source: E4Tech UK(May,2018)*

3.10 Total cost of shipping

The following three elements, according to Stopford (2009) 3rd edition, represent the vast majority of shipping costs.

1.Capital Costs

The capital costs of shipping involve the capital cost invested in purchasing a vessel, leasing or even accepting the depreciation value. The freight rate, which has traditionally been extremely unpredictable due to shifts in demand and supply, has a substantial impact on the ship's purchase price and is a major determinant of the capital costs connected with transportation.

Depending on the type of vessel, the capital costs involve about 40 to 42 percent of the total cost of shipping (Stopford, 2009).

2. Operational Costs

The operating costs account for crew costs (such as wages, supplies, etc.), stores (such as lubricating oils), repairs and maintenance, insurance (such as P&I insurance, marine insurance), and administration (such as registration costs, management fees, and other incidentals), and they reveal that the highest operating costs are incurred by commercial vessels are associated with tankers (Sean et al.,2019). The operating costs involves around 14 percent of the total cost of shipping (Stopford,2009). The balance percentage would the cost of insurance and maintenance.

3. Voyage costs

The voyage costs involve every cost related to the cost of fuel, port expenses and canal costs which are specific to the voyage. When ports are named in a voyage charter, they are typically covered by the agreed-upon spot rate and paid for by the shipowner. When ports are not established or not known in advance during a time charter, they are compensated by the charterer (Stopford,2009).

The most significant expense component of a voyage costs is fuel oil. The fuel costs involve about 40 percent of the total cost of shipping (Stopford, 2009). The price of bunker fuels has fluctuated throughout time therefore, this cost factor has had a considerable impact on overall shipping expenses.

In the MSF455 model, the base input that would be used to calculate the percentage of fuel costs is total cost of shipping. Based on the different case scenarios, the percentage of fuel costs, the energy generated for the existing and new fuel the data would be assimilated to prepare the CO_2 emission taxes. The tax emissions would be compared to the original total costs of shipping and decipher whether due to the fit for 55 maritime derivatives of EU- ETS and the addition of CBAM (Carbon Border Adjustment Mechanism) would the total costs of shipping be impacted.

4. METHODOLOGY

Introduction

This chapter's goal is to outline the research methodology used to answer the research and sub-research questions. In doing so, we have approached it in a qualitative research and model-based methodology.

4.1 Qualitative approach

By performing qualitative research, a technique called as induction is used. Through the collection of data relevant to a certain field of study, the researcher then develops various notions and theories. The qualitative research approach taken was to interview a few shipping industry experts, the individuals were chosen based on their knowledge of the subject matter which would help in giving insights into answering the sub-research questions. In order to better understand a company's perspective on the new legislation aimed at lowering carbon emissions and working toward it, a qualitative technique was thought to be more appropriate for this research.

4.2 Interview

To conduct the qualitative analysis, semi-structured interviews was chosen. A semi-structured interviews provide people more freedom to respond to questions on their own views and terms than a normal interview does while yet providing a better framework for comparison than a concentrated interview (May,1997). The candidates chosen for the interview were from two different fields related to the shipping industry.

Participant one: The first individual is a commercial manager in a shipping company that is into retrofitting of vessels with scrubbers and one of its kind carbon capture modules. The company is based out of the Netherlands and is assisting shipowners ride the wave of the decarbonization transition. With this interview, we will get an insight into the future outlook of vessel owners towards the decarbonization goal, cost of retrofitting a vessel with scrubber units and the company's view on the fit for 55 maritime directives.

Participant two: The second individual works in the logistics division for a commodity trading company in the Netherlands. The organization has numerous locations throughout the world. The branch office in the Netherlands deals with concentrated juices being shipped from Brazil, South America to Ghent, Belgium. With this interview, we will look at the strategy used by the company to operate its vessels in the future to cope with the EU-ETS, Fuel EU maritime and their views on the latest developments towards greener fuels.

The results of the interview would be discussed briefly in the section 5 of this paper. The complete transcript of the interview with the details of the participant and the interview questions and answers is attached in the appendix 7.

4.3 Model based approach- MSF455 Model

The inclusion of maritime sector in the fit for 55 would have a crucial impact on the shipping industry. As the transition towards greener fuel is like placing a bet with a lot of uncertainty, shipping companies are still contemplating the best fuel mix to reduce their GHG emissions and at the same time trying to keep the Operational costs (Opex) minimal. To assist in taking the right steps towards the fit for 55 maritime directives, we will use the following model MSF455 found in the journal article published on July 2022, written by George Mallouppas, Elias A. Yfantis, Angelos Ktoris and Constantina Ioannou to assess the impacts of the EU Fit for 55 Legislation Package in relation to Shipping (Mallouppas et al.,2022).

4.4 Top-down methodology flow chart:

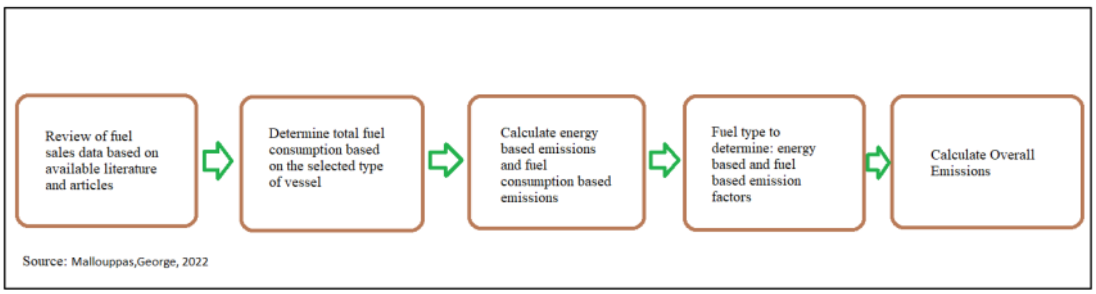


Figure 4.1 Top-Down Methodology flow chart. Source: Mallouppas et al.,2022

The top-down methodology uses a fuel-based approach which gathers information through fuel statistics used in the maritime sector and fuel emission factors (Liesbeth et al.,2001). As this methodology does not have the ability to track vessels real time which could lead to inconsistency in the calculation of emission, an energy-based method is feasible for this study and is utilized to calculate the GHG emissions. Many nations regularly generate nationally and internationally emission inventories using the fuel-based approach (EEA,2014).

The MSF455 model uses a top-down methodological approach which estimates the new operational expense based on the inputs of predicted and future costs of CO_2 penalties and cost of fuels, alternate fuel mixes with conventional fuels, percentage of taxation on maritime bunkers (not taxed as of today) and the flow of goods (import and export) within/outside EU. As the model uses the data to gauge the flow cargo within and outside EU based on the route taken by the vessel, CBAM specifies a factor of γ= 1.0 for Intra EU trade routes and γ = 0.5 for Extra EU trade routes (PwC,2022).

Using the MSF455 model with the available and assumed data for vessel opex, alternate fuels, we will simulate scenarios and the suitable fuel mix that will be keep the operational expense within minimum and provide insights into the Intra EU and Extra EU flow of goods.

4.5 Basic structure of the MSF455 model:

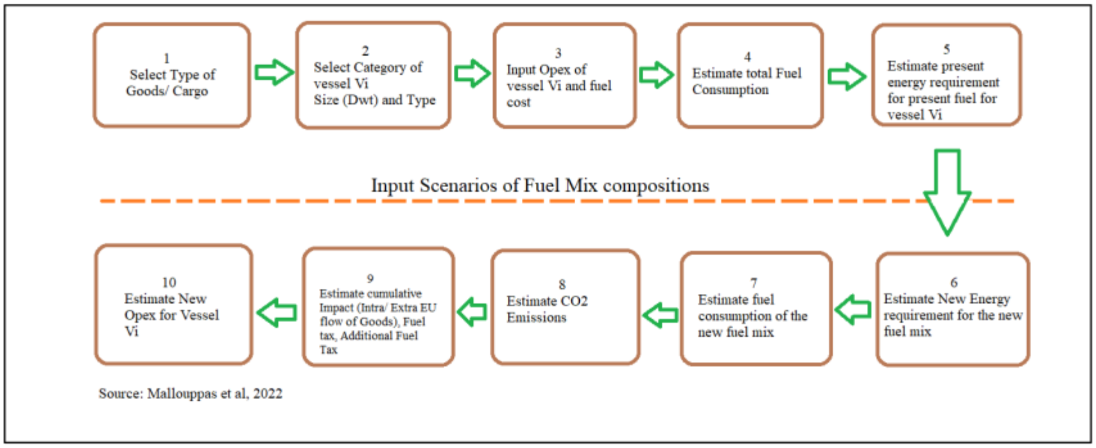


Figure 4.2 Basic structure of the MSF455 model and steps to calculate. Source: Mallouppas et al.,2022

4.6 Steps to calculate New Opex for vessel:

Step 1: Select the type of goods or cargo. The type of cargo selected goes in sync with type of vessel to be analyses (vessel Vi)

Step 2: Select the relevant type of vessel (Vi) that carries the cargo mentioned in Step 1. The input of the vessel can be based on a range of vessel's dead weight (DWT).

Step 3: Input the Opex of the vessel based on the DWT. The Opex can be inputted from various source based on market assumptions.

Step 4: Estimate the fuel consumption based on the formula:

$$FC_i = \frac{Opex * f}{C_{2022}}$$ Equation 1

FC_i = fuel consumption of the fuel mix in kg per vessel Vi
Opex = Opex of the vessel selected
f = The percentage of fuel cost to Opex i.

C_{2022} = Fuel cost per barrel of oil equivalent (boe) for 2022

See Table below for USD/boe based on the European Union REF2020 scenario (European Commission, no date). The fuel cost barrel of oil equivalent (USD/boe) table forms the basis of MSF455 model. The REF2020 scenarios were used to develop the fit for 55 packages. The oil prices based in REF2020 scenarios are not in sync because the current market situation is impacted by the COVID pandemic and Russia- Ukraine war (Mallouppas et al., 2022).

In USD/Boe	2020	2022	2023	2024	2025	2026	2027	2028	2029	2030
Oil	39.8	47.84	51.86	55.88	59.90	63.94	67.98	72.02	76.06	80.10

Table 4.1: International oil fuel prices assumptions based on the EU REF2020 scenario (European Commission, no date). *Values derived by linear interpolation annually. Source: (Mallouppas et al., 2022).*

Step 5: Estimate total energy requirement for vessel Vi

$$FE_i = FC_i * LHV_{HFO}$$ Equation 2

FE_i = Total energy requirement per vessel Vi

LHV_{HFO} = Latent Heating Value of HFO (40 MJ/Kg)

Step 6: Based on the new energy composition, the new energy requirements are determined.

$$FE_{ij} = FE_i * \eta_{ij} * \alpha_{ij}$$ Equation 3

FE_{ij} = The new energy composition based on new energy requirements
j = Subscript j indicates the new fuel type
η_{ij} = Change in total energy requirements due to new fuel (Change in combustion efficiency). An improved efficiency of combustion of 98 % is considered for alternate fuels as compared to fossil fuels. Though the efficiency also depends on other facts such as type of engine and fuel injection method, fuel combination etc.
α_{ij} = Percentage of fuel j of vessel Vi

Step 7: Determine fuel mass i of fuel mix based on new energy requirements of vessel Vi:

$$FCij = FEij/LHVj$$ Equation 4

FCij = Fuel consumption of vessel Vi and fuel type j

LHVj = Latent heat value of fuel type j

Step 8: Estimate total CO_2 emissions of new fuel mix of vessel Vi

$$CO2_{,i} = \sum_j (FCij * EFj)$$ Equation 5

EFj = Fuel-based emission factor of fuel j. Note, the emission factors for other greenhouse gases can be attained from 4th IMO GHG study (IMO,2021).

Step 9: Estimate the cumulative impact based on scenarios for fuel tax, and additional fuel cost, CO_2 tax, intra- and extra-EU up to 2030

$$taxplus_{ik} = CO_2tax_{ik} + fueltax_{ik} + additional\ fuelcost_{ik} \quad \text{Equation 6}$$

$taxplus_{ik}$ = Added tax per year k on vessel Vi,

CO_2tax_{ik} = CO_2 penalty tax based on carbon penalty tax as per CBAM until 2026

$$CO_2tax_{ik} = γ * δ_k * ε_k * CO_{2,\,I} \quad \text{Equation 7}$$

γ = 1.0 For Intra- EU imports/ exports, 0.5 For Extra – EU imports/ imports based on CBAM.

$ε_k$ = CO_2 penalty in EUR/tonne for year k based on CBAM until 2026

Year (k)	2023	2024	2025	2026	2027	2028	2029	2030
ε (%)	20%	45%	70%	100%	100%	100%	100%	100%

Table 4.2: *CO_2 penalty as per CBAM (Carbon Border Adjustment Mechanism)* (European Commission, 2021). Source: *Mallouppas et al., 2022*

$$fueltax_{ik} = \sum_j \theta kj * FEij * Ckj \quad \text{Equation 8}$$

$fueltax_{ik}$ = Fuel tax on maritime bunker fuel

$θ_{kj}$ = Maritime tax for year k and fuel type j

C_{kj} = Cost of fuel j for year k per MJ

Note: Because it is anticipated that vessel route optimization may involve avoiding ports with significant maritime tax implications, it should be noted that $\boldsymbol{θ_{kj}}$ is only applied to intra-EU routes.

$$\text{additional fuelcost}_{ik} = \sum_j FEij\ (Ckj - Cj2022)$$ Equation 9

C_{kj} = Cost of fuel j for year k per MJ

Cj = Cost of fuel reference year 2022

additional fuelcost$_{ik}$ = additional fuel cost of fuel j based on projects and reference year (2022)

Step 10: Percentage of change in New Opex for vessel Vi

$$\pi_{ik} = \text{taxplus ik} / Opex\ Vi$$ Equation 10

π_{ik} = Percentage of change in New Opex for vessel Vi for year k

Fuel Mix	VLSFO 0.5%	HFO	MGO	Green H2	Green NH3	Green Methanol	Biogas	LNG	Bio Diesel
Latent Heat Value (MJ/kg)	41.6	40.0	43.0	120.0	18.60	19.90	50.0	50.0	38.0
Emission factor (-)	3.188	3.114	3.206	0.00	0.00	0.00	0.00	2.755	0.00
Change in energy requirements (η_{ij}) (%)	100	100	100	98	98	98	98	98	98

Table 4.3: Fuel parameters used for the scenarios. Source: Mallouppas et al., 2022
According to the planned Fit for 55 legislation packages, CO_2 penalty and fuel cost scenarios with forecasts up to 2030 (and beyond) are shown. Values for EUR/metric quantity have been gathered from the literature and converted to EUR/MJ in this work. (Mallouppas et al, 2022).

Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
δ (Eur/ tonne)	-	42.50	50.71	58.93	67.14	75.36	83.57	91.70	100.00
(EUR/MJ) HFO	0.008	0.009	0.010	0.010	0.011	0.012	0.012	0.013	0.014
(EUR/MJ) MGO	0.008	0.009	0.010	0.010	0.011	0.012	0.012	0.013	0.014
(EUR/MJ) Green H2	0.031	0.030	0.029	0.028	0.027	0.026	0.025	0.024	0.023

(EUR/MJ) GreenNH3	0.031	0.030	0.029	0.028	0.027	0.026	0.025	0.024	0.023
(EUR/MJ) Green Methanol	0.042	0.039	0.037	0.034	0.032	0.030	0.029	0.026	0.022
(EUR/MJ) Biogas	0.018	0.016	0.014	0.012	0.011	0.009	0.007	0.005	0.004
(EUR/MJ) LNG	0.004	0.009	0.013	0.018	0.022	0.026	0.031	0.035	0.040
(EUR/MJ) Advanced Biodiesel	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026

Table 4.4: CO_2 penalty and fuel cost scenarios with forecasts up to 2030. Source: Mallouppas et al., 2022

4.7 Data for modelling:

We shall use a top – down methodological approach to develop the new TCS for a group of cargo vessels based on the TCS available in the case paper: The competitiveness of European Short-sea freight Shipping compared with road and rail transport published by the European Commission DG environment written by Delhaye et al., 2010. The base fuel percentage of the daily cost of these vessels would be compared to the four case studies done by Delhaye et al., 2010. In the paper the Delhaye compared the operating costs of cargo vessels in the likes of bulk carriers, tankers and container vessels entering Europe and checking the total costs of shipping of the vessels to the determine the cost increase in transportation due to the change in fuel to comply with the environmental regulation in EU. The cost structure from the paper is attached in appendix 4 of this paper.

The data is taken from the literature review of Delhaye et al., 2010

Ship Type	DWT/TEU	Voyage Type	Total cost Shipping €/ Day	Fuel Cost €/ Day	% Fuel cost to TCS
	Medium Range (25000 - 45000)	Intra EU	30,953	9242	30 %
	LR1 (45,000–80,000)	Deep Sea Vsl	36,636	11,154	30 %
Tanker (In DWT)	Suezmax (120,00 – 200,000)	Deep Sea Vsl	53,838	19,122	36 %
	Feeder (1000 – 2000 TEU)	Intra EU	31,015	14,341	46 %
	Panamax (5000 – 6000 TEU)	Deep Sea Vsl	63,370	24,540	39%
Container Vessels	Post Panamax (8000-9000) TEU	Deep Sea Vsl	82,337	29,002	36%
	Mini – Handymax (10000 – 40000)	Intra EU	25,519	10,198	40%
	Panamax (60,000 – 80000)	Deep Sea Vsl	33,927	12,111	36%
Bulker	Capesize (110,000 - 200,000)	Deep Sea Vsl	43,406	17,528	40%

Table 4.5: Cost structure of cargo vessels. Source: Delhaye et al., 2010

4.8 Scenarios

we have created 18 scenarios for the three types of cargo vessels and the energy requirements for various years, starting in 2023, will be examined using the TCS/day of the specific set of vessels using the above information. A fuel blend mix will be created in accordance with the Fuel EU Directive for the year of 2025 and 2030 would be considered which is also mentioned in the journal published by CE Delft for ‘Cost of fit for 55’ (Roy et al.,2022), and the results of the energy requirements and fuel tax will be examined. The scenarios would be based as follows:

Year	Vessel Groups	Present Fuel	Energy requirement based on present fuel	Fuel mix	Fuel Mix percentage	New Energy requirement	CO_2 Emission tax € /ton Yearly	Percentage Increase in TCS

Table 4.6: Sample framework for scenario calculations

Certain assumptions made for the scenarios are;

1. The fuel assumed for most of the vessels are VLSFO, unless specified elsewhere.

2. The fuel blend for the year 2025 is assumed to be a mix of LNG + MGO based above the minimum mixing ratio recommended by the Fuel EU directive. As AFIR is pushing forward the use of LNG in the TEN-T maritime ports. For our scenarios we have a considered a fuel blend of 30 % LNG and 70% MGO.

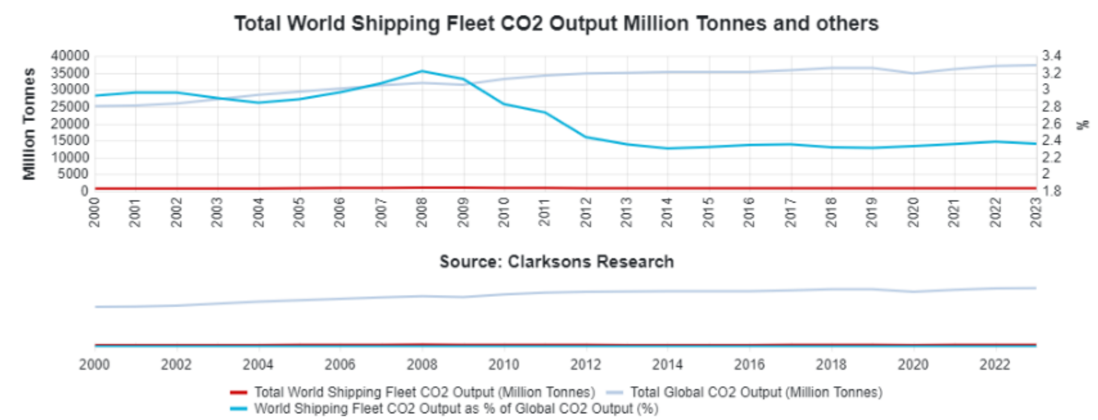
3.For the 2030 scenarios of LNG + Biofuels, the fuel blend for the year 2030 is further subdivided into four blends (LNG + Green H2), (LNG + Green Methanol), (LNG + Advanced Biodiesel) and (LNG + Green NH3). It is assumed that by 2030, the technology and supply of Biofuels is available to combine these fuel mixes in the main engine of a vessel. For these scenarios we have a considered a fuel blend of 40 % LNG and 60% Biofuels.

5. RESULTS AND ANALYSIS

In the below chapter, we will describe the study's findings from the model-generated data of MSF455. These findings would broadly address the first, second, third, and fourth sub-research topics. First, we'll talk about the CO_2 emissions inventory's outcomes, secondly, we will look at the data obtained from MSF455 for the opex of the vessels based on the fuel mix as suggested by Fuel EU directive for the different scenarios discussed in the previous chapter. There on we will look at the ideal fuel mix to reduce the opex of the vessels. The detailed summary of the calculations are attached in appendix 5 and 6.

5.1 World Shipping CO_2 Emissions

Global shipping emissions in 2018 totaled 1076 million tons of CO_2, or around 2.7 percent of all emissions brought on by human activity (EU director climate Change,2022). By 2050, a variety of realistic long-term economic and energy scenarios predict that these emissions will rise from 90 to as much as 130 percent above 2008 levels. The goals of the Paris Agreement, a global framework to avoid serious climate change by limiting global warming to well below 2°C and pursuing efforts to restrict it to 1.5°C, would be undermined if the climate change impact of shipping activities grows as expected.



Source: Clarkson Shipping Intelligence Network

Figure 5.1 Total World Shipping Fleet CO_2 Output. Source: Clarksons' SIN

Based on Clarkson's' Shipping Intelligence Network's database documentation of the CO_2 emissions for 2022 (data in appendix 2), there is a reduction in the carbon dioxide emission as compared to the year 2008 however the CO_2 emission does need to be cut down tremendously to achieve the GHG emission goals. The A substantial source of CO_2 emissions at the EU level, maritime transportation contributed 3 to 4% of all CO_2 emissions in the EU in 2019, or more than 144 million tons of carbon dioxide.

5.2 CO_2 Emissions Netherlands – Inland and Sea Going Shipping

The Netherlands is a country with a lengthy history of shipping throughout Europe's inner waterways and on the open seas. It is also actively working to decarbonize its economy. With a marine policy that includes goals for GHG reductions and the possibility of a green agreement for the industry, the present Dutch government is likewise portraying itself as a pioneer in the decarbonization of shipping. In addition to the vast volumes of cargo being transferred through the deep-sea vessels, the inland water ways also play a crucial role in transporting the goods inlands. This causes an increase in CO_2 emissions from both inland and seagoing vessels in the waterways of the Netherlands.

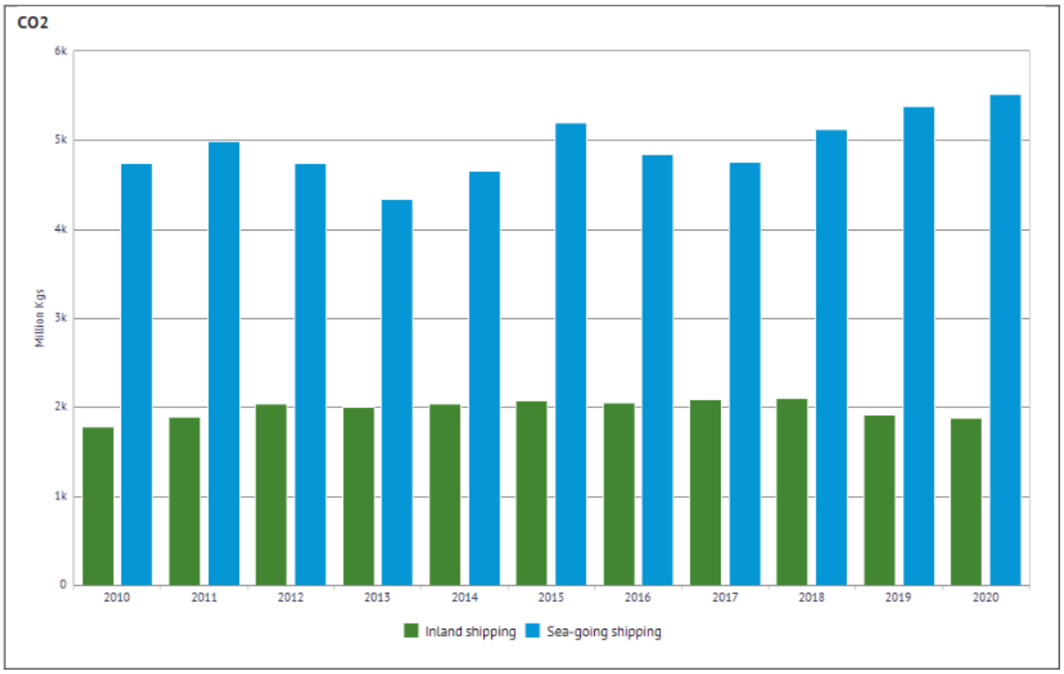


Figure 5.2 CO_2 Emissions Netherlands – Inland and Sea Going Shipping. Source: CBS StatLine databank

By contrasting the information provided to Statistics Netherlands, the ETS system, and environmental yearly reports complied by CBS survey (CBS Dataportaal,2022) using the real time data acquired by the movement of vessels using AIS transponders fitted on the vessels, it is evident that the cumulative waterways shipping CO_2 emissions from Inland shipping and sea -going shipping is on the rise (data in appendix 3). The United Nations predicts that as the population of the world increases, the demand and supply for goods will also increase exponentially causing a demand in the shipping sector, thereby further increasing the CO_2 emissions. GHG emissions in the Netherlands waterways shipping can be decreased in a variety of methods, including slow steaming, streamlining, energy recovery systems, alternate energy carriers for vessel propulsion, and other efficiency improvements (E4tech UK, 2018).

Increasing energy efficiency (i.e., lowering fuel/energy consumption through better engine performance, lower on-board vessel energy usage, improved aero/hydrodynamics, or improved route optimization) or switching to an energy source or fuel with lower life-cycle GHG emissions are multiple ways to lower the greenhouse gas (GHG) emissions of shipping.

5.3 Results of Qualitative research and Model

Qualitative research result:

The detailed transcript of the interview is attached in the appendix 7. The interview-based results do shed some light on the predicament the companies are facing on how to tackle the upcoming rules and regulations concerning decarbonization. The new fit for 55 maritime derivatives will eventually depending on the market rate in the years to come have an impact on cost of the commodity towards the end user and also increase the cost of operation due to the transition towards greener fuel, retrofitting of vessels etc. The companies are onboard with the switch to greener energies and to be in line with the rules and regulations but the dilemma companies are facing is that who will be bear the cost impact of decarbonization eventually.

Participant one interview result:

From the interview with Surendran, Logistics division from LDC Netherlands, it is evident that companies like Louis Dreyfus company (LDC) have taken proactive steps to already experiment with Biofuels. LDC has three concentrated juice carriers which shuttle between Brazil, South America and Ghent, Belgium. Recently LDC announced that it successfully carried B30 Biofuel trails on one of its juice carriers. The fuel trail was carried out with collaboration with Wisby Tanker AB. Throughout the ship's voyage, a number of experiments were carried out to evaluate the effect of the B30 biofuel blend on the fuel system and general performance. The findings demonstrate that B30 is a feasible and environmentally friendly alternative to conventional Very Low Sulfur Fuel Oil (VLSFO), reducing voyage greenhouse gas (GHG) emissions by around 24%, equivalent to 723 tons of CO_2 equivalent (tCO_2e). B30 biofuel is made up of 70% traditional VLSFO bunker fuel and 30% advanced carbon-neutral biodiesel.

Further to it, to make the voyage carbon neutral from Brazil to Ghent, the remaining 76% of the trip's GHG emissions were offset by LDC using carbon credits obtained through its own Carbon Solutions Platform, making this marine shipment the first carbon-neutral transport of orange juice ever made. For this cause, LDC made the decision to retire 2,262 tCO_2e in third-party certified carbon credits from the Kariba REDD+ Project in Zimbabwe, which preserves over 785,000 hectares of forest, aids local communities, and is accredited by globally accepted carbon standards ((Louis Dreyfus company, 2022).

As mentioned in the interview, the company's operational plant is in Ghent, Belgium. The reply to whether vessels would divert to transshipment hubs, the view was;

"With *the current scenario, we mainly depend on our plant in Ghent and we do not have any other facility elsewhere. The focus of operations is Ghent, so we will have vessel going in and out of Ghent.*"

The vessels will continue to operate from the EU. The additional costs due to the fit for 55 maritime directives would be absorbed by the company though in the long run it will also depend on the demand and the price of the commodity for the concentrated juices in the future. The pricing structure for the customer is confidential the company would not be able to disclose due to the secrets of the business.

Participant two interview result:

From the interview with Errikos, commercial manager with Value Maritime BV, it was an interesting interview to get a perspective of how shipowners within EU look at the decarbonization goals set out by EU and IMO.

Ship owners are onboard and working towards the decarbonization goals. The company has retrofitted scrubber units for vessels within the EU. The scrubber unit can be fitted on cargo vessels of 2 MW to 8 MW engines. The company has developed first of its kind scrubber unit that can capture CO_2 emissions too. Depending on the scrubber unit opted for, the cost of retrofitting is approximately 2 million dollars. The cost can range can go up to 8 million dollars for a capsize vessel. As mentioned by Erikkos, the ship owners are willing to retrofit their vessels not only to comply with the latest rules and regulations but also to reduce their operational costs, as explained by him,"Usually *the vessels that have scrubber fitted for e.g. a tanker. The tanker would be time chartered with an 8 percent premium. Because of the scrubber units, there are a lot of savings therefore, these are not seen as an additional cost it is basically an investment that you try to hedge yourself from upcoming fuel increases. So, it's not something that they would pass on to the customer but in the case of time charter they will pass it to the customer but the customer will also save in this, actually* *the customer would save more like up to 12%. It's a difference of 4 %. So, the earning for e.g., for an MR tanker that has scrubber fitted and a tanker that does not have a scrubber fitted, the earning difference is 12 percent this means that they earn 12 percent because of lower operating expense due to the cost in bunkers."*

From the interview, it is also evident that ship owners are willing to try different types of dual fuels to reduce the CO_2 emissions. The scrubber units sold by Value maritime can be used on vessels with dual fuel. Predominantly its used to reduce the Sulphur particles from the HFO fuel, however if the vessel is carrying dual fuel for e.g., HFO and Methanol. When the vessel is using Methanol as fuel, the scrubber unit can also be used to capture the CO_2 emissions. So, it serves the purpose of reducing carbon emissions and particulate matters.

One of the points to highlight from the interview is that, though companies like Value maritime are collaborating with ship owners to work towards reducing the GHS emissions, the EU and IMO are yet in the process of approving and certifying these units. As stated here,

"They (ship owners) try to keep up with the regulations and the pace, however the issue is the certification, recognition, approval from governing bodies such as classification society, flag state, EU commission. The scrubber units are class and flag state approved, even if the Eu-ETS incorporates the shipping sector, the system for scrubbers is yet to be certified by the EU and IMO. So, you cannot capture CO_2 and have reduced carbon tax credits until EU approves these units. It is an on-going process to get the approvals."

FROM MSF455 MODEL RESULTS:

a. Tanker Vessels

Intra EU – Tanker Medium Range (25000 -45000) DWT

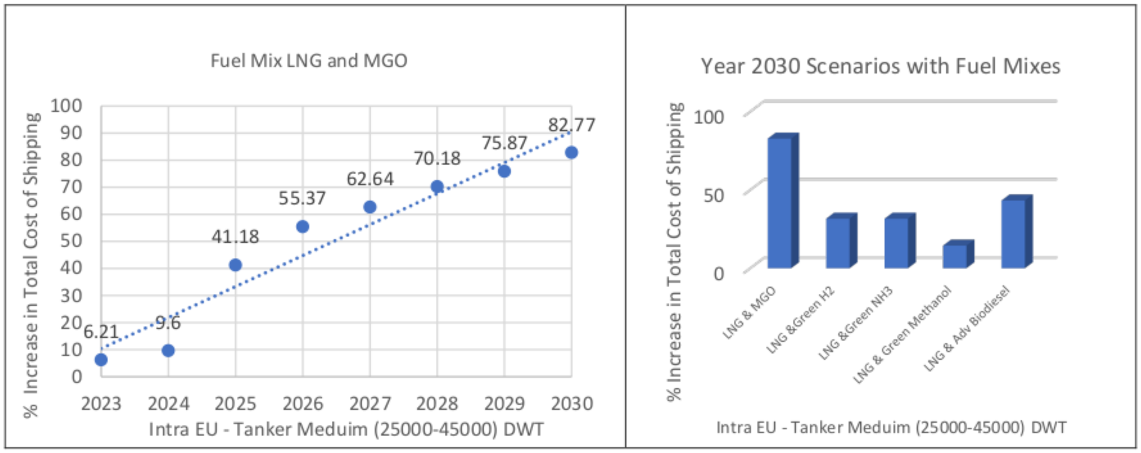


Figure 5.3.1 – Scenario 1 & 2 Intra EU – Tanker Medium Range (25000 -45000) DWT. Source: Author

Scenario 1: Fuel Mix LNG and MGO

As the fit for 55 directive- AFIR has placed keen interest on the development of LNG infrastructure for the maritime industry (Jaan, 2022), we have taken the fuel mix of LNG and MGO from the year 2025 for the first scenario until the year 2030. The analysis of the data generated from MSF455 model with fuel mix (LNG and MGO) for an Intra EU medium range tanker vessel sailing within the European Union indicates that the TCS (Total cost of shipping) of the vessel would increase exponentially every year. To comply with the fit for 55 package of Fuel EU, ETS, CO_2 penalties, additional fuel costs and taking into consideration the CBAM factor of 1.0 for all routes within the EU, the percentage TCS increases from 6.21% in 2023 to 82.77% in 2030. Particularly in the Netherlands Intra trade plays a vital role, the potential rise in the TCS of vessels could have a detrimental effect on the flow of good within the EU in the years to come. There would be a rise in the price of the commodity being transported and consequently leading to the increased price of the products to the end users.

Scenario 2: Fuel Mix LNG and Green Biofuels

The second scenario combines the LNG fuel with Biofuels as seen the diagram above to mitigate the exponential rise of the TCS, the second scenario for the Year 2030 with the mix of LNG with the various Biofuels available gives an indication of how much the TCS of the vessel can be reduced. From the original fuel mix of 82.77 % (LNG + MGO), for the year 2030 the fuel mix of LNG + Green Methanol would be the ideal combination to reduce the total cost of shipping. By this scenario the TCS could be reduced to as much as 14.4 percent with a fuel mix proportion of LNG 40 % and Green Methanol 60%. The second-best fuel combination would be either LNG + Green H2 or LNG + Green NH3. The fuel mix of LNG + Adv. Biodiesel is rate low among the fuel mixes because of the price of Biodiesel. Though to put it in perspective the LNG+ Biodiesel gives a 43.26 % TCS which is the practical % fuel to TCS. Practically the TCS reduction could be in the range of 40 to 45% depending on the Biofuels availability.

Extra EU- Tanker LR1 (45,000–80,000) DWT

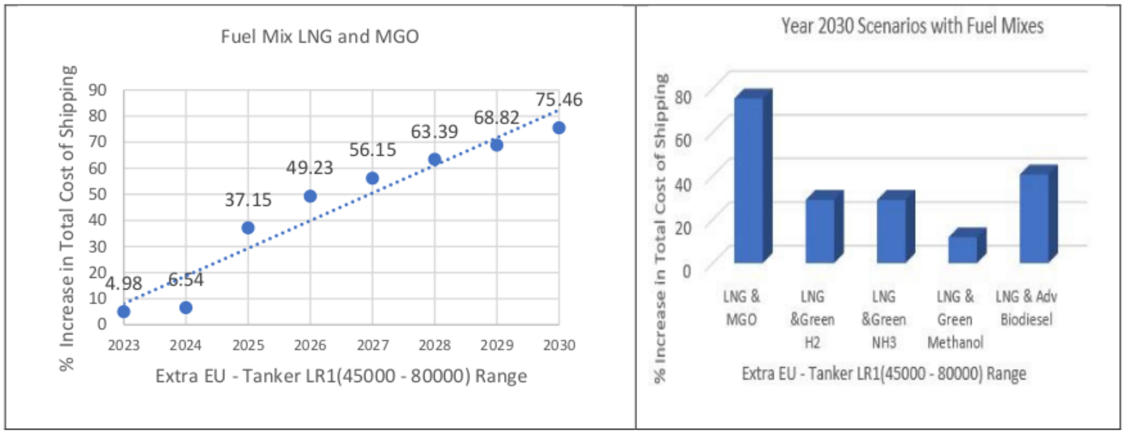


Figure 5.3.2 – Scenario 1 & 2 - Extra EU- Tanker LR1 (45,000–80,000) DWT. Source: Author

Scenario 1: Fuel Mix LNG and MGO

The tankers LR 1 sees a steady increase in the TCS, but as compared to the Intra EU tankers the percentage increase is not as drastic because of the economics of scale and due to the factor of the total cost of shipping being reasonable for LR1 vessels. Using the fuel mix of LNG + MGO increase in percentage of TCS is 4.98% in 2023 and creeps up to 75.46% by 2030. LR1 vessels carry some of the most crucial clean petroleum products for the daily running of the economy. Some of the products that are carried by LR1 are Naphtha and distillate products petroleum products. As the total cost of shipping increases the cost of transporting these commodities will increase for this segment of cargo. The proportion of increase would depend on the ETS and CBAM. Especially now with the current situation of war between Russia and Ukraine, as a substantial percentage of oil was imported from Russia using the LR1 and MR tankers, the demand for cleaner petroleum products would rise in the EU as EU looks for cleaner oil elsewhere (Kapoor et al.,2022). Thus, the possibility of LR1 vessels operating will increase as imports to the EU increase, however the rise in the total cost of shipping would also impact the imports.

Scenario 2: Fuel Mix LNG and Green Bio Fuels

The scenario two presents the fuel mix of LNG with Biofuels with the percentage of LNG as 40 % and Biofuels as 60%. In the scenario 2, the percentage TCS of fuel mix (LNG + MGO) of 75.46% is reduced to 11.8 % for a fuel mix of (LNG + Green Methanol). The percentage of TCS is reduced substantially because as per the EU ETS the emissions for international routes from and to the EU are considered to be only 50 %, with a condition that from 2027, 100 % all emissions for all trips should be taken into account, however the 50% cap could be still applicable to non-European nations. The second-best fuel combination would be LNG + Green H2 or LNG + Green NH3 with percentage of 29% respectively. The combination of LNG + Adv. Biofuels rated a percentage of 40.64%. The CO_2 emissions for each of the scenarios have similar values of 19209 Kg, as all emission factor of the Green Biofuels are practically nil. Thereby the percentage increase in the TCS boils down to the cheapest combination of available fuel. In practice, the TCS reduction could be achieved depending on the availability and price of Biofuels.

Extra EU – Tanker Suezmax (120,000 – 200,000) DWT

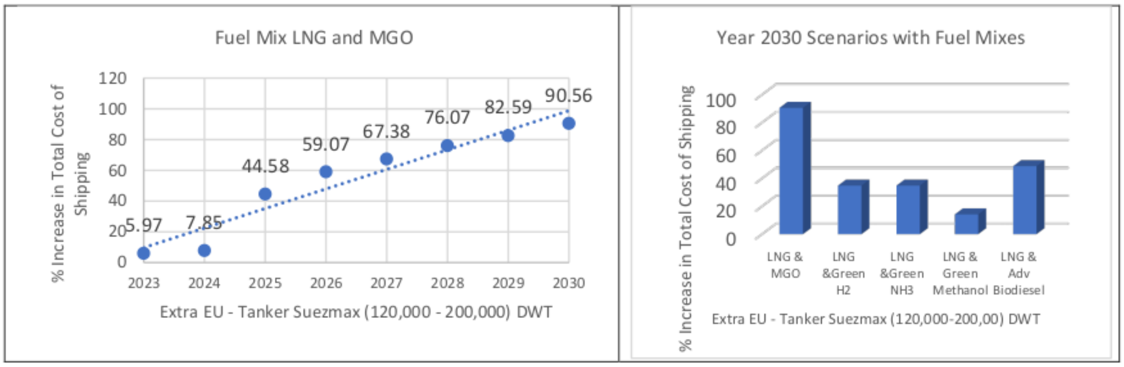


Figure 5.3.3 – Scenario 1 & 2 - Extra EU – Tanker Suezmax (120,000 – 200,000) DWT. Source: Author

Scenario 1: Fuel Mix LNG and MGO

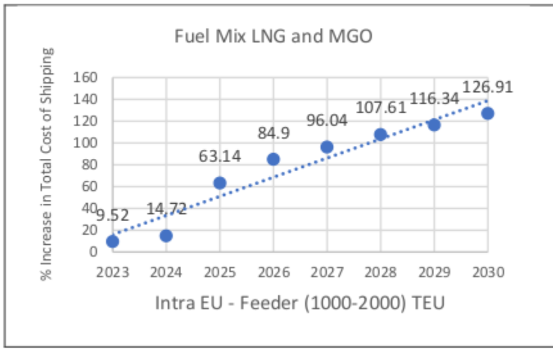
The Suezmax tankers with a deadweight of 120,000- 200,000 has a TCS of 90.56 % in the year 2030 as compared to 5.97 % in 2023. In comparison to Handymax and LR1 tankers the cost of operating these vessels is high and therefore the total cost of shipping increases. The Suezmax tankers are suitable to carry crude oil and residual fuel oil. Prior to the Russia-Ukraine war, in 2021, activity grew to almost 57 million barrels per month, up 7.5% from the average of the previous year. Russia has been one of the primary crude oil exporters to most European consumers, sending an average of 53 million barrels to the continent each month (IHS Markit,2022). The crude oil was transported from Russia via Suezmax and Aframax tankers. With a number of sanctions in place to not import oil from Russia, Europe has to import its oil from major oil refineries in the US, West Africa, Brazil and middle east (Cahill,2022). Until the sanction phase in period to cut off Russian oil, European countries would import a lot oil, however once the phase in period is over the dependency on other countries to import oil would increase. As for the Russia- Ukraine war, there seems to be no end in sight, if in the years to come the total cost of shipping of the Suezmax tanker increases exponentially as indicated in Scenario 1, the cost of import would be possibly high.

Scenario 2: Fuel Mix LNG and Green Bio Fuels

The scenario 2 represents the fuel mix of LNG with Biofuels with the percentage of LNG as 40 % and Biofuels as 60%. In comparison to the scenario one of year 2030 (LNG + MGO), the ideal fuel mix would be of LNG + Green Methanol with a percentage of 14.17. The total CO_2 emission for this fuel mis estimated to be at 33874 Kgs. The cumulative impact of taxes for the fuel taking into consideration the CO_2 penalty + tax on maritime fuel + additional fuel costs come to 7626 € annually. The second-best fuel combination would be LNG + Green H2, LNG + NH3. Both the fuel combinations have a TCS percentage of 34.18%. Though the cumulative impact of taxplus is around 18739 €. Due to the slightly higher costs of LNG + Green Biodiesel, the TCS percentage for this fuel mix is 48.77%. Though this TCS is fairly low as compared to the initial TCS of LNG + MGO fuel mix, the percentage of TCS would change with the fuel mix percentage. Therefore, for this scenario also, based on the fuel mix and simulated costs of biofuels, LNG + Green Methanol would be ideal. A lower TCS would assist in reducing the import/export costs.

b. Container Vessels

Intra EU – Container Feeder (1000 – 2000) TEU



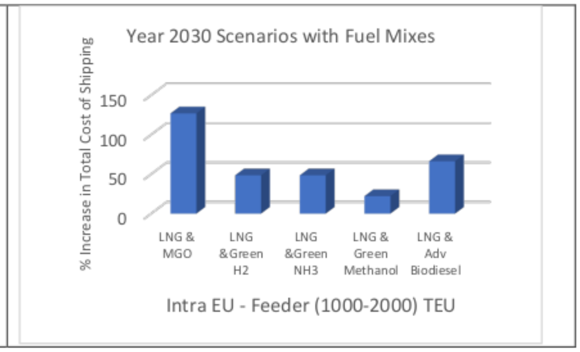


Figure 5.3.4 – Scenario 1 & 2 - Intra EU – Container Feeder (1000 – 2000) TEU. Source: Author

Scenario 1: Fuel Mix LNG and MGO

Assuming a fuel mix of LNG 70 % and MGO 30%, the feeder container vessel (1000- 2000) TEU has a TCS of 126.91 % in 2030, as compared to a measly figure of 9.52 % in 2023. The feeder vessels are a lifeline for short sea shipping within Europe. Based on the 2020 statistics, 17.5% of the containers in EU were being transported through short sea shipping (Eurostat Statistics,2022). Based on the fuel mix of LNG + MGO, the cumulative tax for the CO_2 emission, fuel and additional fuel costs sums to 39,361.0 € annually. The TCS is high because the additional tax element in the MSF455 model calculates the fuel taxes based on the EU ETS and the recommended taxes on fuels for the voyages within the EU and are to be considered 100 % emission, and a CBAM factor of 1.0 added to the calculation. As the EU ETS covers all the voyages covered within EU region, the implications of a higher EU ETS would be severe. In addition, the high TCS could possibly make the competitiveness of the Intra EU cargo less. To go around the EU ETS and to prevent high TCS, the feeder vessels could be replaced by bigger feeder vessels thereby assuring economics of scale by carrying more container per km. Another option for the feeder vessels to reduce high TCS would be to enroute the cargo via a port not within EU.

Scenario 2: Fuel Mix LNG and Green Biofuels

The scenario 2 represents the fuel mix of LNG with Biofuels with the percentage of LNG as 40 % and Biofuels as 60%. The fuel mix shows a total cost of shipping reduction percentage of 22.12 as compared to the fuel mix of LNG + MGO of 126.91 % for the same year of 2030. The fuel mix of LNG + Green Methanol seems to be the viable with. The total CO_2 emission for this fuel mix is 24935 kg as compared to the LNG+ MGO to be 69459 Kg. The stark difference in the total amount of CO_2 emitted reflects in the tax paid for it. The taxplus for the LNG + Green Methanol stands at 6861 €, compared to 39361 € for LNG + MGO. The second-best fuel mix combination would be LNG + Green H2 and LNG + Green NH3. The TCS reduction for these two fuels stands at 48.49%.

Extra EU – Container Panamax (5000 – 6000) TEU

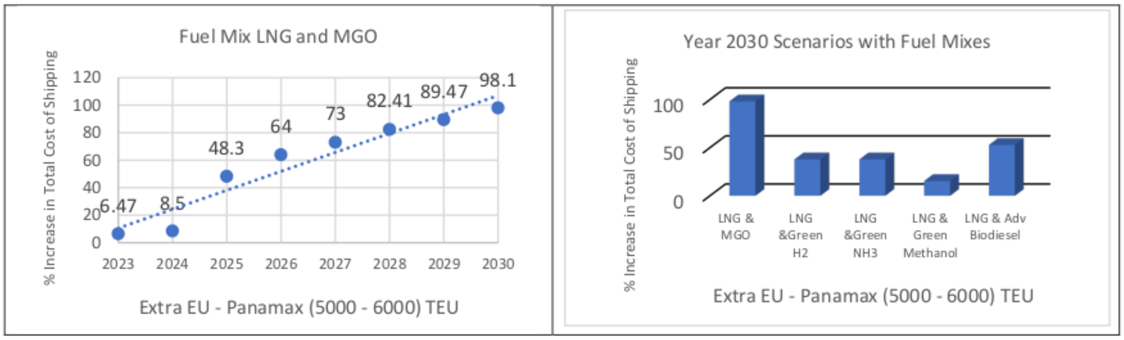


Figure 5.3.5 – Scenario 1 & 2 - Extra EU – Container Panamax (5000 – 6000) TEU. Source: Author

Scenario 1: Fuel Mix LNG and MGO

As compared to the Intra EU container feeder vessels, Panamax container vessel experiences a continual growth in TCS, but the percentage increase is less pronounced due to economies of scale and the reasonable total cost of shipping for the Panamax vessel. The Panamax container vessel (5000–6000 TEU) has a TCS of 98.10% in 2030 compared to a dismal figure of 6.47% in 2023, considering a fuel mix of LNG 70% and MGO 30%. At TCS of 98.1% in 2030, the taxplus for this fuel mix would be 62168 €. The major EU ports handled 94.3 million twenty-foot equivalent units (TEUs) in 2020. In 2020, Rotterdam was the largest container port in the EU, with 13.3 million TEU, followed by Antwerpen with 12.0 million TEUs and Hamburg with 8.6 million TEUs handled in total (Eurostat Stastitcs,2021). The sheer dominance in handling huge volumes of container cargo indicates the competitive advantage of these ports and also the trust shown by the shipowners, charters and cargo owners. With the exponential increase in the TCS over the years, shipowners are susceptible to opt for cheaper options to escape the additional high costs of taxes. In all possibility, to avoid the additional high taxes the vessels could be directed to close by non-Eu ports and thereby the competitive edge of the Eu ports could possibly be lost.

Scenario 2: Fuel Mix LNG and Green Biofuels

The scenario 2 depicts a fuel mix of LNG and biofuels, with an LNG percentage of 40% and a biofuel percentage of 60%. In the second scenario, the percentage TCS for a fuel combination of LNG and green methanol drops from 98.10% to 15.35%. The cumulative impact of the CO_2 emission additional taxplus for the fuel of LNG + Green Methanol would be 9725 €. This is drastic drop as compared to the fuel mix of LNG + MGO emphasized in the scenario 1. The second-best fuel combination would be LNG + Green H2, LNG + Green NH3. As the per Mj/kg of fuel price for Green H2 and Green NH3 are simulated to be the same, the TCS reduction for both the fuel mix are also similar 37.71%. Due to the price of 0.026 € Mj/Kg, Advanced biodiesel + LNG has a TCS reduction of 52.83%. In reality, the TCS reduction would depend on the available Biofuel and the buying price.

Extra EU – Container Post Panamax (8000 – 9000) TEU

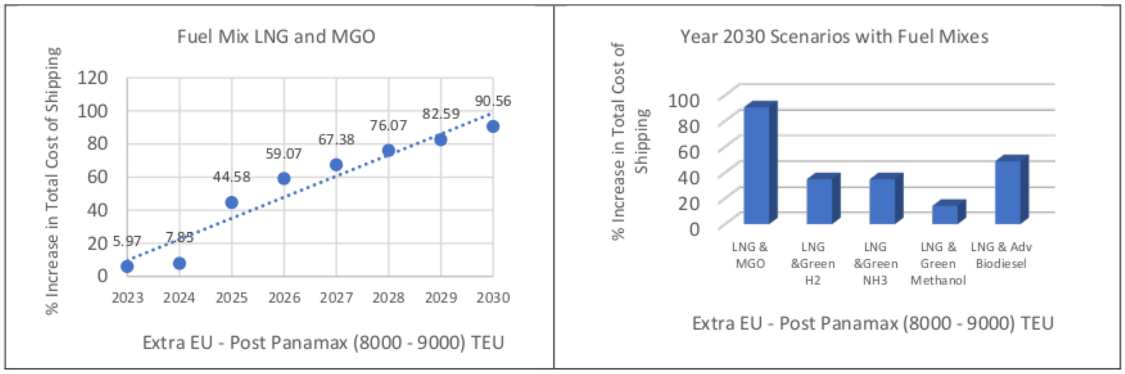


Figure 5.3.6 – Scenario 1 & 2 - Extra EU – Container Post Panamax (8000 – 9000) TEU. Source: Author

Scenario 1: Fuel Mix LNG and MGO

The % TCS for the 8000–9000 TEU Post Panamax container ship is 90.56% in 2030 compared to 5.97% in 2023. The operating costs of these vessels are expensive in compared to feeder vessels 1000-2000 TEU and Panamax container vessels, increasing the total cost of shipping. Similar to the Panamax vessel in terms of vessel functionality, the post Panamax vessel is capable of carrying more containers as compared to the Panamax vessel and thereby achieving higher economics of scale. In scenario 1, there is a gradual increase of total cost of shipping with the fuel mix of LNG + MGO. The cumulative CO_2 emission taxplus for 2030 based on this scenario is 74562 €. The post Panamax would face the similar situation as Panamax vessel in terms of avoiding the EU ETS. The post Panamax could also be diverted to a non-EU port. This would decline the cargo volumes handled in the EU especially in big port like Rotterdam, Antwerpen, Hamburg etc.

Scenario 2: Fuel Mix LNG and Green Biofuels

In scenario 2, a fuel blend of LNG and biofuels is shown, with a 40% LNG and 60% biofuel ratio. TCS for an LNG and green methanol fuel mixture falls from 90.56% to 14.17%. For the fuel of LNG + Green Methanol, the cumulative effect of the CO_2 emission additional taxplus would be 11664 €. The second-best fuel combination would be LNG + Green H2, LNG + Green NH3. Considering the same per Mj/kg fuel costs for green H2 and green NH3, the TCS reduction for both fuel mixes is also predicted to be identical at 34.81%. Advanced biodiesel + LNG has a TCS reduction of 48.77% because it costs 0.026 Euros Mj/Kg in 2030.

c. Bulk Carrier Vessels

Intra EU – Mini – Handymax (10000 – 40000) DWT

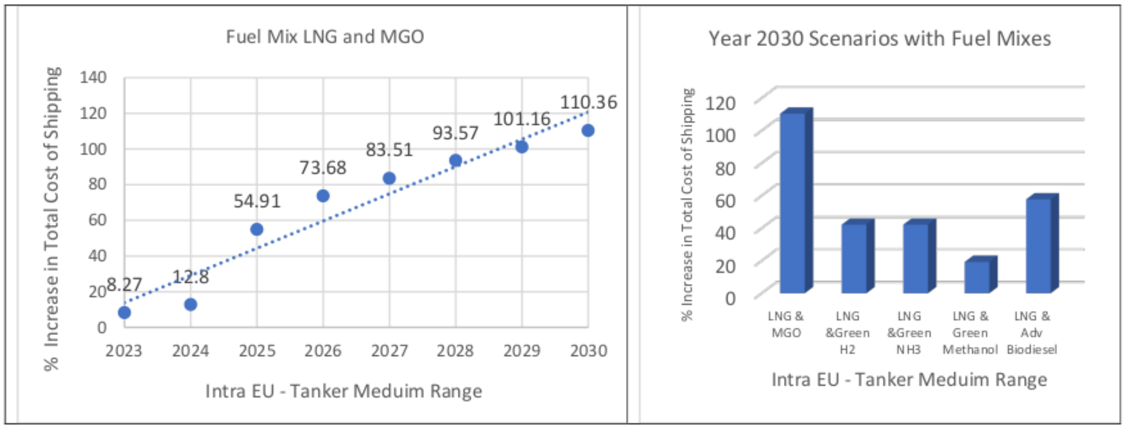


Figure 5.3.7 – Scenario 1 & 2 - Intra EU – Mini – Handymax (10000 – 40000) DWT. Source: Author

Scenario 1: Fuel Mix LNG and MGO

Assuming a fuel mix of LNG 70 % and MGO 30%, the mini Handymax vessel (10000- 40000) DWT has a TCS of 110.36 % in 2030, as compared to a measly figure of 8.27 % in 2023. With the fuel combination of LNG + MGO, there is a progressive increase in the overall cost of shipping in scenario 1. The cumulative CO_2 emission taxplus for 2030 based on this scenario is 28162 €. The cumulative CO_2 emission is fairly highly because as per the EU-ETS, 100 % of the voyage within EU is to be taken as emission. Port of Rotterdam is the largest dry bulk port in Europe handling millions of tons of cargo in a year (PoR, no date). As similar to the dominance shown in handling container handling, dry bulk cargo handling is also a strong forte. Due to the high TCS and to avoid EU-ETS, there are chances that the dry bulk cargo volumes could be diverted to other nearby non-EU ports. This could lead to loss of cargo handling volumes and potential to earn revenue for the European ports. On the other hand, there would be an increase in the cost of the commodity being transported, which would raise the cost of the goods for end users.

Scenario 2: Fuel Mix LNG and Green Biofuels

In scenario 2, a fuel blend of LNG and biofuels is shown, with a 40% LNG and 60% biofuel ratio.

In the second scenario, the percentage TCS for a fuel combination of LNG and green methanol drops from 110.36% to 19.24%. The cumulative CO_2 emission taxplus for 2030 drops to 4908 €.

The second-best fuel combination would be LNG + Green H2 or LNG+ Green NH3 with percentage TCS up to 42.17%. Advanced biodiesel + LNG has a % TCS reduction of 57.68% because it costs 0.026 Euros Mj/Kg in 2030.

Extra EU – Bulk Panamax (60,000 – 80000) DWT

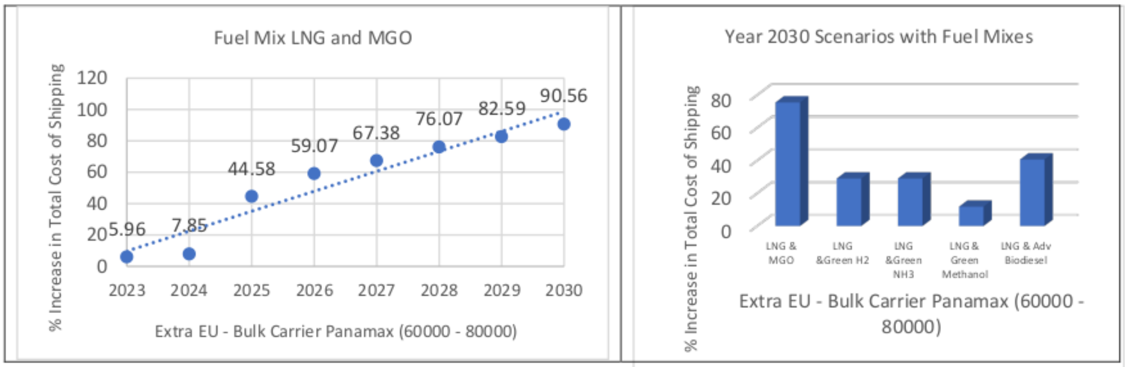


Figure 5.3.8 – Scenario 1 & 2 - Intra EU – Mini – Handymax (10000 – 40000) DWT. Source: Author

Scenario 1: Fuel Mix LNG and MGO

As compared to the Intra EU bulk mini Handymax, Bulk Panamax vessel experiences a continual growth in % TCS, but the percentage increase is less pronounced due to economies of scale and the reasonable total cost of shipping for the Panamax vessel. The % TCS is 5.96% in 2023 and comparatively its 90.56% in 2030. The cumulative CO_2 emission taxplus for 2030 based on this scenario is 30723 € for the year 2030. As mentioned for mini Handymax, since the EU-ETS is applied only to 50% of the voyage, there is possibility that the inflow of cargo from non-Eu nations due to the comparatively less taxes.

Scenario 2: Fuel Mix LNG and Green Biofuels

In scenario 2, a fuel blend of LNG and biofuels is shown, with a 40% LNG and 60% biofuel ratio.
In the second scenario, the percentage TCS for a fuel combination of LNG and green methanol drops from 90.56% to 14.17%. The cumulative CO_2 emission taxplus for 2030 drops to 4806 € for LNG + Green Methanol.
The second-best fuel combination would be LNG + Green H2 or LNG+ Green NH3 with percentage TCS up to 34.81%. Advanced biodiesel + LNG has a % TCS reduction of 48.77% because it costs 0.026 Euros Mj/Kg in 2030.

Extra EU – Bulk Capesize (100,000 – 200,000) DWT

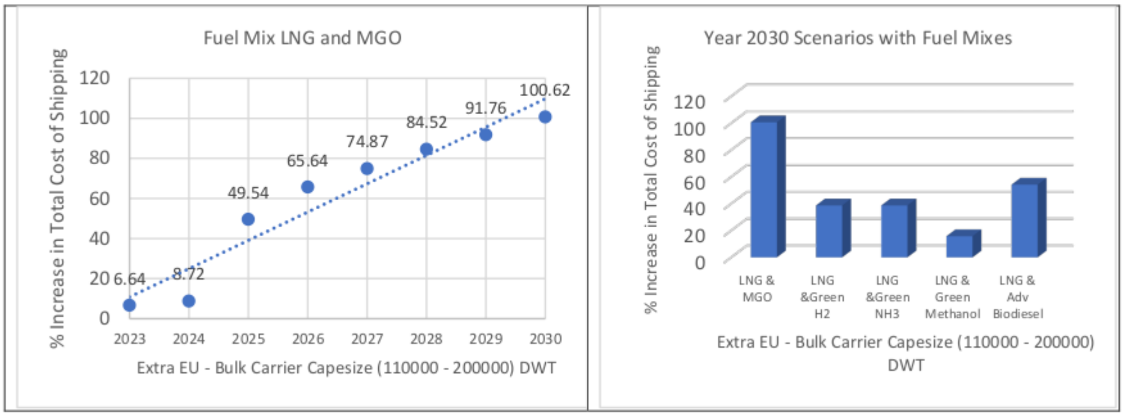


Figure 5.3.9 – Scenario 1 & 2 - Extra EU – Bulk Capesize (100,000 – 200,000) DWT. Source: Author

Scenario 1: Fuel Mix LNG and MGO

Assuming a fuel mix of LNG 70 % and MGO 30%. The % TCS is 6.64% in 2023 and comparatively its 100.62% in 2030. The cumulative CO_2 emission taxplus for 2030 based on this scenario is 43674 € for the year 2030. As mentioned for mini Handymax, since the EU-ETS is applied only to 50% of the voyage, there is possibility that the inflow of cargo from non-Eu nations due to the comparatively less taxes. Due to the sheer enormous size of these vessels, not all ports can accommodate capsize vessels in the ports. Port of Rotterdam has the ability to berth these size vessels. Therefore, there is competitive advantage for Port of Rotterdam.

Scenario 2: Fuel Mix LNG and Green Biofuels

In scenario 2, a fuel blend of LNG and biofuels is shown, with a 40% LNG and 60% biofuel ratio.
In the second scenario, the percentage TCS for a fuel combination of LNG and green methanol drops from 100.62% to 15.74%. The cumulative CO_2 emission taxplus for 2030 drops to 6831 € for LNG + Green Methanol. The second-best fuel combination would be LNG + Green H2 or LNG+ Green NH3 with percentage TCS up to 38.67%. Advanced biodiesel + LNG has a % TCS reduction of 54.18% because it costs 0.026 Euros Mj/Kg in 2030.

6. CONCLUSION AND RECOMMENDATIONS

This chapter provides a summary of the research, its major conclusions, and its significance. We will then review the findings in light of our sub-research topics. We will also emphasize the limits of this study and offer areas for recommendations in the field of the new technoeconomic MSF455 model and its ramifications on the Fit for 55 maritime directives.

6.1 Summary and key findings

This study's main objective was to evaluate the implications of the induction of the maritime directives in the fit for 55 and its conduciveness on the maritime vessels within Europe and foreign going vessels visiting ports in Europe and in addition based on the fuel mix to give the recommendations to reduce the total cost of shipping. To analyze the data, we used the MSF455 model which uses the vessels operating costs and the percentage of fuel cost component to give the results of percentage increase/decrease in the vessels operating costs using the added carbon taxes through the inputs from the EU ETS, ETD and CBAM. Using the results attained from the MSF455 model, we designed an optimized fuel mix featuring Biofuels available in the future using the AFIR directive of fit for 55 to reduce the Operating costs of the vessels, thereby making it a conducive analysis.

First, to answer the first sub-research question, we looked at the most recent research data from Clarksons database on climate change and the need to scale back CO_2 emissions in the shipping industry and also the contribution of shipping activities involved in the Netherlands. We observe that in order to keep global warming below 2°C by the end of this century, CO_2 emissions must be reduced by 40–70% from 2008 levels by 2050. To reduce the rise of CO_2 emissions, IMO came up with the decarbonization goal to reduce CO_2 using the tools of EEDI and CII. These tools will help monitor the CO_2 expressed in grams of CO_2 emitted per cargo-carrying capacity and nautical mile. Then, reviewing the available literature review we noticed that shipping contributes to about 3 % of the global CO_2 emission. Though steps are being taken to reduce, it is expected that the CO_2 emission would double if business continues as usual.
Second, we looked at the available literature review for the available Biofuels in the near future and reviewed the new and revised fit for 55 directives applicable for the maritime sector. In addition, in the methodology chapter we looked at the comprehensive study done by European Commission DG environment for the competitiveness of European Short Sea Shipping freight compared to rail and road. The case studies and data input available of different types of commercial short sea shipping and deep-sea going vessel within/Outside EU were used in the model MSF455 to generate the various scenarios for total cost of shipping and the CO_2 tax values till 2030 based on the inputs from EU-ETS, CBAM, Fuel EU and AFIR. As the AFIR directive emphasizes more of the LNG infrastructure and Fuel EU emphasizes minimum recommendation for fuel blending from 2025, these recommendations were used to develop the scenario with the model's output based on base

fuel as VLSFO and future fuel mixes of LNG+ MGO and LNG + Biofuels until 2030. We discovered that each fuel mix ratios have pros and cons when it comes to the CO_2 tax emission. The scenarios depend on the availability of the Biofuels, however based on the study in this paper it seems LNG+ Green Methanol would be the recommended fuel mix based on less CO_2 emissions and the future price of the fuel.

Third, to answer and relate to the second and third sub-research question, we analyzed the data output from the MSF455 model for the different fuel mix. Based on the analysis, the effect on routes within (Intra-EU) and outside (Extra-EU) of the EU in relation to three additional costs, referred to as taxplus which consists of fuel maritime tax, additional fuel costs and CO_2 penalties, its notable that the additional fuel costs component was very high for vessels trading within the Europe (Intra-EU). This could act as a deterrent for vessels sailing within the EU to avoid the EU-ETS. From the 18 scenarios created, for the Intra EU vessels, the least additional fuel charges for fuel mix of LNG + MGO was 1920 € in 2023 for an Intra- EU tanker mid-range and the maximum additional fuel charges were 30589 € in 2030 for container feeder vessel (1000-2000) TEU Intra-EU. In comparison, the Extra-Eu vessel's additional fuel taxes were comparatively lesser because only 50 percent taxplus were applicable due to the nature of the voyage. Thus, this can indicate that the flow of goods (import and export) could become less competitive within Intra- EU as compared to Extra-EU. The most significant observation noted was the percentage of total cost of shipping for the Intra-EU vessels was the highest (crossing 100%) as compared to the Extra-EU vessels. This indicates that the freight of transporting goods within the EU would become higher in the future.

Fourth, to answer the final sub-research questions, analyzing the 18 scenarios, it's evident that the percentage total cost of shipping would be very high, especially for vessels sailing within the EU. To avoid the payment of EU-ETS, as the shipowners could possibly divert their vessels to a non-EU port as a transshipment hub. This not only undermines the EU-ETS but also a possibility of carbon leakage. The EU-ETS mentions shipowner responsible and could be held responsible to avoid the taxes. In many cases the shipowner acts as only the carrier of the cargo and the cargo owner is responsible for the voyage instructions etc. Therefore, the EU-ETS seems unfair to put the responsibility on the shipowner for evading the taxes, where in reality the cargo owner could be held liable. Similarly, if it's a time-chartered vessel, the charter pays for the fuel and the shipowner is mere providing services with no control over the voyage of the vessel. Therefore, we can expect certain changes in the charter party contracts in the years to come to incorporate the entity who would be responsible for the payment of the additional taxes.

Finally, based on the scenarios of each type of vessel analyzed, the tax segment is very high due to the EU-ETS especially for vessels within the EU causing the TCS to increase exponentially. All of the aforementioned information and scenarios seems to support the findings of this paper and show that, while the EU ETS's inclusion of shipping may be a project with excellent intentions, it may also have important unintended consequences that should be carefully considered before the relevant legislation is passed. As the European Commission is yet to finalize the directives in the fit for 55 for maritime, a formidable and favorable tax regime would prevent the vessels from escaping the EU-ETS, reduce carbon slippage and genuinely contribute to the reduction of the greenhouse gases and carbon reduction goals.

6.2 Further research and recommendations

Feedback MSF455 model

As the shipping industry is going through a rough patch of its own and at present no single shipping company, governmental organization has that 'one right answer' towards the GHG reduction goals, at this time a tool like the MSF455 model makes a genuine effort to give some perspective into what can be expected in the future. As this model is one of the few models to directly address the 'Fit for 55' initiative for the maritime sector, it does genuinely give some good insight on the percentage increase in the operational costs. This figurative index will give shipowners a decisive action in taking constructive business plans.

As this is a new tool, certainly there are few features which could be added to improve its effectiveness, one could be to add an elasticity index to carry out sensitivity analysis. As a recommendation to use this model, since the primary monetary figure is 'Opex' as mentioned in the published paper, it is recommended to use the total cost of shipping as mentioned by Stopford in the maritime economics publication. Total cost of shipping will include all the essential costs like capital costs, operational costs and voyage costs. Though operational costs may not very easily accessible as this is kept as a secret by many shipping companies. Secondly, in order to strengthen the model's robustness, it should take into account the safety and environmental risk assessment, which can be a crucial factor in the adoption of alternative fuel mixes in the risk-averse shipping industry .

Further research and recommendations

As the research of this paper suggests that a good fuel mix could be LNG + Green Methanol. Moving forward, it would be advantageous for shipping companies to switch to dual fuel engines with biofuels as one of the fuels. Maintenance expenditure, ship and shore staff training costs, and operating costs will change as the fuel strategy is changed.

To eliminate the rise of CO_2, the way forward is to analyze the available means of alternate fuels to access the reduction capabilities possible through this medium. We feel thorough data analysis of the CO_2 emitted must be recorded and reported using the digitalization platform within the shipping companies. NYK Group initiated "Sail Green" project where it uses DSS (Digital Smart Ship) to reduce GHG. The DSS monitors the energy efficiency and machinery monitoring to improve operational efficiency of the vessels and reduce GHG by constant monitoring (NYK Line, 2020).

The interviews gave us some insights into how commodity trading companies, shipowners and retrofitting companies within the EU are working towards the reduction of GHG emissions. Shipping companies would benefit by having dual fuel engines which would help in reducing the total operational expenses, improve profits as found in our model results and also mentioned by commercial manager, Erikkos. As stated in the interview that the retrofitting units are installed on certain vessels and approved by classification society and flag state, however the EU and IMO are yet to approve it. In retrospect, this takes us back to the problem statement where we mentioned that there is no sound legal structure and technical solutions provided by the European Commission yet. No doubt the ‘fit for 55’ plan is in place to protect the environment and secure the future of EU against climate change. It is an uphill task that will need a lot of cooperation from all the parties from root level until the top. Therefore, in introspect, the European Commission may want to provide clear directives and assist shipping companies make good decision which would reflect in the goal of fit for 55 and make it a success.

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APPENDIX

1. TEN T - LNG bunkering in TEN-T maritime ports - AFIR

Table 2: LNG bunkering in TEN-T maritime ports

EAFO	TEN-T Seaports & LNG Bunkering for LNG fueled vessels					
2020-Q1	Total		Core		Comprehensive	
	Ports	LNG facilities	Ports	LNG facilities	Ports	LNG facilities
Belgium	4	2	4	2	0	
Bulgaria	2	0	1		1	
Croatia	7	0	1		6	
Cyprus	1	0	1		0	
Denmark	22	1	2		20	1
Estonia	8	2	1	1	7	1
Finland	17	1	5		12	1
France	28	2	9	2	19	
Germany	21	3	6	2	15	1
Greece	25	0	5		20	
Ireland	5	0	3		2	
Italy	39	1	14		25	1
Latvia	3	0	2		1	
Lithuania	1	1	1	1	0	
Malte	4	0	2		2	
Netherlands	13	3	5	3	8	
Poland	5	0	4		1	
Portugal	13	1	3	1	10	
Romania	5	0	2		3	
Slovenia	1	0	1		0	
Spain	37	14	13	11	24	3
Sweden	25	2	5	2	20	
United Kingdom	42	0	16		26	
Total	328	33	106	25	222	8

Source: EAFO for LNG Bunkering, MoS Study EU Cie (2018)

European Commission - Proposal for a Regulation of the European Parliament and of the Council on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council. Source: EAFO for LNG bunkering, MoS Study EU Cie (2018)

2. CO_2 Emissions Data – Clarksons Shipping Intelligence Network

Clarksons Shipping Intelligence Network Timeseries			
Created 08 August 2022 11:42			
	901834	901835	901836
	Total World Shipping Fleet CO2 Output	Total Global CO2 Output	World Shipping Fleet CO2 Output as % of Global CO2 Output
Date	Million Tonnes	Million Tonnes	%
2000	735.32	25,119.00	2.93
2001	751.71	25,332.00	2.97
2002	768.26	25,911.00	2.97
2003	788.17	27,176.00	2.90
2004	810.10	28,470.00	2.85
2005	849.28	29,411.00	2.89
2006	901.68	30,375.00	2.97
2007	962.53	31,294.00	3.08
2008	1,028.80	31,946.00	3.22
2009	983.95	31,464.00	3.13
2010	937.19	33,132.00	2.83
2011	934.51	34,210.00	2.73
2012	847.90	34,760.00	2.44
2013	823.52	34,987.00	2.35
2014	813.08	35,245.00	2.31
2015	818.06	35,209.00	2.32
2016	826.84	35,220.00	2.35
2017	840.66	35,696.00	2.36
2018	845.44	36,420.00	2.32
2019	843.29	36,441.00	2.31
2020	812.77	34,807.00	2.34
2021	850.74	36,077.00	2.36
2022	882.78	37,007.00	2.39
2023	879.46	37,249.00	2.36

3. CBS StatLine databank (Netherlands CO2 emissions data– Inland and Sea going shipping)

Time	Inland shipping	Sea-going shipping
Units	Million Kgs	Million Kgs
2010	1,779	4,750
2011	1,895	4,995
2012	2,041	4,742
2013	2,005	4,336
2014	2,038	4,663
2015	2,072	5,201
2016	2,049	4,849
2017	2,096	4,761
2018	2,107	5,125
2019	1,915	5,384
2020	1,882	5,516

CBS StatLine databank (Netherlands CO2 emissions – Inland and Sea going shipping)

4. Cost structure of vessels used for the data analysis – The competitiveness of European Short-sea freight Shipping compared with road and rail transport published by the European Commission DG environment (Delhaye et al.,2010)

Dry Bulk (€/day)			
Size	**Handysize**	**Panamax**	**Capesize**
Guide DWT	**10,000 - 40,000**	**60,000 - 80,000**	**110,000 - 200,000**
Manning	€1,389	€1,847	€2,069
Insurance	€473	€702	€817
Repairs & Maintenance	€1,107	€1,458	€1,824
Stores & Lube Oil	€374	€511	€611
Administration	€947	€1,099	€1,237
Capital Repayments	€3,847	€5,837	€6,898
Interest	€3,162	€4,798	€5,671
Gross Margin	€1,921	€2,763	€3,251
Port	€2,100	€2,800	€3,500
Fuel (Ton/day)	32.0	38.0	55.0
Fuel (€/day)	€10,198	€12,111	€17,528
Speed (knots)	12.0	13.0	13.0
Full Cargo Weight (Ton)			
Via Panama		69,252	
Via Suez			
Via Cape			151,931
European	24,739		
Total (€/day)	**€25,519**	**€33,927**	**€43,406**

Cost structure of Dry Bulk

Tanker (€/day)			
Size	**MR1**	**LR1**	**Suezmax**
Guide DWT	**25,000 - 45,000**	**45,000 - 80,000**	**120,000 - 200,000**
Manning	€2,369	€2,369	€2,600
Insurance	€554	€592	€1,038
Repairs & Maintenance	€1,408	€2,108	€2,777
Stores & Lube Oil	€585	€654	€885
Administration	€1,031	€1,292	€1,523
Capital Repayments	€5,748	€6,684	€9,358
Interest	€4,725	€5,495	€7,692
Gross Margin	€2,791	€3,263	€4,398
Port Charges (€/day)	€2,500	€3,025	€4,445
Fuel (Ton/day)	29.0	35.0	60.0
Fuel (€/day)	€9,242	€11,154	€19,122
Speed (knots)	12.0	15.0	15.0
Full Cargo Weight (Ton)			
Via Panama		59,404	
Via Suez			158,078
Via Cape			
European	34,763		
Total (€/day)	**€30,953**	**€36,636**	**€53,838**

Cost Structure - Tanker

Container Ship (€/day)			
Size (TEUs)	**1000-2000**	**5000-6000**	**8000-9000**
	2000	**5500**	**8500**
Guide DWT	**15,000 - 25,000**	**50,000 - 60,000**	**90,000 - 100,000**
Manning	€1,588	€2,176	€2,313
Insurance	€443	€931	€1,168
Repairs & Maintenance	€977	€2,603	€2,786
Stores & Lube Oil	€580	€1,557	€1,847
Administration	€550	€931	€962
Capital Repayments	€4,378	€11,276	€16,848
Interest	€3,599	€9,269	€13,850
Gross Margin	€2,059	€4,886	€6,762
Port	€2,500	€5,200	€6,800
Fuel (Ton/day)	45.0	77.0	91.0
Fuel (€/day)	€14,341	€24,540	€29,002
Speed (knots)	14.0	18.0	18.0
Full Cargo Weight (Ton)	18,000	66,000	102,000
Total (€/day)	**€31,015**	**€63,370**	**€82,337**

Cost structure – container vessels (Feeder, Panamax, Post Panamax)

5.Summary Scenario 1: Fuel mix LNG + MGO

Intra EU – Tanker Medium Range (25000 -45000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Tanker	Mini – Handymax (250000 – 45000)	2023	VLSFO	1160573	VLSFO		100		1160573	1917	6.19
		2024	VLSFO	1077082	VLSFO		100		1077082	2961	9.56
		2025	VLSFO	1004797	LNG	MGO	70	30	990730	12747	41.18
		2026	VLSFO	941309	LNG	MGO	70	30	928131	17139	55.37
		2027	VLSFO	885368	LNG	MGO	70	30	872973	19389	62.64
		2028	VLSFO	835703	LNG	MGO	70	30	824003	21723	70.18
		2029	VLSFO	791314	LNG	MGO	70	30	780235	23485	75.87
		2030	VLSFO	751402	LNG	MGO	70	30	740883	25619	82.77

Table 5.3.1 – Scenario 1

Extra EU- Tanker LR1 (45,000–80,000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Tanker	LR1 (45,000–80,000)	2023	VLSFO	1373655	VLSFO		100		1373655	1821	4.97
		2024	VLSFO	1274835	VLSFO		100		1274835	2390	6.52
		2025	VLSFO	1189278	LNG	MGO	70	30	1172628	13611	37.15
		2026	VLSFO	1114134	LNG	MGO	70	30	1098537	18035	49.23
		2027	VLSFO	1047922	LNG	MGO	70	30	1033252	20572	56.15
		2028	VLSFO	989139	LNG	MGO	70	30	975291	23224	63.39
		2029	VLSFO	936600	LNG	MGO	70	30	923487	25213	68.82
		2030	VLSFO	889360	LNG	MGO	70	30	876909	27647	75.46

Table 5.3.2 – Scenario 1

Extra EU – Tanker Suezmax (120,000 – 200,000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Tanker	Suezmax (120,000 –	2023	VLSFO	2422367	VLSFO		100		2422367	3211	5.96
		2024	VLSFO	2248102	VLSFO		100		2248102	4214	7.83
		2025	VLSFO	2097228	LNG	MGO	70	30	2067867	24003	44.58
		2026	VLSFO	1964716	LNG	MGO	70	30	1937210	31804	59.07
		2027	VLSFO	1847955	LNG	MGO	70	30	1822083	36277	67.38
		2028	VLSFO	1744293	LNG	MGO	70	30	1719872	40955	76.07
		2029	VLSFO	1651643	LNG	MGO	70	30	1628520	44462	82.59
		2030	VLSFO	1568339	LNG	MGO	70	30	1546382	48754	90.56

Table 5.3.3 – Scenario 1

Intra EU – Container Feeder (1000 – 2000) TEU

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Container	Feeder (1000-2000) TEU	2023	VLSFO	1783110	VLSFO		100		1783110	2945	9.49
		2024	VLSFO	1654833	VLSFO		100		1654833	4549	14.67
		2025	VLSFO	1543774	LNG	MGO	70	30	1522161	19584	63.14
		2026	VLSFO	1446232	LNG	MGO	70	30	1425984	26332	84.90
		2027	VLSFO	1360283	LNG	MGO	70	30	1341239	29787	96.04
		2028	VLSFO	1283977	LNG	MGO	70	30	1266002	33375	107.61
		2029	VLSFO	1215778	LNG	MGO	70	30	1198757	36083	116.34
		2030	VLSFO	1154458	LNG	MGO	70	30	1138296	39361	126.91

Table 5.3.4 – Scenario 1

Extra EU – Container Panamax (5000 – 6000) TEU

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Container	Panamax (5000 – 6000) TEU	2023	VLSFO	3088850	VLSFO		100		3088850	4095	6.46
		2024	VLSFO	2866639	VLSFO		100		2866639	5373	8.48
		2025	VLSFO	2674253	LNG	MGO	70	30	2636813	30607	48.30
		2026	VLSFO	2505283	LNG	MGO	70	30	2470208	40554	64.00
		2027	VLSFO	2356395	LNG	MGO	70	30	2323405	46258	73.00
		2028	VLSFO	2224212	LNG	MGO	70	30	2193073	52223	82.41
		2029	VLSFO	2106071	LNG	MGO	70	30	2076586	56696	89.47
		2030	VLSFO	1999847	LNG	MGO	70	30	1971849	62168	98.10

Table 5.3.5 – Scenario 1

Extra EU – Container Post Panamax (8000 – 9000) TEU

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Container	Post Panamax (8000 – 9000)	2023	VLSFO	3704640	VLSFO		100		3704640	4911	5.96
		2024	VLSFO	3438129	VLSFO		100		3438129	6444	7.83
		2025	VLSFO	3207390	LNG	MGO	70	30	3162486	36708	44.58
		2026	VLSFO	3004733	LNG	MGO	70	30	2962667	48639	59.07
		2027	VLSFO	2826164	LNG	MGO	70	30	2786598	55480	67.38
		2028	VLSFO	2667629	LNG	MGO	70	30	2630282	62634	76.07
		2029	VLSFO	2525935	LNG	MGO	70	30	2490572	67998	82.59
		2030	VLSFO	2398535	LNG	MGO	70	30	2364955	74565	90.56

Table 5.3.6 – Scenario 1

Intra EU – Mini – Bulk Handymax (10000 – 40000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Bulker	Handymax (10000-40000) DWT	2023	VLSFO	1275769	VLSFO		100		1275769	2107	8.26
		2024	VLSFO	1183991	VLSFO		100		1183991	3255	12.75
		2025	VLSFO	1104530	LNG	MGO	70	30	1089067	14012	54.91
		2026	VLSFO	1034742	LNG	MGO	70	30	1020256	18840	73.83
		2027	VLSFO	973248	LNG	MGO	70	30	959622	21312	83.51
		2028	VLSFO	918653	LNG	MGO	70	30	905792	23879	93.57
		2029	VLSFO	869858	LNG	MGO	70	30	857680	25816	101.16
		2030	VLSFO	825985	LNG	MGO	70	30	814421	28162	110.36

Table 5.3.7 – Scenario 1

Extra EU – Bulk Panamax (60,000 – 80000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Bulker	Panamax (60,000 – 80000) DWT	2023	VLSFO	1526499	VLSFO		100		1526499	2024	5.96
		2024	VLSFO	1416683	VLSFO		100		1416683	2655	7.83
		2025	VLSFO	1321606	LNG	MGO	70	30	1303104	15126	44.58
		2026	VLSFO	1238102	LNG	MGO	70	30	1220768	20042	59.07
		2027	VLSFO	1164522	LNG	MGO	70	30	1148219	22861	67.38
		2028	VLSFO	1099198	LNG	MGO	70	30	1083809	25808	76.07
		2029	VLSFO	1040812	LNG	MGO	70	30	1026242	28019	82.59
		2030	VLSFO	988317	LNG	MGO	70	30	974481	30723	90.56

Table 5.3.8 – Scenario 1

Extra EU – Bulk Capesize (110,000 - 200,000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Bulker	Capesize (110,000 - 200,000) DWT	2023	VLSFO	2169993	VLSFO		100		2169993	2876	6.63
		2024	VLSFO	2013884	VLSFO		100		2013884	3774	8.70
		2025	VLSFO	1878728	LNG	MGO	70	30	1852426	21502	49.54
		2026	VLSFO	1760022	LNG	MGO	70	30	1735382	28490	65.64
		2027	VLSFO	1655425	LNG	MGO	70	30	1632249	32497	74.87
		2028	VLSFO	1562563	LNG	MGO	70	30	1540688	36688	84.52
		2029	VLSFO	1479566	LNG	MGO	70	30	1458852	39830	91.76
		2030	VLSFO	1404942	LNG	MGO	70	30	1385272	43674	100.62

Table 5.3.9 – Scenario 1

6. Summary Scenario 2: 2030 Fuel mix LNG + Biofuels

Intra EU – Tanker Medium Range (25000 -45000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Tanker	Medium Range (25000 -45000) DWT	2030	VLSFO	751402	LNG	G. H2	40	60	736374	9789	31.63
		2030	VLSFO	751402	LNG	G. NH3	40	60	736374	9789	31.63
		2030	VLSFO	751402	LNG	G. Methanol	40	60	736374	4465	14.43
		2030	VLSFO	751402	LNG	G. Adv Biofuel	40	60	736374	13390	43.26

Table 5.3.1 – Scenario 2

Extra EU - Tanker Deep Sea LR1 (45,000–80,000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Tanker	Deep Sea LR1 (45,000–80,000) DWT	2030	VLSFO	889360	LNG	G. H2	40	60	871573	10626	29.00
		2030	VLSFO	889360	LNG	G. NH3	40	60	871573	10626	29.00
		2030	VLSFO	889360	LNG	G. Methanol	40	60	871573	4325	11.80
		2030	VLSFO	889360	LNG	G. Adv Biofuel	40	60	871573	14888	40.64

Table 5.3.2 – Scenario 2

Extra EU- Tanker Deep Sea Suezmax (120,00 – 200,000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Tanker	Deep Sea Suezmax (120,00 – 200,000) DWT	2030	VLSFO	1568339	LNG	G. H2	40	60	1536972	18739	34.81
		2030	VLSFO	1568339	LNG	G. NH3	40	60	1536972	18739	34.81
		2030	VLSFO	1568339	LNG	G. Methanol	40	60	1536972	7626	14.17
		2030	VLSFO	1568339	LNG	G. Adv Biofuel	40	60	1536972	26255	48.77

Table 5.3.3 – Scenario 2

Intra EU – Container Feeder (1000 – 2000 TEU)

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Container	Feeder (1000 – 2000 TEU)	2030	VLSFO	1154458	LNG	G. H2	40	60	1131369	15040	48.49
		2030	VLSFO	1154458	LNG	G. NH3	40	60	1131369	15040	48.49
		2030	VLSFO	1154458	LNG	G. Methanol	40	60	1131369	6861	22.12
		2030	VLSFO	1154458	LNG	G. Adv Biofuel	40	60	1131369	20573	66.33

Table 5.3.4 – Scenario 2

Extra EU - Container Panamax (5000 – 6000 TEU)

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Container	Panamax (5000 – 6000 TEU)	2030	VLSFO	1999847	LNG	G. H2	40	60	1959850	23894	37.71
		2030	VLSFO	1999847	LNG	G. NH3	40	60	1959850	23894	37.71
		2030	VLSFO	1999847	LNG	G. Methanol	40	60	1959850	9725	15.35
		2030	VLSFO	1999847	LNG	G. Adv Biofuel	40	60	1959850	33478	52.83

Table 5.3.5 – Scenario 2

Extra EU – Container Post Panamax (8000-9000) TEU

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Container	Post Panamax (8000-9000) TEU	2030	VLSFO	2398535	LNG	G. H2	40	60	2350564	28658	34.81
		2030	VLSFO	2398535	LNG	G. NH3	40	60	2350564	28658	34.81
		2030	VLSFO	2398535	LNG	G. Methanol	40	60	2350564	11663	14.17
		2030	VLSFO	2398535	LNG	G. Adv Biofuel	40	60	2350564	40152	48.77

Table 5.3.6 – Scenario 2

Intra EU - Mini – Bulk Handymax (10000 – 40000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Bulker	Handymax (10000 – 40000) DWT	2030	VLSFO	825985	LNG	G. H2	40	60	809465	10761	42.17
		2030	VLSFO	825985	LNG	G. NH3	40	60	809465	10761	42.17
		2030	VLSFO	825985	LNG	G. Methanol	40	60	809465	4909	19.24
		2030	VLSFO	825985	LNG	G. Adv Biofuel	40	60	809465	14719	57.68

Table 5.3.7 – Scenario 2

Extra EU – Bulk Panamax (60,000 – 80000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Bulker	Panamax (60,000 – 80000) DWT Panamax	2030	VLSFO	988317	LNG	G. H2	40	60	968551	11809	34.81
		2030	VLSFO	988317	LNG	G. NH3	40	60	968551	11809	34.81
		2030	VLSFO	988317	LNG	G. Methanol	40	60	968551	4806	14.17
		2030	VLSFO	988317	LNG	G. Adv Biofuel	40	60	968551	16545	48.77

Table 5.3.8 – Scenario 2

Extra EU - Capesize (110,000 - 200,000) DWT

Vessel Groups		Year	Present Fuel	Energy requirement based on present fuel (MJ)	Fuel mix		Fuel Mix percentage (%)		New Energy requirement (MJ)	Emission tax per ton CO_2 €/ton Yearly	Percentage Increase in TCS %
Bulker	Capesize (110,000 - 200,000) DWT	2030	VLSFO	1404942	LNG	G. H2	40	60	1376843	16786	38.67
		2030	VLSFO	1404942	LNG	G. NH3	40	60	1376843	16786	38.67
		2030	VLSFO	1404942	LNG	G. Methanol	40	60	1376843	6832	15.74
		2030	VLSFO	1404942	LNG	G. Adv Biofuel	40	60	1378643	23519	54.18

Table 5.3.9 – Scenario 2

7. Transcript of the Interview with Participants:

Name: Surendran Venkatakrishnan
Company: Louis Dreyfus company (LDC) Holding BV
Position: Logistics Division
1. Could you please briefly express your role in the company and the responsibilities *I've been working with LDC from 2018 in Dubai in the coffee division. I took a year's break to do my Masters and now I have joined the LDC's juices division in the Netherlands office. I am part of the operations team, planning shipment inbound and outbound of Europe. My role is planning and shipment of these juices once they arrive in Ghent.*
2. What commodity trading and route does the vessel follow? *There are two types of products of juices, 'not-from-concentrate (NFC) and frozen concentrated orange (FCO) juices. These products are shipped in bulk in specialized vessels. These products can be drummed and also sold in bulk depending on the client's requirement. These juices are procured from export terminal in Brazil to our own facility in Ghent, Belgium. From the Ghent facility, these products are shipped to EU, Middle East and Australia, New Zealand.*
3. Will addition of EU-ETS carbon taxes impact the cost of the commodity to the EU? *Any additional costs that would be coming would add to our additional costs. As the facility is located in Ghent and the operations are carried out from there would be some hike in cost element.*
4. Would it be viable for LDC change of fuel towards greener Biofuels in the future? *There have been some changes in the fleet with trying out with different kind of a fuel blend to reduce the GHG's. At the moment from LDC's press news release, one vessel was under trail with B30 biofuel blend. The trail was successful and reduced the CO_2 by 24 %, the remaining 76% were offset by carbon credits. The details of this are available on the LDC's press new release.*
5. Do you see LDC vessels trading in the EU changing destination to transshipment hubs? *With the current scenario, we mainly depend on our plant in Ghent and we do not have any other facility elsewhere. The focus of operations is Ghent, so we will have vessel going in and out of Ghent.*
6. In your opinion, because of the EU-ETS, the cost of commodity to rise? *The commodity price will depend on the market. This might have an additional impact but we will have a better idea in the future how prices change.*

Name: Errikos Tsagkaris
Company: Value Maritime BV
Position: Commercial Manager
1. Could you please briefly express your role in the company and the responsibilities. *I am commercial manager responsible selling the Filtree system of scrubber units and scrubber units with the carbon capture model. I am responsible for selling these units to dry bulk carriers worldwide and also tanker companies specifically in Greece. My responsibilities involve opening doors with my network and duties involve from presentation of the product up until the contract signing. Once the contract is signed by the concerned parties the technical department take charge. We are also venturing into container vessel segment.*
2. What kind of vessels are being fitted with scrubber unit? *The scrubber units can be fitted on cargo vessels from 2 MW to 15 MW engines, for example, for a dry bulk carrier say up to Panamax size and tankers of MR size. The scrubber units are very useful when sailing in the SECA region. The cost difference between MGO and HFO is huge, almost 600 USD/ ton. Therefore, HFO can be consumed using the scrubber unit installed. The scrubber units are installed on container feeder vessels; however, we see a growth in tanker market. Additionally, they are installed on tanker vessels in order to make the time charter contracts more attractive.*
3. How expensive is it to retrofit a vessel with a scrubber unit/carbon capture module? *It depends on the engine size, the filtree system, and type of scrubber (open loop or closed loop) and a hybrid loop (mix of both). The Filtree unit costs approximately 2 million for the scrubber unit including the carbon capture unit including retrofitting and installation. It can go up to approximately 8 million for ca capsize vessel. For eg. Wartsila makes scrubber units for Capesize vessels. It can take up to 20 days for the retrofit. It has to be done in a drydock depending on the vessel, however it can be done without dry docks too.*
4. What are ship owners' reaction to the decarbonization goals of the EU and IMO? *Since the fit for 55 in coming place since 2023, owner try to hedge themselves from these situations. However, a lot of shipping companies are looking for technologies to reduce their emissions therefore they approach our company just for the carbon capture module mainly. They try to keep up with the regulations and the pace, however the issue is the certification, recognition, approval from governing bodies such as classification society, flag state, EU commission. The scrubber units are class and flag state approved, even if the Eu-ETS incorporates the shipping sector, the system for scrubbers is yet to be certified by the EU and IMO. So, you cannot capture CO_2 and have reduced carbon tax credits until EU approves these units. It is an on-going process to get the approvals.*
5. In your opinion, how is the cost for retrofitting borne, the owner of vessel bares the cost or passed on to the customer? Different financial options?

Usually the vessels that have scrubber fitted for e.g. a tanker. The tanker would be time chartered with an 8 percent premium. Because of the scrubber units, there are a lot of savings therefore, these are not seen as an additional cost it is basically an investment that you try to hedge yourself from upcoming fuel increases. So, it its not something that they would pass on to the customer but in the case of time charter they will pass it to the customer, but the customer will also save in in this, actually the customer would save more like up to 12%. It's a difference of 4 %. So, the earning for e.g., for an MR tanker that has scrubber fitted and a tanker that does not have a scrubber fitted, the earning difference is 12 percent, this means that that they earn 12 percent because of lower operating expense due to the cost in bunkers. The financing options would be either a loan or in our case as it's an installation done outside the vessel its treated as a separate asset, therefore we are able to provide leasing. If the lease agreement is breached, we can arrest the vessel and get the scrubber unit uninstalled.

6. With EU introducing 'fit for 55' to maritime sector, do you feel more vessels being fitted with scrubber units within the EU?

Yes, we see a lot of vessels especially sailing in the SECA region tend to move forward into fitting scrubber units due to the spread and lowering their opex. A lot of port the Northern Europe have banned opened loop scrubbers as the water get discharged into the sea. Due to this open loop scrubber investment have slowed down however in new built vessels closed loop or hybrid loop scrubbers are being installed. In closed loop system, the water is captured onboard the vessel and discharged out in the open ocean after treating. Our system called the clean loop system captures the particular matters and the water discharged is Ph neutral. These kinds of systems are the ones shipowner in the EU are looking for.

7. Do you see a trend in ship owners change of fuel towards greener Biofuels due to decarbonization goals of 2050?

A lot of shipowners are investing into dual fuels. For e.g., Methanol and HFO/VLSFO engines however the question is supply of the Biofuels, therefore ship owners are using HFO with scrubber units fitted with carbon capture units. Methanol does not have any Sulphur however it does emit CO_2 and this greener fuel is not a sustainable solution. The vessels that run LNG are far too expensive, therefore the switched. Now they are looking for vessels with sails. If you take for instances our system, you have dual fuel we can also capture CO_2 from the Methanol. Nevertheless, it's important to have supply because you can't wait or have the vessel off hired because you don't have bunkers in that area.

8. Do you see, these vessels retrofitted with scrubbers moving on to dual fuel in the future?

Usually, the vessels that are retrofitted are vessels that use HFO. The new builds tend to install engines capable of burning dual fuels.