UNIVERSITY OF GOTHENBURG
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Master Degree Project in Logistics and Transport Management

The Potential for Alternative Fuels in Maritime shipping

(A Literature Review)

—Focus on LNG and Biofuels (Biodiesel & Ethanol)—

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Abstract

This report deals with the environmental impacts of using oil-based fuels in the sea shipping industry. Evaluating three alternative fuels to replace or complement current fuels used in sea shipping sector in order to achieve better environmental performance.

The increase in the sea shipping activities in the recent draw the attention toward the environmental impacts and emissions resulted from these logistic operations. Greenhouse gases such as carbon dioxide, alongside with other emissions can result in major environmental issues, affects aquatic systems, shortages of freshwater as well as affecting human health.

This paper evaluated and compared different types of alternative fuels (LNG, Biodiesel, and BioEthanol) that have less damaging environmental effects and it can complement or replace oil-based fuels used in the maritime shipping industry and can fulfill the International maritime organization environmental requirements and regulations.

After analyzing the three types selected, the author finds out that liquefied natural gas LNG has more advantages than biodiesel and bioethanol. LNG has the highest potential to become the fuel of the future since it has better environmental impacts than oil-based fuels and it can offer high operational efficiency and it can bring high economic outcome.

KEYWORDS: Alternative fuels, sea shipping industry, liquefied natural gas LNG, biofuels.

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Abbreviations

CO_2: Carbon dioxide

ECAs: Emission control areas

EEDI: Energy Efficiency Design Index

GHG: Greenhouse Gas

HFO Heavy fuel oil

IMO: International Maritime Organization

LNG: Liquefied natural gas

LSFO low sulphur fuel oil

NO_x: Nitrogen Oxides

PM: Particulate Matter

SECAs: Sulphur emission control areas

SEEMP: Ship Energy Efficiency Management Plan

SO_x: Sulphur oxides

UNCTAD: United Nations Conference on Trade and Commerce

1. Introduction and background

This part contains a brief introduction to the paper subject. The aim is to prepare the reader about the research problem. This part provides general information about shipping and its relationship with environment and a short introduction about alternative fuels. This section includes the following; Shipping and Environment, alternative fuels, research problem, Research purpose & questions and research scope.

1.1. Shipping and Environment

Shipping has been considered as one of the most important activities performed by humans throughout history, especially when prosperity depended primarily on international and interregional trade (Corbett & Winebrake, 2008). Sea shipping particularly has a fundamental role in the globalization of the world economy (Stopford, 2010). Due to its important role in globalization, the demand for shipping services increased significantly since the mid-1990s, even during periods of global recession (Cullinane & Cullinane, 2019). The maritime shipping move 90 percent of the total freight moved worldwide and the total shipping has risen to fulfill 10.6 billion tons in 2017 (UNCTAD, 2017). In the 19th century, steamships engines used coal to generate power and later switched to burn fossil fuels (Stopford, 2010). Ships mainly use three types of fuels; the majorities run on diesel and the rest uses heavy Fuel Oil -HFO- and Low Sulfur Fuel Oil -LSFO- (Ibid.). This transition to fossil fuels led to an increase in sea shipping demand, lower shipping costs and stop considering the distance and volume as a problem (Corbett & Winebrake, 2008). Sea shipping is accounted for 1.2 tonnes of cargo each year for every person on the planet, for rich countries such as the European Union, imports are closer to 3 tonnes per capita (Stopford, 2010). This increase in the total shipping volume draw the attention in the recent decades toward the environmental effects resulted from these logistic operations and this topic is gaining increased importance around the world (Sathaye et al, 2019). As a result, more studies have been conducted to increase the understanding of the environmental effects and the pollutant emissions produced from maritime shipping operation. GHG emissions (mainly CO2) and health-damaging pollutants were the main focus of these studies (Cullinane & Cullinane, 2019). Further, the negative impacts of burning fossil fuel by ships are no longer accepted by local communities who are becoming more aware of the health risk of pollution caused by shipping industry near their coastal waters (Stopford, 2010). The increases in oil costs along with the aforementioned environmental concerns boosted the efforts of searching for alternative sources of energy that have less damaging consequences and can contribute to reducing negative environmental effects of shipping operations (Holmborn, 2015).

Natural gas, ethanol, and Biofuels, in general, are some examples of many sources of energy that already exist in the shipping industry and can be considered as a future prospect to replace the types of petroleum fuels used currently in the maritime industry (Holmborn, 2015). These types of fuels can replace the use of what is considered as the major factor responsible for global warming and main sources of local environmental pollution. For these reasons, they are known as “alternative fuels” (Manzanera, 2011).

1.2. Alternative Fuels

Using alternative sources of energy is not a new concept in the transportation sector, several alternatives have been used before throughout history. In the 1920s, biomass or natural gas was converted into liquid fuels by Germans F. Fischer and H. Tropsch, this process was massively used in the late 1930s & early 1940s and also during oil crises in the 1970s & 1980s (Chryssakis et al, 2014). In recent years, the demand for alternative fuel has increased significantly due to the current and future regulation regarding the environmental impacts created from logistic operations and transportation (Chryssakis et al, 2014). This growth in demand is expected to continue for the next 10 years in order to cope with this more stringent emissions legislation (Ibid.). According to European parliament’s study regarding alternative fuels conducted by Kampetet al. (2003), Alternative fuels can be defined as *"All existing fuels which are not diesel and gasoline produced from mineral oils"*. This definition was set on the basis that petroleum diesel and gasoline are the most used fuels on a global scale and the widest technologies used in transportation are the internal combustion engines by Otto and Diesel. Moreover, this study referred as well to the alternative propulsion technologies as *"All propulsion technologies besides Otto and Diesel engines"* (Kampet et al, 2002). There is a long list of fuels that can be used in transportation sectors, these fuels considered nearly sulphur free and can be used for compliance with sulphur content regulations, the most ones commonly considered today are Liquefied Natural Gas (LNG), Biodiesel, and bioethanol, Liquefied Petroleum Gas (LPG), Synthetic Fuels, Hydrogen, and Nuclear fuel (Chryssakis et al, 2014). Some of these fuels can be mixed with conventional, oil-based marine fuels, or replace conventional fuels completely (Cullinane & Cullinane, 2019). Further, when considering the overall environmental impact of a given fuel, it is important to take into consideration not only the direct impact on the vessel's emissions, but also the emissions resulted during the production of the fuel as well as other effects, such as land and water use which is important for certain types of fuels, such as biofuels (Chryssakis et al, 2014).

1.3. Research Problem

Concerning the future use of alternative fuel for maritime shipping, there are two problems that need to be addressed.

First, despite being the most environmentally sustainable transport mode for bulk cargo, container shipping industry is still considered to be an important contributor to the global emissions such as; Carbon dioxide (CO2), nitrogen oxides (NOx), sulphur dioxide and (SO2) emissions along with other environmental impacts (Andersson, et al. 2016). Even with many types of alternative fuel available in the shipping industry, the complex nature of each of them makes it a hard for the ship owners or policymakers to evaluate cleaner options of alternative fuel and find the best choice (Ashnani, et al, 2015). The second issue concerning the use of alternative fuels relates to the operational performance, relative cost, convenience, and availability of alternative fuel. (European Commission, 2001). Of course, the economic situation plays a fundamental role when deciding the favorite type of fuel to be used as an alternative since costs for market-deployment of alternatives production plants and infrastructure are generally higher than petroleum-based fuels due to the lack of economies of scale (European Commission, 2001). This issue can be accompanied with other types of issues such as; conflicting interests, developing potentials, optimization of logistics, terminal design and operational safety (Molitor & Gahnström, 2011).

1.4. Research purpose & Research Question

In light of the issues mentioned above, this paper aims to investigate, evaluate and compare three different types of alternative fuels (LNG, Biodiesel, and Bioethanol) that have less damaging environmental effects and it can complement or replace oil-based fuels used in the maritime shipping industry. Moreover, evaluating alternative fuels that could meet future environmental requirements and regulations. The purpose is to examine each type of fuel influences on the environment and try to find the most proper solution to meet the two issues mentioned in the previous section, better environmental performance and higher operational efficiency.

This would require answering the following question:

Which alternative fuel could have the potential to replace the current fuels used in the maritime shipping industry from an environmental, operational and economical point of view?

1.5. Research Scope

With the high number of fuels that can be used for power generation, this paper focus on three types of alternative, liquefied natural gas LNG, and two types of biofuels; Biodiesel and Bioethanol.

The three aforementioned fuel types have high potentials to be a great part of the future of Sea shipping industry.

Liquefied natural gas was described by various studies as the "best available alternative". It is currently used on a considerable amount of vessels and has high potential to replace oil-based fuels; LNG have low emission levels as well as fine engine performance (Cullinane & Cullinane, 2013, Rozmarynowska 2010 and Carlton et al, 2013).

Biodiesel offers a considerable emissions reduction as well as it has the ability to work directly on the current diesel engines, which are widely used in sea shipping industry (Cullinane & Cullinane, 2019, USDA, 2018 and Getachew et al, 2015).

Bioethanol is widely used in the automotive fuel market and shown its ability to offer emissions reduction as well as offering good engine performance (Hsieh & Felby, 2017 and Micic & Jotanovic, 2015).

2. Methodology

2.1. Research Strategy

This paper is a literature review, and it is a critical analysis of previously published studies and theoretical articles by summarizing their content, comparing the different results obtained from them and classifying them on the basis of; the methods used, the content value, and the obtained results (Collis & Hussey, 2014).

Rhoades (2011) classified the four different types of literature reviews; evaluative, explorative, instrumental and systematic reviews.

Evaluative reviews usually are used to assess the literature of a certain topic and discuss its coverage and contribution to knowledge. This is done by comparing the findings of the different published researches in the studied area and evaluates the quality of such research.

The second type of literature review is the exploratory review; this type aims to seek the knowledge of what exists in the academic literature in terms of theory, empirical evidence and research methods done in a specific area of interest. This review is used to emphasize and sharpen the knowledge around specific research questions that remain unclear or unanswered.

The third type is the instrumental review; this review focuses on setting a framework for future research in a highly specific research problem.

And finally, the systematic review is also a literature review that collects secondary data from currently published researches and helps to produce new findings by analyzing this data qualitatively or quantitatively (Rhoades, 2011).

In this paper, an exploratory review method is used to closely explore the literature done in a specific area of interest i.e. Alternative Fuels. And to answer specific questions, which alternative fuel is the best in terms of environment outcome that can be used in the sea shipping industry and which fuel can give a high operational and economic performance.

A SWOT analysis is done on the best alternative fuel after closely examining the literature and comparing different types of alternative fuels. This SWOT analysis is used to emphasize the different qualities of the chosen fuel in terms of environmental impacts, economic value and operational efficiency.

Predictive reasoning is used to answer the simple question of “what will happen?” This is done by using statistical techniques and models to forecast the future (Collis and Hussey 2014). This paper uses predictive reasoning in the form of scenario analysis to assess what will happen if, for instance; European laws are used in different geographical areas where air pollution has high levels.

2.2. Data collection

Data collection is a very important process in the research. There are two types of data; primary data and secondary ones (Collis & Hussey 2014). Comparing the two types of data; primary data is original data that comes in the crude form, selected by the researcher himself to serve the exact purpose of the research. This collection of primary data is done by observation, survey, focus group discussion or in-depth interviews (Collis & Hussey 2014).

On the other hand, secondary data is refined data collected from reliable resources such as; previous studies done, statistics, books, newspapers, articles and governmental websites (Ibid.).

In this research, data is mainly selected by performing a literature review on the previous academic studies, journals…etc on the topic of the environmental impact of alternative fuel and the operational efficiency in sea shipping industry. This is done to gain more knowledge and a wider perception of the topic. This method provides a critical evaluation of the previous studies and it will contribute to the final results because it allows for the adjustments and revisions during the course of the study.

2.3. Literature review

Literature review refers to all the secondary data that relevant to a specific subject that helps with exploring what others contributed to the area of the subject (Collis & Hussey, 2014).

In the literature review the following topics will be covered; environmental impacts from the emissions produced when using oil and alternative fuels; GHG, NOx, SOx and PM, environmental laws & regulations, and 3 types of possible alternative fuels; Liquefied natural gas, Biodiesel and Bioethanol.

The data collected and used in this thesis are mainly from books, official websites and relevant scientific articles. The data collected mainly from searching through, Gothenburg University website, Google Scholar and scientific search engines such as Research Gate. The keywords used in search are the most relevant to the study such as; environment and shipping, environmental laws, sea shipping industry, GHG, NOx, SOx and PM from marine engines, alternative energies, liquefied natural gas, biofuels and internal combustion engines.

Inclusion criteria: literature includes both environmental effects on the planet and public health when using oil and alternative fuels. Along with operational efficiency for the fuels mentioned earlier. Articles that involved pollution resulted from engine technical issues were not included. Recent studies on the amount of emission were included while information regarding the chemical components of emissions is obtained from both recent and older studies.

2.4. SWOT Analysis

SWOT analysis tool is generally used in strategic planning, it helps to formulate and assist strategies and plans to identify organization's performance internally and externally (Bonnici & Galea, 2015). This is done by recognizing and identifying strengths, weaknesses, opportunities and threats for products, resources, capabilities, core competencies and technologies in order to observe best choices available to apply in current and future situations that would enhance the overall performance (Ibid.). SWOT analysis essentially focuses on evaluating a range of dilemmas against each other in order to identify strategies that align, fit or match specific resources to achieve the desired goals (Ritson 2008).

Ritson (2008) explained the process of SWOT analysis and mentioned that evaluating alternatives includes 5 continues steps, "Internal analysis of strengths and weaknesses, External analysis of opportunities and threats, Identification of the key strategic issues, Evaluation of options and selection of strategy and Implementation of the chosen strategy."

According to Gurei & Tat (2017) SWOT analysis is a thinking model that is used as an approach and analysis technique for managements. This model helps in detecting the internal and external environments' weaknesses and strength. By revealing these features, SWOT analysis helps in discovering the opportunities to make advantages(Ibid.). Moreover, another advantage of SWOT analysis is that it can be used along with other theories and strategic tools, and can be applied on all individual, organizational, national and international levels (Gurei & Tat, 2017).

The decision makers can use SWOT analysis to increase their awareness about their issues in-hand and the future issues that may arise and thus, implement the strategies that align with the situation. (Al-Rousan & Qawasmeh 2019).

In this paper, SWOT analysis is done in order to identify the essential features and barriers when applying an alternative fuel in the sea shipping industry and to evaluate the key strategic issues related to each fuel.

2.5. Scenario Analysis

Reger & Mietzner (2005) define Scenarios as" a Powerful tool to aid in decision making in the face of uncertainty". Scenario analysis tool is mainly used for future studies, it aim to develop an alternative view related to possible futures events which can diminish surprises and create a higher awareness of the expected outcome related to a specific subject (Ibid.).

Scenarios can support decision-makers in order to plan effectively the appropriate responses to possible future events and increase the understanding of how a particular path could lead to specific or several outcomes (Postma & Liebl, 2005).

2.5.1. Shell Scenario Model:

Since the early 1970s, Shell has been using this approach to increase the awareness and the understanding of the possible future events. This model designed by Shell Corporation aims to ask the question "What if" in order to help leaders and decision makers to design the possible plans and to widen their perspective (Shell, 2019).

Shell scenario planning process consists of 6 steps:

Preparation: this step includes designing the description of the project in order to help set and understand the goals of the scenario project.

Pioneering: in this step, ideas are gathered to build the scenario, this step is critical in the planning process since it helps to reveal blind spots and expand perceptions.

Map making: in this stage, the materials provided by team members are gathered and incorporated into the scenario structure to generate the scenario. This step is executed to shape a logical and relevant set of stories.

Navigation*:* this step is aiming to steer the scenario that faces newly emerged challenges that are not well understood.

Reconnaissance: in this stage, a common understanding of the scenario is achieved. This process aims to control and monitor implications reached from scenarios and to recognize the different conclusions that can be achieved through scenario planning.

Preparation: In this process, scenario planning starts all over. it is important to review the scenarios over time and adapt them with the changes happens within the organization. This is done since scenarios are not definitive future predictions, but it is an instrument to develop mitigations of the identified new risks expected to occur in the future.

In this paper, a scenario analysis will be performed after concluding the findings from the literature review and analyzing the results using the SWOT analysis tool. This is done in order to form a possible expectation of how the final result could be applied in the future of the sea shipping industry.

2.6. Reliability and Validity

Validity is defined as the ability to measure what is intended to be measured (Hamed, 2016). The closeness of the results and the more accurate represent the reality the higher the research validity (Collis & Hussey, 2014).

In this research, the literature review of scientific and academic content increase the validity of the found results. The validity is high in such research because the findings are supported by different sources of literature that were carried out using different methods and scales including the review of previous qualitative and quantitative researches.

Reliability represents the concept of repetitiveness which is the ability to re-do the research and obtain the same results (Collis & Hussey, 2014). By closely explaining the methodology, inclusion and exclusion criteria, search engines used, main keywords used, the incorporation of a high number of reliable researches and citing the relevant references, this research is highly reliable and can be repeated with no differences in the obtained results.

3. Literature Review

In this chapter, topics related to the research questions are presented by collecting data from previous studies. This part will cover the following: Environmental concerns, IMO & the EU environmental regulations and the alternative fuels; LNG, Biodiesel, and Bioethanol.

3.1. Environmental Concerns

The first part will cover the most copious emissions produced from the sea shipping industry, its effects on the environment and on public health. The emissions included in this section are; Greenhouse gases, Carbon dioxide, Sulfur dioxide, Nitrogen oxide, and Particulate matter.

3.1.1. Greenhouse Gases (GHG)

The main factor that contributes to increasing Earth temperature is the Greenhouse gas effects (Darkwah, 2018). This effect blocks some of the planet's heat that should have been released from earth atmosphere to the outer space and act like the glass of a greenhouse, letting the sunlight in and preventing heat from escaping (Ibid.). The natural ratio of greenhouse gases is what makes life as we know exists. However, many reasons contribute to increase and intensify this ratio, primarily the burning of fossil fuels - coal, oil - for power generation (IPCC, 2007). The release of GHG and carbon dioxide into the atmosphere considered to be (alongside with deforestation) the major cause of global warming and has significant effects on the entire planet (Ibid.). Furthermore, the rise of GHG levels and the increase of the earth’s heat can have many negative consequences related to human life, such as; growing risks of having shortages in supplies of freshwater, coastal flooding, huge population displacement, rising sea levels, and health problems (Buha, 2011). Earth's atmosphere contains various types of greenhouse gases, including; Carbon dioxide (CO2), Water vapor (H20), Methane (CH4), Ozone (O_3) and Nitrous oxide (N20) (Ranveer, 2015). The Shipping industry is accountable for a significant amount of the global climate change, shipping industry emits approximately 3.3 % of global Greenhouse gas emissions, producing around one billion tons of Carbon dioxide and GHGs every year and these emissions are estimated to continue growing to reach 9 % by 2050 (OLMER et al, 2017).

3.1.2. Carbon Dioxide (CO_2)

Carbon dioxide is the main element of greenhouse gases that contribute to increasing earth temperature and causing the phenomenon of global warming (IPCC, 2007). The concentration of carbon dioxide in the atmosphere rose from 277 parts per million (PPM) in the year 1750 to 405.0 (PPM) in 2017 (ESSD, 2018) and it is on the way to reach 550 ppm by the next 30-80 years (Smith & myers, 2018). After the stabilized rate in CO_2 emissions in 2016, carbon dioxide emissions rose 1.6 % in 2017 and expected to increase by around 2 % in 2018 (GCB, 2018). This increase is mainly due to the boost in world oil demand by in 2017, around 1.6% or 1.5 million barrels a day (ITF, 2018). 932 million tonnes of carbon dioxide were emitted in 2015 by international sea trade industry (OLMER et al, 2017). In fact, if the shipping industry were a country, it would be the sixth larger producer of CO_2 in the world (Kolieb, 2008). Mainly, the largest producers of CO_2 are countries with high level of economic development such as China and the United States, for instance, the major ship owning country in terms of ship numbers is China, with 5,512 commercial ships, China alone produces 25% of the total CO_2 levels in the entire world (Liu 2016 And UNCTAD, 2018). In 2015, global shipping was responsible for 2.6 % of global CO_2 emissions, Distributed as follows; 87 % from international shipping, Domestic shipping 9 % and fishing 4 % (OLMER et al, 2017). Container ships, bulk carriers, and oil tankers have the highest rate of these emissions between 2013 and 2015 (Ibid.). As mentioned earlier, CO_2 is the main cause of global warming, the high concentration of CO_2 leads to a reduction in outgoing infrared radiation which means that the climate must change in a way to restore its natural balance between incoming and outgoing radiation (Darkwah, 2018). These changes include a rise in the climate temperature which will finally result in countless symptoms that affect human life in various ways (Ranveer, 2015). Furthermore, high level of CO_2 and GHG can result in major environmental and health problems, huge population displacement since 50 % of the world population lives within 100 km of the sea, effects on aquatic systems, shortages of freshwater, coastal flooding (Buha, 2011 and Ranveer, 2015). The exposure to CO_2 above normal rates may as well significantly affect human health and cause dizziness, confusion, sweating, dim vision breathing problems and in some cases can lead to lung cancer (Ranveer, 2015 and Rice, 2003).

3.1.3. Sulfur dioxide (SO_2)

Sulphur Oxides (SO_x), remarkably Sulphur Dioxides (SO_2), are emitted when fuels containing sulphur are combusted. Traditionally, sulfur oxide (SO_2) resulting from the combustion of fossil fuels is considered to be one of the major factors causing air pollution all around the planet (WHO, 2000). Sulfur oxide (SO_2) is colorless, toxic and has a sharp odor, naturally exists and generated by human activities (Foxall, 2010). Sea shipping in particular, uses unrefined fuel which is the dirtiest fuel in the market, the sulphur content is 2.5 to 3.5 %, which is 3000 times higher than road fuel used in Europe (EEB, 2011). At a global level, the sea shipping industry has a large share of SO_2 emissions and it generates between five to ten percent of the total SO_2 emissions worldwide (ITF, 2016). The highest levels of SO_x emission globally are produced from the Chinese ports and water areas, in fact, Chinese ports produces around 50 % of the total sulphur in the region (WRI, 2019).

High level of sulfur dioxide can form sulfuric acid, which is the main element of acid rain that can lead to acidify waterways to the detriment of aquatic life and contribute to deforestation thus, leading to higher levels of CO_2 in the atmosphere (WHO, 2000). Alongside with environmental effects, sulphur dioxide affects human health directly, as the exposure to SO_2 causes numerous health issues including: eyes irritation and in some cases blindness, skin diseases, and affect the respiratory system, particularly lung function, causing coughing and in severe cases conditions such as asthma and chronic bronchitis (Foxall, 2010).

3.1.4. Nitrogen oxide (NOx)

The term NOx, combine; nitric oxide (NO) and nitrogen dioxide (NO2), it is typically formed by human activities such as transport and industries (Depayras et al, 2018). Moreover, the combustion of fossil fuels is by far the dominant source of NOx emissions (EEA, 2014). Nitrogen oxides are not a greenhouse gas but they have a major effect on climate by creating ozone (O3) and hydroxyl (Depayras et al, 2018). The low-level ozone has a considerable amount of impact on arctic warming and is responsible for about 0.3°C of the annual average arctic warming (Kolieb, 2008). This rise is 20 % higher than the amount that took place in the 20th century (Ibid.). Several studies posed NOx to be the most threatening air pollutants due to its huge negative impact on humans and the environment (WHO, 2018 - Latake, 2015 and Depayras et al, 2018). Like others emissions generated from burning fossil fuel, NOx emissions contribute to acid deposition in soil and water, causing an imbalance in ecosystems by affecting rivers lakes, water quality reduction, and damaging forests, crops and other vegetation covers (EEA, 2014). The exposures to air containing a high concentration of NOx affect the human respiratory system and increase the risk of having breathing problems such as asthma, especially for old people and children (Mauzerall et al, 2005). Sea international shipping industry emitted 25.8 million metric tons of NOx in the year 2007, which represents 30 % of the entire NOx emissions (Kolieb, 2008). These emissions are expected to increase to around 34.2 million metric tons by the year 2050 (Kolieb, 2008). NOx Emissions from international shipping are mainly formed during combustion and it is higher when using older engines (Kolieb, 2008).

3.1.5. Particulate matter (PM)

Another issue related to environmental and health concerns is the particulate matter (PM) generated through the burning of fossil fuel. PM is the major driver for climate change and it is affecting humans and nature in both developed and developing countries (Abulude, 2018). In the year 2000, the sea shipping industry produced 250,000 tonnes of particulate matter (PM) and this ratio is expected to increase 40–50 % more by the year 2020 (EEB, 2011). Numerous reports have established the negative impact of PM on health, reduced air quality raises the risk of stroke, heart disease, lung cancer, and chronic and respiratory diseases (WHO, 2018). In fact, air pollution generated from international shipping kills every year around 50,000 people only in Europe (EEB, 2011). In East Asia, the pollution levels are considered the highest in the world, emissions by maritime shipping in 2013 are responsible for approximately 37500 premature deaths in East Asia (Zhaofeng et al, 2013).

Besides the negative health effects, Particulate matter is responsible for reducing atmospheric visibility and affecting plants (Mukherjee, 2017). The current data available on particulate matter (PM) shows a reduction by 22 % in the last 20 years in developed countries while in some areas in Asia and Africa showed significant increases (Mukherjee, 2017).

3.2. Environmental Regulations

This section will cover the environmental regulations and laws concerning the pollution produced from the sea shipping industry and what are the environmental standards and tools established by international organizations and policymakers to lower pollution levels.

3.2.1. IMO Environmental regulations and legislations

The International Maritime Organization (IMO) is the "United Nations specialized authority for the safety, security and environmental performance of international shipping, its responsibility is to set fair and effective regulations and framework for the shipping industry to be universally adopted and implemented" (IMO, 2019).

The IMO in 1973 developed “the International Convention for the Prevention of Pollution from Ships” known as MARPOL Convention, which is the one of the most important environmental conventions (IMO, 2019). MARPOL Convention was developed in order to reduce all kind of pollution produced from ships including dumping, oil and air pollution. (Ibid.) MARPOL consists of six Annexes, the latest Annex is the MARPOL Convention Annex VI 1997, is titled; the Prevention of Air Pollution from Ships (Ibid.).

MARPOL Annex VI sets limits on SOx and NOx emissions (IMO, 2019.). The IMO emission standards are commonly referred to as Tier I, Tier II and Tier III. The Tier I standards were defined in 1997 and started in May 2005, while the Tier II/III standards were introduced by Annex VI amendments adopted in 2008 after increasing the pressure to regulate more strict laws on atmospheric emissions (Cullinane & Cullinane, 2019).

3.2.2. Emission Control Areas

According to IMO, starting the 1st of January 2015, the sulphur limit for fuel oil used by ships trading in Emission Control Areas (ECAs) must not exceed 0.10% against the limit of 1.00% in effect up until 31 December 2014. These rules introduced under the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI (Regulations for the Prevention of Air Pollution from Ships)

The Emission Control areas established under MARPOL Annex VI for SOx are

1. Baltic Sea area

2. North Sea area.

3. North American area.

4. United States Caribbean Sea area (IMO, 2014).

SOx and particulate matter emission controls apply to all fuel oil used onboard, this interpreted as; all engines together with items such as boilers and inert gas generators (IMO, 2014).

In October 2012, these standards were officially transposed into Europe. The current EU regulations state that;

1. European Sulphur emission control areas (SECAs) include the Baltic Sea, the North Sea and The English channel.

2. From 2015, ship sailing in the Sulphur Emission Control Areas (SECAs) cannot use fuel with more than 0, 1% of sulphur.

3. Globally, European ships have to cut their fuel's sulphur content to a maximum of 3.5% in 2012 and to 0.5% in 2020 or 2025.

When the date 2020 is subject to review by the IMO on the global level (depending on the availability of the required fuel oil), the EU decided to stick to the implementation date of 2020.

4. In Europe only, passenger ships sailing outside SECA will have to use sulphur content no more than 1,5%, which was set in 2005 (Cullinane & Bergqvist, 2013).

Figure 1, Emission control areas map (IMO 2019).

3.2.3. IMO Sulphur Standards

The IMO on 27th of October 2016 announced that January 1st, 2020 has been set as the implementation date for a reduction in the sulphur content of the fuel oil used by ships. The IMO took a decision during its Marine Environment Protection Committee to implement a global sulphur limit of 0.50% m/m in 2020 (IMO, 2014). These limits are expressed in terms of (% m/m) percent concentration by mass. The 2020 date is subject to a review globally in and may be delayed to 1 January 2025, depending on the availability of the required fuel, while in Europe it will still be implemented in 2020. (IMO, 2014) This decision represents a significant cut from the 3.5% m/m sulphur limit currently used globally (excluding Emissions control areas) down to 0.50% m/m (Ibid.). The following table shows Sox limits regulations and the implementations dates.

Outside an ECAs established to limit SOx and particulate matter emissions	**Inside an ECAs established to limit SOx and particulate matter emissions**
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020 or 2025	0.10% m/m on and after 1 January 2015

Figure 2, Sulphur limits and implementation date (IMO, 2014).

3.2.4. Regulations and standards for Nitrogen Oxides (NOx)

Nitrogen Oxides (NOx) are formed during combustion at high temperatures, and it is depending on the engine maximum operating speed (rpm) (Cullinane & Cullinane, 2013).

As shown in the table below, Tier I and Tier II limits are global, while the Tier III standards apply only in NOx Emission Control Areas. The limits are expressed in (g/kWh) gram/kilowatt-hour.

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kWh) n = engine's rated speed (rpm)		
		n < 130	n = 130 - 1999	n ≥ 2000
I	1 January 2000	17.0	45·n(-0.2)	9.8
II	1 January 2011	14.4	44·n(-0.23)	7.7
III	1 January 2016	3.4	9·n(-0.2)	2.0

Figure 3,NOx limits established by IMO (IMO, 2014)

3.2.5. Greenhouse Gas Standards

The IMO has set a goal to cut 50% of CO2 emission from the sea shipping sector by 2050 (IMO, 2018). The two mandatory mechanisms were developed by IMO intended to ensure an energy efficiency standard for ships. These regulatory mechanisms are the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships (IMO, 2014).

These approaches adopted by the IMO aim to reduce the greenhouse gases of the shipping industry by applying a range of 'Technical and Management Strategies' which could potentially reduce fuel consumption and thus emit less GHG emissions (Cullinane & Cullinane, 2019). The Energy Efficiency Design Index (EEDI) is an index that requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments (IMO, 2014). The energy efficiency of a ship' in terms of g-CO2 (generated) per tonne-mile (cargo carried); calculated for a particular reference ship operational situation (Ibid.). The intention is that by forcing limits of this index, IMO can push ship engines technologies to more energy efficient ones over time (Cullinane & Cullinane, 2019).

The Ship Energy Efficiency Management Plan (SEEMP) is the second mechanism and it was introduced by IMO MARPOL Annex VI (IMO, 2014). This operational measure establishes a mechanism to improve the energy efficiency of vessels (Ibid.). The SEEMP was developed in collaboration with the shipping industry to make ship owners more aware of new technologies and think about how the energy is used on board, SEEMP includes a guidance document from the IMO describing the best practices for operating the vessels to achieve better environmental results (Cullinane & Cullinane, 2019).

3.2.6. Directive (2014/94/EU)

The European Parliament in 2014 issued the directive 2014/94 regarding on the deployment of alternative fuels infrastructure in order to support the IMO regulation with preventing air pollution from ships (European parliament 2014). The directive is concerned with cutting pollution at sea and also at berth, the directive state that EU members should construct infrastructure for shore-side electricity supply in maritime and inland ports for ships at berth (Ibid.). Further, the directive also mandates EU members to build LNG refueling network to increase the possibility of using LNG as a fuel for ships in inland water and at sea shipping, the network should be finished by 2025 and 2030 respectively (Ibid.).

3.3. Alternative Fuels

In this section, a description of the characteristics of the selected fuels is presented. The fuels types in this section are; Liquefied Natural Gas, Biodiesel and Bioethanol.

3.3.1. Liquefied Natural Gas

LNG stands for Liquefied Natural Gas, is natural methane gas ($CH4$), it is obtained by cooling it down to minus 163 °C at atmospheric pressure in order to convert it into a liquid to help its transport and storage. (Carlton et al, 2013). LNG is also a fossil fuel, however, among all fuel options, remains the favorite alternative to replace oil-based fuels (Rozmarynowska, 2010). Considering that oil is eventually a finite source, there are very large reserves of LNG, therefore, the risk of gas productions doesn't meet the demand is eliminated (Cullinane & Cullinane, 2013). In addition, LNG has the highest possibility to become the fuel of choice for all shipping segments (Ibid.). Moreover, the availability of LNG is growing rapidly from conventional and shale reserves (Carlton et al 2013). The use of liquefied natural gas as shipping fuels is not a new idea; LNG has been used as a marine fuel for many years. Norway was one of the first countries that introduced LNG as marine fuel (Rozmarynowska, 2010). Due to strict environmental regulation, continuing high oil prices, the demand for LNG-fuelled increased considerably in the vessel market within the last decade, mainly in the EU (Ibid.). In 2014, 48 LNG fuelled vessels were in operation worldwide (Aparicio & Tønnesen).

The number rose to reach 121 vessels by the end of 2018 with expectation to reach 500 vessels by 2020 (DNVGL, 2018). These numbers represents a small fraction from nearly 94000 vessels in operation in of 2018 (UNCTAD, 2018). The majority of the LNG powered vessels operates within the EU 61%, followed by the United States 14%, Asia 7%, and rest of the world 18% (DNVGL, 2018). This growth in demand is expected to continue increasing in the next 10 years, first within the small-sized ships operating in areas where LNG infrastructure is available and where the LNG prices are competitive to oil-based fuel prices, and then by larger vessels when the infrastructure becomes more available around the world (Chryssakis et al, 2014). The natural gas main producers include countries such as Russia, United States, Canada, United Kingdom, Netherlands, and Qatar. And since transporting the natural gas over long distances is considered a complicated task, it is generally imported from close regional neighbours of gas producers (Rozmarynowska, 2010). LNG transportation over long distances is done in two ways, pipelines and tankers (Chryssakis et al, 2014). Pipelines are the preferred method of LNG transporting and tankers are usually used to transport LNG over longer distances (Ibid.).

In term of environmental performance, using LNG as a ship fuel is one of the best available options (Cullinane & Cullinane, 2013). Natural gas is considered the cleanest form of fossil fuels, it is cleaner than coal and oil and does not require additional after treatment technologies in order to fulfil Tier III established in MARPOL Annex VI (Rozmarynowska, 2010).

Natural gas provides significant emissions reduction compared to oil fuel, it has potential to reduce the following emissions; CO_2, NOx, SOx, and PM without any kind of exhaust gas after treatment (Stenersen & Thonstad, 2017). LNG reduces CO_2 emissions by 25% and the smaller amount of nitrogen in the combustion process reduces NOx production by around 85%. (Carlton et al, 2013). The CO_2 reductions are mainly due to the lower carbon content in the fuel, as well as to the higher efficiency at high loads of gas fuelled engines compared to diesel engines (Stenersen & Thonstad, 2017). However, LNG does not contribute to reducing CO_2 emissions to the levels that would be required for addressing climate change (Chryssakis et al, 2014). SOx and PM emissions are reduced by more than 90%. This is due to the low sulphur content of the fuel (Stenersen & Thonstad, 2017). The role of LNG in GHG reduction in comparison with oil has been reported by many investigators. In 2008 a study by Lenneras (2008) measured the environmental effects of LNG fuelled ships operating in the Norwegian waters, the study results concluded that, compared to diesel fuel, the CO_2 emissions are reduced by 23%, nitrogen oxide emissions by 89% and total elimination of sulfur and PM emissions from LNG.

On the other hand, the main environmental downside of using LNG as a fuel is escaping methane (known as the methane slip) that contributes to GHG. Methane slip is connected to combustion engines where natural gas and air are pre-ignited inside the cylinder (Stenersen & Thonstad, 2017). Emissions of unburnt methane are a cause for concern, the properties of methane, when considered as a greenhouse gas are 28 times higher than CO_2 over a 100-year perspective (Anderson et al, 2015).

LNG Engine concepts include; the dual fuel engines and the spark ignited gas-only engines (Chryssakis et al, 2014). The dual fuel engine uses both LNG and conventional fuel and it represents a flexible solution when the availability of LNG is uncertain (e.g. lack of LNG bunkering stations) (Rozmarynowska, 2010). Another option ship owners have is to convert the current engines to use LNG or to be a dual fuel engine, this is also one of the options widely used since 1999 (Antunes & Roskilly, 2012). The different engine concepts have different levels of methane slip, the highest methane slip reported for dual fuel engines (Brynolf et al, 2014). Until now, the main strategy taken by engine suppliers is to apply primary measures as optimizing engine components by design and engine control strategy and this showed better results on methane slip compared to old generation marine gas engines (Stenersen & Thonstad, 2017). Using catalyst systems has also the possibility to reduce around 90% of methane slip, though this has so far not been tested on a wide-scale (Brynolf et al, 2014).

The LNG environmental advantages are also associated with economic competitiveness for LNG over oil fuel, which is another benefit that can be achieved when using LNG. Given the volatility of oil prices, LNG Prices in terms of net energy value has been consistently lower by a sizable margin (Carlton et al, 2013). For several years the prices of LNG depended on HFO prices, but LNG was often cheaper and has lower tax rate especially in the EU (TE, 2018). The low LNG prices can also lead to considerable savings as well in some regions where taxes are charged on GHG emissions. In Norway, vessels owner reported significant overall cost saving both from the lower price of LNG fuel and from reduced taxes for emissions, even with 12% higher capital investment in an LNG-powered ship over diesel-driven vessel (Lenneras, 2008) Moreover, LNG is a pure fuel and cleaner that HFO, therefore, it can help to generate more operational savings since using LNG as fuel reduces engines operational costs and technical issues, and avoid failures (Herdzik 2011). On the other hand, the large storage volume of LNG fuel is one of the main disadvantages of using LNG (Carlton et al, 2013). On board, fuel tanks space required is about 2.5 times more than the space required for the conventional fuels (Herdzik, 2017). As a result, LNG required storage space may impact on the available cargo volume for the ship (Carlton et al, 2013). Further, the current situation of LNG port infrastructure varies between different regions (Marleneet al, 2016). Its development is higher at developed countries such as in the EU where the members encourage the investments in LNG infrastructure (Ibid.). However the LNG bunkering facilities at ports are still not yet sufficient to be able to meet high numbers of LNG powered vessels which may cause several issues such as; scheduling problems and increase the congestion at ports (Ibid.). Regarding LNG safety aspects, the possibility of LNG release during normal ship operation is very low due to safety systems that are currently used, even in case of accidents, LNG storage container damage will not create an explosion since LNG is stored at atmospheric pressure (Herdzik, 2017).

3.3.2. Biofuels

During the oil crisis in 1973, Biofuels were highly considered as a supplement to fossil fuels for transportation (Arshad et al, 2018) Biofuels are already in use in some large vessels as a part of an ongoing experiment and the primary results are promising, (Chryssakis et al.,2014). Two primary sources are used to produce biofuels, edible crops, non-edible crops such as waste and algae (Ibid.). Until recent times, most biofuels are derived from plant-based sugars and oils and it has a huge potential to play a vital role in the future of the shipping sector since it is mainly produced from renewable sources, thus, it could tackle global warming effect, diminish emissions as well as lower the dependence on fossil fuels (Hsieh & Felby, 2017). Globally, biofuels production represents 3% to total oil equivalent and expected to reach 10 % by 2030 (Chryssakis et al, 2014). It is expected that bioethanol will save approximately 10 billion liters of gasoline and biodiesel will save 20 billion liters of diesel by 2020. (European Commission, 2015) There are three different categories of Biofuels, typically referred to as first, second and third generation Kalligeros et al, 2017. The categorizing criteria depend on the technology and/or the raw materials used for its production (Ibid.). These three generations/categories include various types of potential biofuels that can be used in the marine sector and could meet the IMO environmental emissions requirements (Florentinus et al, 2012). Furthermore, many forms of fuels fall under the name Biofuels that can be used in the transportation sector and more specifically marine sector, the list includes Bio Oil, Biodiesel, Bioethanol, Butanol, Methanol, and many others, yet the most common commercially produced biofuels are biodiesel and bioethanol. (Florentinus et al, 2012 and Hsieh & Felby, 2017).

3.3.3.1. Biodiesel

Rudolf Diesel in 1910 introduced the first biodiesel derived from peanut oil, however, during following years, over 350 species of plants supply the production of biodiesel (Noor et al, 2018). As all biofuels, Biodiesel is also categorized as first and second generation, this classification depends on the materials used in its production (Ibid.). The first generation biodiesel refers to fuel produced from edible feedstock like soybean or coconut, while the second generation is derived from non-edible feedstock such as waste oil (Ibid.). The biodiesel production process involves transesterification of vegetable oil or animal fat with short-chain alcohol such as methanol or ethanol (Getachew et al, 2015). In 1990, the EU employed Biodiesel as the first biofuels in the transportation sector and since then, the EU became the major producer of biodiesel represented by 75 percent in total transport biofuels market (USDA, 2018). The consumption of biodiesel increased by 8 % since 2015 within the EU with Germany, Sweden, France and Italy taking the lead as the main biodiesel consumer with 62% of the total biodiesel consumption (Ibid.). Biodiesel gained its importance to substitute petroleum diesel through several characteristics such as reducing exhaust pollution and its' non toxic feature (in the case of spill), However, the most important feature this renewable fuel has, is that biodiesel can be used in the current traditional diesel engines with almost no technical modification required (Manzanera, 2011). This aspect is highly considered since 95% of international shipping fleet uses diesel engines (Cullinane & Cullinane, 2019). In marine engines, the biodiesel can be used 100% as pure fuel, commonly referred as B100 or it can be mixed with conventional diesel, referred to as BXX, where the XX represents biodiesel percentage in the mixture (Noor et al, 2018). In 2010, the US Navy ships started to test biodiesel and used 50% in the blend and the results showed no technical issues (Hsieh & Felby, 2017).The environmental concerns are much lesser when using biodiesel as a fuel, depending on the mixture ratio and the feedstock used to derive the fuel, the results of using biodiesel showed a significant reduction in carbon monoxide, sulphur, particulate matter and hydrocarbons (Getachew et al, 2015). For instance, B20 biodiesel can eliminate approximately 20% of Carbon Monoxide and 15% of total PM (Khan et al, 2013). NOx emissions can be eliminated when using engine mechanical systems such as catalysts (Cullinane & Cullinane, 2019). The CO2 emissions were 78.5% less than petroleum diesel and the ozone-forming potential is around 50% lesser than fossil fuel (Khan et al, 2013). Pure biodiesel is sulphur free (Ibid.).

Several aspects can affect engines' performance when using biodiesel such as the type & quality of feedstock used to derive the fuel, injection pressure, combustion chamber and the mixture ratio, generally the power output for blended fuel is slightly lower, and therefore the consumption of fuel could be increased up to 10% (Noor et al, 2018).

Several studies discussed the benefits and the difficulties of using biodiesel and biofuels in general. The challenges for using Biodiesel on a wider scale presented in securing the volume needed, for instance, to produce the oil equivalent amount of biofuels (first and second generation) would require around 5% of the agricultural land in the world (Chryssakis et al, 2014). This indirect land use change will contribute to increasing the rate of deforestation thus resulting in higher GHG emissions reversing those emitted from engines using biodiesel. (European Commission, 2015) Furthermore, securing this huge volume may potentially lead to higher competition for resources, thus causing food crises in some countries (Noor et al, 2018). For instance, in 2011, biodiesel production in the EU used 20 % of the world's traded vegetable oil (European Commission, 2015). Moreover, biofuels production requires a large amount of fresh water which will result in increasing the demand for freshwater resources (Chryssakis et al, 2014). All these aspects put a pressure on biofuels producers, ship owners, and governments since the current cost of biodiesel B20 is slightly higher than petroleum diesel and if the Percentage of biodiesel increased in the blend the cost will go further up (European Commission 2015).

3.3.3.2. Bioethanol

Being the most biofuel consumed up to 2017, Bioethanol (also known as "ethyl alcohol") has a great potential to replace fossil fuel in the future (USDA, 2018). The main feedstock to produce first generation bioethanol includes sugar cane and corn and for the second generation, a nonedible stock such as wood is used to derive the fuel (Ibid.). As the case in biodiesel, bioethanol can be mixed with other petroleum fuels such as gasoline and referred to as EXX, where the XX represents the amount of bioethanol in the blend (USDA, 2018). In case the blend with diesel, an additive package should be added to hold the blend and the mixture is referred to as E-diesel (Ibid.). However not all types of engines can burn blended fuel with bioethanol, it should be made or modified to be able to burn this type of fuel (Micic & Jotanovic, 2015) USA and Brazil are the main producers and exporters for bioethanol (Hsieh & Felby, 2017). The possibility to use it in large vessels is growing rapidly as the oil prices are increasing, although, most of the bioethanol fuel today is used in automotive transportation (Ibid.). Unlike biodiesel, the biomass used to derive the fuel does not result in varying engine performance (Bessou et al, 2009). The power density of bioethanol is less than biodiesel and fossil fuel, the energy yield for bioethanol is about 2/3 of conventional gasoline (1 liter gasoline = 0.65 bioethanol) and also, this variation creates the need for using larger fuel tanks and thus, reduce to cargo space volume on vessels (Micic & Jotanovic, 2015) . The load on engine parts is lower when using bioethanol and results in less mechanical problems since the bioethanol have higher octane than oil fuels since higher concentration of octane reduce technical failures (Micic & Jotanovic, 2015). The previous aspects increased the efforts for engines manufacturers to devote more research for multi-fuel engines. The engines have improved significantly over the past few years, but it could take decades before it can be used widely in the sea shipping industry (Hsieh & Felby, 2017). The cost of bioethanol is relatively cheaper than oil-based petrol, primarily because most of the current bioethanol production is supported by governments through tax systems (USDA, 2018) In the EU, this support led to decrease Ethanol prices by 5% and 2.3% in 2016 & 2017 (Ibid.) However, as the demand for ethanol increases, the production costs may become higher leading to higher fuel prices and it can affect the cost for some food types such as corn and sugar as well as draining freshwater resources during the production process. (Onuki, 2019).

Emissions estimation through the use of bioethanol is a complicated process since it varies depending on the mix ratio with petroleum fuel and also when considering environmental impacts of the production process. Typically, for each 1 KG of bioethanol produced, 1 kg of CO_2 is co-produced, this amount of CO_2 does not add to the existing

CO_2 level since it was originally captured from the atmosphere when the crops were growing (Florentinus et al, 2012). The Ethanol production process generally uses renewable energy sources to prevent the increase of net GHG in the atmosphere (Chandel et al, 2007) The emissions in pure bioethanol are less than conventional petrol due to the low vapor pressure in it, yet in cold weather, pure ethanol can cause an engine starting problem, so it is mainly used as a blend, commonly E85 (Micic & Jotanovic, 2015). However, the blend percentage may affect the ratio of vapor emissions, for instance, 40 % ethanol in the blend result in higher vapor emissions from both fuels than one of them does on its own (Ibid.). The high oxygen level in bioethanol helps to reduce particulate matter emitted from exhausts and thus preventing more premature deaths caused by pollution, as well as reducing ozone forming by approximately 30% (Chandel et al, 2007). Pure Bioethanol is sulphur free and its production process and burning in engines do not produce sulphur emissions (Hsieh & Felbym, 2017). The reduction of particulate matter reache 41% when using E15 around as well as a decrease by 5% of the NOx emission when using the same blend (Micic & Jotanovic 2015). However the production process of bioethanol can generate a considerable amount of nitrogen leading to increasing acidification, the nitrogen mainly produced after cultivation of crops and as the demand for ethanol increase this will reverse the positive impacts of using bioethanol (Hsieh & Felby, 2017). Furthermore, the increase of demand ultimately will lead to relying on non-renewable energy sources for the production process which will increase GHG levels and other pollutants. (Chandel et al, 2007).

3.4. Oil Production and Prices

Without a doubt, the oil prices and oil production rate are important factors to keep the world trade running as well as having huge effects on the world's economy. Crude oil prices depend mainly on supply and demand ratio, meaning that, fuel prices and shipping are directly affected by each other (Açık & Başer, 2018). For instance, the increased demand from China, India and also from developing countries raised oil prices in the last decades (Ibid.). Typically, the future world's economic growth is forecasted based on oil production rate and oil prices market (Kennedy, 2013). The current oil consumption by sea shipping industry is approximately 5 million barrel per day

Fossil fuels consumption is expected to treble by the year 2050 (Açık & Başer 2018). Oil prices prediction is usually a complex process, as prices are often related to many politic and economic aspects, however, in the past 20 years, and changes in oil prices tended in most cases to be permanent (Kennedy, 2013). Several studies expect 40% increase in oil prices by the year 2028 (OECD, 2018) As regards to maritime shipping, fuel prices can have a significant impact on the industry as it accounts for 50-60 % of the ship's total operation costs (Carlton et al, 2013). In the recent decade, bunker prices kept increasing in line with crude oil prices, which affected directly the total costs for shipping companies (Shi et al, 2013). The world demand for crude oil will reach 104.7 mb/d -million barrels per day- by 2023 due to the economic growth expectation by The International monetary fund (IEA, 2018). There is a huge body of literature that shows the importance of finding sources for energy other than oil due to its future limitation. Carlton et al. (2013) stated that growing demand, especially in developing countries will increase the risk that oil production will not meet this high demand, which accordingly will lead to much higher oil prices.

4. Results

In this chapter, the results and findings are derived from the literature review are summarized and presented. It is divided into three main categories: the negative impacts of continuing using oil fuel on environment, the importance of finding an alternative fuel and tighten environmental laws, and finally, the fuel determination guideline and characteristics.

4.1. The consequence of continuing using oil-based fuels on the environment

It is clearly stated by recent studies that continuing the use of fossil fuel in the current growth rate will add to the increasing of the earth's temperature. Most climate scientists agree that burning fossil fuel is one of the major causes of global warming. Sea shipping in particular, consumes a large amount of fossil fuel on a yearly basis and the consumption is expected treble by the year 2050. Higher fuel consumption will increase the global warming effects, thus in the long run, will increase the rate of acid rain, deforestation, smog and will increase the number of premature deaths all over the world. Countless studies concluded that continuing using oil fuels will lead eventually to catastrophic results on earth environment and also will affect people's health. From sea shipping industry, one billion tons of GHG emissions are produced on a yearly basis and it is continuing to increase by 250 % in the next 30 years to reach approximately 9 % of the global GHG emissions. The Carbon dioxide emission will jump from 405.0 PPM (parts per million) to 550 PPM by the next 30-80 years. SOx emissions from sea shipping industry represent 10 % of the global sulphur emissions.

High levels of CO2 will affect the quantity of oxygen in the atmosphere, thus, killing plants, animals and posing many health threats to humans. SOx emissions are captured by plants and trees and affect the overall ecosystem and when increasing SOx concentration in the atmosphere over a long period of time will result in infinite impacts on water, food and human's health. Furthermore, NOx emissions affect plants, trees and cause a reduction in forest growth and higher levels of NOx will have an effect on the overall ecosystem as well as people's health. PM will cause a reduction in air quality, high risk of strokes, heart diseases, lung cancer, and respiratory diseases. The PM from the shipping industry is responsible for 50000 premature deaths every year only in Europe and this number is likely to rise in the next 30 years.

The expected growth rate of the world's economy is associated with the increase of demand for oil in the next 50-70 years. By that time, the impacts of using conventional fuel will become greater on the environment and people's health. The greenhouse effect will increase the earth temperature and oceans levels. The outcome of increasing the use of mineral oil fuels will result in limitless consequences on the environment such as destroying the aquatic systems, shortages of freshwater, ocean acidification, acid deposition in soil and water, huge population displacement because of high sea levels and floods. The Health effects of people are many as well, Diseases from breathing these gases or from food affected by pollution are many, skin diseases, respiratory system problems particularly lung function, asthma and in some cases lung cancer. All these reasons are pushing for cutting the use of oil fuels and find other sources for energy, especially when knowing that the world's demand for fuel is increasing rapidly.

4.2. The importance of finding new energy sources and strengthening the environmental regulation

Fortunately, today's world is spending and devoting more and more resources to prevent pollution caused by burning fossil fuels. IMO in particular established a set of rules and laws that helped to decrease the number of pollutants emitted from international shipping and it has a vision to cut more pollution and help ships switch to cleaner fuels. Environmental laws are expected to show more efficient results over the next few years, however, emission control areas introduced by IMO and MARPOL Convention 1997 helped to reduce the amount of CO2, NOx. SOx and PM, and IMO conducted several studies to develop the understanding and promote the use of different alternative fuels. Strengthening the current regulation is, for instance, exporting the current EU laws to serve other areas in the world would help the efforts to switch to cleaner fuels and increase the development of alternative fuels port infrastructure rate

It is a fact when saying that oil production will come to an end. Despite how and when, people eventually will be forced to find another source of power. The environmental concerns of using oil are many within all kind of industries and sea shipping sector is not an exception. Switching to cleaner fuel has a huge impact on human's life in various ways, clean environment, better health, and less cost, especially when considering high costs of mitigating the environmental and health consequences of using oil fuel in all levels. Laws and regulation regarding exhaust emissions from sea shipping industry and tools associated with it for example, SEEMP helped to reduce the pollution levels but still need more improvement to meet the required level to prevent the future environmental damages caused from these emissions. Most of the commonly accepted scientific researches and studies, confirm the advantages of replacing conventional fuel with less damaging alternatives like natural gas, Biofuels, and even other alternatives have less GHG emissions and practically sulphur free. Using alternative fuels and install the infrastructure for it will considerably decrease harmful effects from using oil fuel such as CO_2, PM, SO_x and other pollutants produced by burning fossil fuel. Furthermore, the availability of potential alternative can also eliminate the concerns of one day the oil supply will not meet the demand, so we can conclude that finding an alternative source of energy will resolve issues related to the environment, people's health and world's economic development.

4.3. Fuel Determination Guideline

This section will present the most important characteristics when evaluating a certain fuel. After determining the guideline, it will be used in the SWOT analysis section in order to observe the differences among the three fuels selected.

The guidelines are: the environmental performance, fuel availability, compliance with environmental regulation, fuel prices, and operational efficiency.

4.3.1. Environmental Performance

The most important factor when analyzing a certain fuel is its environmental performance. Air pollution is the main disadvantage of oil fuel since it produces a high amount of greenhouse gases and increases earth temperature, thus contributes to the global warming phenomenon. CO_2 levels are greater in oil fuel and this applies as well to SO_x, NO_x, and PM levels. Some alternative has various different levels of air pollutants than others but in most cases, it has lower levels than oil fuel products. Cutting the overall emissions and enhancing environmental performance is the main purpose of switching to cleaner fuels.

4.3.2. Fuel Availability

It has been mentioned earlier that world demand for crude oil will increase to 104.7 MB/D by 2023 due to the growing expectation in international trade (IEA, 2018). This high demand will increase the pressure on the oil refining industry. Additionally, in maritime shipping, the pressure is greater since the demand will increase not just for ordinary ship fuels but also for the fuel that has less sulphur content to comply with the IMO regulation. Fuel availability is a critical factor to ship operators when planning the routes and refilling ports. Refilling frequency is also an important factor in sea shipping as it can affect directly ship's operation cost and time. The fuel sources should be sufficient enough to meet the demand required by the shipping market. Oil is available now but its availability is going to decline in the future so the alternative should fill this gap caused by future oil scarcity. The fuel availability is associated with different other parameters that help to understand which fuel is more suitable than others, factors such as; production/refining plants, logistics networks, infrastructure, and fuel storage tanks should be convenient, accessible and safe.

4.3.3. Compliance with Environmental Regulation

Starting 1st of January 2020 ships globally should cut its fuel sulphur limit to 0.05. In SECAs, ships already use fuel with 0.1 of sulphur content. The selected fuel should meet this requirement of sulphur content together with the rest of Annex VI amendments regulations. Meeting these regulations and cutting the overall emissions is one of the important factors when choosing an alternative fuel.

4.3.4. Fuel Prices

For ships owners, Fuel prices represent a key factor when deciding the type of fuel. The fuel prices have a significant role since it accounts for 50-60 % of the ship's total operating costs. Oil products have usually steady prices with a slight amount of changes over short periods, however, oil prices are expected to become higher in the future due to the reduction in the oil reservoir. Moreover, the fuel production process including extraction of the fuel itself from its raw sources and the manufacturing process is an important element that affects fuel final price.

4.3.5. Operational Efficiency

Operational efficiency refers to power output, mechanical performance, engine compatibility, and fuel storage space onboard. It has been mentioned that around 95% of container ships use a diesel engine. Using fuel that can already work with these engines has a major advantage over other fuels, Biodiesel, for instance, can be used directly without any technical modifications. Fuels that can work on multiple engines or require a slight amount of modification can also have the prospect to substitute current oil fuels. However, some alternatives require more space to store onboard which can reduce the containers space on the ships thus, increasing the number of trips between routes and increasing emissions and operational cost. The Same principle applies when analyzing the power output of a given fuel, Bioethanol has a lower power density than conventional petrol and thus increases the amount of fuel consumed. In addition, preventing mechanical issues and getting the best engine performance is also an important element when deciding the type of fuel, since it is connected directly to mechanical and operational costs. Furthermore, port Infrastructure and facilities for alternative fuels play a major role as well, factors such as fuel storage spaces in ports and refilling equipment must be available, convenient and safe to practice

5. Analysis

In this chapter, the results and findings from the literature review are discussed based on the evaluation criteria and examined in order to establish the answer for the research question mentioned in section 1.4.

A SWOT analysis will be executed to identify the key advantages and issues and to evaluate the differences between the selected fuels. The second part of the analysis will include a scenario analysis process to measure the feasibility of the findings.

5.1. SWOT Analysis

In this part, an analysis will be performed of the strengths & weaknesses and opportunities & threats for the liquefied natural gas, Biodiesel and Bio ethanol in order to understand the values and barriers when applying these fuels in the sea shipping industry.

5.1.1. SWOT Analysis for Liquefied Natural Gas

Liquefied Natural Gas	
Strengths	**Weaknesses**
• Low air pollution levels • Offer the option of dual-fuel engines. • Give the Option of switching current engine to use LNG. • Low mechanical failure rate. • Good engine performance. • Safe to handle.	• Need technical modification for the current engines. • Low power density. • Need for bigger fuel tanks. • High fuel consumption. • Reduce cargo space.
Opportunities	**Threats**
• Comply with IMO regulations. • prices are lower than oil-based fuels • Availability is high. • Low taxes rates.	• Methane slip. • LNG Port infrastructure is still developing.

Figure 4, SWOT Analysis for liquefied natural gas

Strengths

When identifying the Strengths of using LNG as a shipping fuel, it is obvious that the most important advantage of LNG represents in its environmental outcome. LNG environmental performance is considerably improved compared to oil-based fuels, the number of emissions saved during combustion process recognizes LNG as one of the best alternative fuels. Numerous studies reported a reduction of 25% in total CO2 emissions. NOx reduction reached 85% and Sox and pm were 90% without any kind of exhaust gas after-treatment technology. These numbers are lower than most petroleum fuels used currently in the sea shipping industry. In addition, low air pollution can reduce global greenhouse gas emissions, thus, improve the local air quality, public health, and reducing the number of premature deaths occurs because of the high air pollutants level. Employ LNG as a shipping fuel may lead as well to increase awareness e for the public regarding the importance of using alternative sources of energy.

As for ship owners, engine performance and effectiveness are essential to ensure the continuity of their business growth. The engines options for LNG are classified mainly under two categories, the dual fuel engines and the spark ignited gas-only engines. The gas-only engines use natural gas a single fuel in the combustion chamber. While the dual fuel engines can use another type of fuel alongside natural gas. This option offers a flexible solution for ship owners and provides them with extra choices. For instance, when LNG availability is uncertain at some ports, engines can fully run with traditional oil fuel without any need for LNG in this combustion process. Moreover, dual fuel engine gives the option of using LNG only in specific areas such as emission control areas and then switch back to oil fuels. This would give the possibility of having smaller LNG storage tanks thus, having greater space for cargo. Furthermore, the third option for ship owners is to switch their current engines to burn LNG. This practice has been used before in the shipping industry and offers a cheaper solution for some ship owners.

In addition to engines variety, LNG engines performance is another merit, modern dual fuel engines can offer an admirable performance and can lower the total amount of operational costs. The maintenance costs for LNG vessels are believed to be low, this is highly important to ship owners since vessels considered to be a long term investment.

Like most types of fuel, LNG requires a specific safe arrangement on board. LNG is usually stored at atmospheric pressure, so the risk of explosion is removed in case of accidents. Moreover, the advanced technology system used currently in LNG powered vessels reduce the insecurity aspects and concerns associated with using LNG as a fuel.

Weaknesses

From an environmental perspective, methane slip is the major concern when using liquefied natural gas. Marine engine types release different amounts of methane during combustion but the highest level occur when using dual-fuel engines. Methane slip occurs onboard due to the unburnt gas in the combustion chamber, which escapes from the chamber throughout the exhaust system to the atmosphere. The usual approach to prevent methane slip is to use engine control strategy and after treatment equipment. This method is not yet tested enough to prove its ability to reduce the quantity of methane escaped to the required level, however, some studies reported that applying after treatment technologies can help reduce around 90% of methane slip.

It has mentioned earlier in the literature that building a gas powered vessel costs approximately 12% more than the diesel-powered vessel. The usual assumption is cost is fully paid in cash, while in the real world, financing a new vessel can be through several options, whether it is a long-term loan with interest or private investment. The cost is one of the main aspects that decide the building of a new ship. Investors may show some concerns when realizing the higher cost of LNG powered ship, while they may have more trust in oil-based fuel powered vessel due to its lower costs and its history of good performance and reliability.

When comparing the power density of LNG fuel to oil-based fuels, it is obvious that LNG has less power output. This would result in several consequences. First, using larger fuel tanks on board to cover the need for fuel for the scheduled trips, second, this also may result in the higher need of refilling frequency of LNG powered ships, this could have an impact on the shipping routes and schedules. Finally, the larger tanks mean taking up room from cargo space, from an investors point of view, this will considerably lower the revenues and lower the economies of scale since vessels usually classified under the category of “long-term investment”.

Opportunities

The opportunities for LNG to be used together with oil-based fuels or even completely substitute oil is reflected in the following aspects

First, LNG believed to be an excellent option to be used in emission control areas and in ports. LNG can completely fulfil tier III requirement established h in MARPOL Annex Vi. LNG environmental outcome in emission control areas doesn’t require the use of after-treatment technology within these areas. Further, comply with IMO regulations is highly important since the low sulphur standards internationally will begin in 2020.

Second, the increasing availability of natural gas worldwide gives the option of using LNG fuel a higher opportunity. As the international economy increases, the concerns about oil security increase as well. Oil production is going to decline at some point, and LNG considered one of the best alternatives to substitute oil in the future. There is a large reserve of natural gas at this point, and its availability is still growing rapidly.

Finally, oil prices are extremely important to ship owners as they stand for 60% of the total operating costs. This element is very important when analyzing alternative types of fuels. LNG has several advantages in term of environmental performance and operational efficiency, but when it comes to LNG prices, it is clear that LNG cost is related to oil prices and affected by it. In most cases, LNG prices were cheaper or sometimes have the same prices, but when analyzing oil production expectation and its decreasing availability, oil prices could be much higher in the future. On the other hand, the growing availability of natural gas gives more stability to natural gas prices than oil products. LNG prices could be an interesting opportunity for ship owners to switch from oil-based fuels to LNG in order to save more cost. These cost savings could be enhanced as well from the reduced taxes for emissions and from ports incentives received for ship operation with clean fuels.

Threats

LNG port infrastructure is currently poor when compared to oil-based fuels. The new emissions standards and the increasing demand for LNG boosted the development of LNG port infrastructure but it still needs more time to be competitive to oil-based fuels. The current EU policy requires at least one LNG bunkering port in each member state and it has a plan to establish LNG facilities in 144 ports by 2025. Currently, when considering using LNG on a wider scale, this number of ports doesn't have the required ability to cover the high demand expected for all LNG powered vessels. This would impact the shipping routes significantly and have an effect on ship owners when they consider switching to LNG or investing in LNG powered vessels.

As the case in oil production, some countries dominate the production of natural gas. Natural gas is usually imported from near countries due to its complex transportation processes. LNG mainly moved through pipeline infrastructure from gas extraction points to liquefaction facilities and then to storage facilities. The nearby countries use pipelines to bring LNG and sea shipping tankers are used when the distance is long. And when compared to oil extraction and transportation infrastructure, LNG transportation still need more time to develop in order to reach more countries at faster rates. This may have an impact on LNG availability at some ports globally, not the availability as a natural resource but its existence at ports as a shipping fuel.

5.1.2. SWOT Analysis for Biodiesel

Biodiesel	
Strengths	**Weaknesses**
• Ability to work on the current diesel engine without technical modifications. • Low air pollution levels. • Can be mixed with petroleum diesel.	• Low power output • Need for bigger fuel tanks. • Performance depends on biomass used. • Performance depends on mix ratio with conventional diesel
Opportunities	**Threats**
• Comply with IMO regulations. • Safe to handle	• Availability is low. • Biodiesel prices are high. • The need large agriculture land to cover the high demand for shipping fuel. • Compete with food production. • Use high amount of fresh water. • GHG are high when of production increased.

Figure 5, SWOT Analysis for biodiesel

Strengths

One of the stronger characteristics of biodiesel is its ability to work directly on traditional diesel engines without the need for any technical adjustment. It has been used before on a few large vessels as a part of an experiment and delivered promising results. It was mention earlier in the literature that around 95% of vessels use diesel engines. This aspect is highly appreciated since it would result in less cost when deciding to switch to another type of fuels. Furthermore, biodiesel has a low mechanic failure rate which is also considered an important aspect for ship owners.

Biodiesel is considered a flexible choice for ship owners and for fuel suppliers since it can be mixed under any ratio. This aspect eliminates the need of having special facilities for bunkering at ports and also eliminates having separate fuel tanks on board.

Biodiesel whether it was pure or part of a mix provided better environmental performance than oil-based fuels. 20% biodiesel in the blend provides 78% less carbon when using after treatment technologies. The particulate matter is less by 15 % and sulphur is 10 % less. The sulphur content of pure biodiesel is nearly zero and NOx emission is totally removed when using a catalytic converter. Generally, the amount of pollution depends on the biodiesel percentage in the fuel blend. However, most common biodiesel ratios provided better environmental performance than oil-based fuels.

Weaknesses

The power density of Biodiesel is lower than oil-based fuels and it depends on two aspects, first, it depends on the feedstock used in production and also it depends on the percentage used in the fuel blend, a higher percentage will result in less power. B20 generally produces less power which can lead to an increase in fuel consumption by approximately 10%. Moreover, the high fuel consumption will create the need for having bigger fuel tanks to store the amount of fuel needed. Additionally, a larger storage tank will affect the space required for cargo and it will result in having a higher number of trips between ports.

The mechanical performance for biodiesel also depends on the biomass used to derive the fuel, which is another concerns for ship owners as they are looking for higher and stable technical performance.

These aspects all together make biodiesel critical choice for ship owners since their objective is to reduce their costs and increase revenues. Other aspects related to the prior weaknesses, is related to environmental performance, the increase in the fuel consumption due to the low power output will reverse the emission saved when using biodiesel over a long time period.

Opportunities

Compliance with environmental laws is an important aspect with evaluating an alternative fuel. Pure Biodiesel is derived from natural biomass and the emissions produced when burning the fuel comply with the current environmental limits.

When using biodiesel as a shipping fuel, the emissions limits are accepted and it fulfills most environmental requirements, especially when using exhaust after-treatment technologies.

Since Biodiesel is derived from natural materials, it is considered safe and it is not toxic to the environment and on the people. In case of accidents, a spill will not affect the environment or nature and also will not cause an explosion.

Threats

If we consider today's technology of producing biofuels in general, it will show a deficiency in supplying the amount needed for shipping and it will not be able to fill the gap created by the future lack of oil. Securing the demand needed will require huge land areas for producing the biomass required to derive the fuel.

The first and second generation of biodiesel is produced from edible feedstock like soybean and non-edible feedstock such as waste oil. Increasing the demand for Biodiesel will eventually create competition for resources, thus causing food crises in some countries in order to secure the biomass needed. For example, in 2015, the EU used 20% of the world's vegetable oil traded in biodiesel production. Another threat to be considered is the high amount of fresh water used in biodiesel production. Freshwater resources already started to decline and increased water consumption will lead to increase the pressure on water resources. The land use effects when producing a high amount of biodiesel will increase the rate of deforestation, affect the ecosystem and it produces high greenhouse gases emissions.

Biodiesel prices depend on the feedstock used in production, the production technology used and the amount of the biofuel used in the blend. Currently, pure biodiesel prices are higher than traditional diesel, B20 mixture ratio cost is little higher than petroleum diesel, and when increasing the amount of biodiesel in the blend the price will increase. This aspect put additional pressure on ship owners as they are aiming to reduce costs, especially when knowing that fuel prices represent 60% of the total operation cost.

5.1.3. SWOT Analysis for BioEthanol

<table>
<tr><th colspan="2">Bioethanol</th></tr>
<tr><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>Low air pollution levels.
Low mechanical failure rate.
Good engine performance.
Can be mixed with petroleum gasoline.</td><td>Need technical modification for the current engines.
Need for bigger fuel tanks.
High fuel consumption.
Performance depends on mix ratio.
Low power output.
High evaporative emissions.</td></tr>
<tr><th>Opportunities</th><th>Threats</th></tr>
<tr><td>Comply with IMO regulations.
Prices are low.
Have production support from tax systems (Mainly in developed countries)
Safe to handle</td><td>Availability is low.
The need large agriculture land to cover the high demand for shipping fuel.
Compete with food production.
Uses high amount of fresh water.
GHG are high when of production increased.</td></tr>
</table>

Figure 6, SWOT Analysis for bioethanol

Strengths

Similarly to Biodiesel, the environmental performance of Bioethanol is better than oil-based fuels. The percentage rate in the fuel blend affects emissions produced when burning bioethanol. E15 can save approximately 5% of NOx emission and about 40% of PM. Bioethanol as pure fuel is sulphur free, thus, SOx emission also depends on the percentage ratio but it is lesser than oil-based fuels at any percentage. The carbon emitted when burning bioethanol doesn't add to the existing carbon levels since it was already captured by the crops used to produce the fuel.

The high engine performance is another strength added when using bioethanol. Bioethanol provided reliable engine performance and less mechanical issues. The high level of octane in the fuel reduces the pressure on the mechanical parts which consequently results in less cost related to engines failure.

As well the case for biodiesel, bioethanol can be mixed with oil-based fuel at any ratio, the most common percentage ratio is E85, where 85 refer to the percentage of bioethanol in the blend. Higher ethanol in the blend means better environmental performance and lesser mechanical issues. Moreover, this aspect also eliminates the need of having additional storage tanks on boards to separate ethanol and oil fuels.

Weaknesses

Ship Engines can't use bioethanol directly as the case in other biofuels. Ship engines would require technical modification to be able to burn blended fuel. Since most ships operate on diesel, this element reduces the prospect of using bioethanol in sea shipping industry when compared to other types of fuel.

Another weak point related to using bioethanol is the low power density of the fuel. Compared to petroleum gasoline, one liter of bioethanol gives two-thirds of the power generated when using conventional petrol. This aspect would result in several other consequences that reduce the opportunity of using bioethanol in sea shipping industry due to the heavy weight of the cargo and the ship itself. The low power of bioethanol will increase fuel consumption and additionally will result in a higher need for having larger storage tanks. The larger tanks will affect the space designed for cargo and thus reducing the cargo held on board.

Opportunities

It was mentioned earlier that compliance with environmental laws one of the key elements when analyzing a fuel. Similar to most biofuels, bioethanol environmental performance gives it the ability to fulfill the environmental requirements and regulation. Since it is also derived from a natural material, bioethanol doesn't contribute to increase the level of CO_2 and have SO_x, NO_x, and pm emissions when it is burned inside combustion chambers wither it was pure fuel or mixed with oil-based fuels.

The prices for bioethanol are cheaper than oil-based fuels by a considerable margin. The lower price for bioethanol is achieved mainly through the production support bioethanol producers get from governments from the tax system. This aspect is essential for ship owners as they are looking for alternative fuel that offers good mechanical performance and cost less than current fuel used.

Threats

The production technology and capacity for bioethanol are higher than most biofuels due to its large use by automotive market. Still, the number of liters expected to replace oil-based fuels is much less than required. Bioethanol is expected to save 10 Billion liters of gasoline by 2020. This number of liters doesn't supply all the demand required by the sea shipping industry.

The low availability of the fuel caused by the lack of the agricultural land needed to supply the biomass required to derive the fuel. Bioethanol is also derived from edible and non-edible natural materials. Increased production for bioethanol will affect the food market by creating higher completion for food resources as well as draining freshwater reserves. Moreover, increased production for bioethanol may also lead to decrease the governmental support for production leading to higher prices compared to other alternatives.

The current production technologies used to produce bioethanol uses environmental methods in order to reduce the impact of the fuel. But when considering the expected high demand for alternative fuels in the future, increased production may additionally lead to the use of other non-environmental methods and technologies that will contribute to air pollution.

5.2. Scenario Analysis

In this section, a scenario analysis will take place. The scenario building process will be executed followed with the scenarios for the three alternative fuels, LNG, Biodiesel and bioethanol.

After analyzing different drivers and barriers of applying LNG and both biofuels in the sea shipping industry, a scenario is developed in order to increase the understanding of how these fuels would possibly be used and how what it can provide to sea shipping industry.

Scenario Building

These scenarios are developed based on the previous results obtained from the SWOT analysis combined with the findings from the literature in order to demonstrate future potential events expected when trying to improve the environmental performance by using the selected alternative fuels in the maritime shipping industry.

The purpose of these scenarios is examining the possibilities of exporting and applying stricter regulation regarding sulphur emissions in other regions that can benefit from forcing these rules. Further, applying the alternative fuels on ships to evaluate its ability to meet the new requirements and to measure the capability of offering the required technical performance.

China might be a great destination for stricter environmental laws, China is the largest creator of sulphur emission in the world and it is also is accountable for 25% of the global CO2 emissions. Stricter regulations may benefit preventing the environmental negative impacts caused by the sea shipping industry. Preventing the increase in earth temperature, sea levels, and air pollutant is one of the most important issues.

More tight regulations will drive the efforts and oblige ship owners to switch to cleaner alternatives that comply with the new emission standards in order to improve their environmental footprint and bring higher economic benefits at the same time through lowering operational costs and from the tax reduction. The amount of emissions reduced by each fuel in the region, are calculated based on each ship emission reduction multiplied with the number of ships converted to the new fuel and then derived from the total emission levels in the region.

5.2.1. Scenario -A- Liquefied Natural Gas

According to literature, liquefied natural gas has the ability to improve environmental performance and offer a fine engine performance at the same time.

The Chinese fleet accounts for 5,512 ships by the end of 2018. Switching to LNG will additionally enlarge the demand for LNG and for ships powered by natural gas. The availability of this fuel can cover the increased demand from the Chinese fleet. Additionally, the increased demand for LNG will boost LNG production and affect natural gas prices. Several factors affect the gas prices such as the level of economic development and the availability and prices of the oil-based fuel as well as LNG rate of supply and demand. Typically, high gas prices tend to encourage production while on the other hand, the increased in the supply help with pushing prices down.

This additional demand for LNG might drive the prices down to be more competitive compared to oil prices. This decrease in price alongside with tax incentives will possibly encourage for more investments in LNG powered vessels and also will drive additional investments for LNG port infrastructure by governments. Furthermore, higher demand for LNG will increase the investments for infrastructure needed for extracting and transporting natural gas such as constructing LNG pipelines and tankers and this will help with covering the high need for LNG in the region that fall under the new laws.

This would result in increasing the trade volume between China and areas such as the EU since both regions apply similar laws which may push the economic boost in China, increase the amount of cargo moved between these two regions and will add to the exporting and importing frequency.

In the case of increasing gas prices due to higher demand, the LNG prices may still be the same or possibly become more expensive than current oil fuel used. In this case, the large vessels would go toward using low sulphur fuel or installing dual fuel engines where they can use LNG only when they have to. But most likely, large vessels will stick with the same engines and use low sulphur fuel since it can comply with laws and it will not bring more revenues if they switched to LNG. The small-sized vessels and large vessels that operate regionally will be the main consumer for LNG. The port infrastructure development toward LNG ships would stay high since governments will keep encouraging ship owners to switch to cleaner fuels. However, the investment rate for LNG powered ships will diminish if the prices keep going up and be more than oil prices, and in the long term, this may affect the economic development of the region.

Furthermore, the environmental consequences of replacing conventional oil fuels with LNG will definitely result in cutting a considerable margin of air pollutants.

It was mentioned earlier that China has the highest number of ships worldwide, approximately 5512 ships. Moreover, Chinese ports are the largest sulphur producer in the entire world. Chinese ports produced 50% of the sulphur in the whole East Asia region by the end of 2017.

In the case of converting 25 % of the Chinese fleet to burn LNG instead of oil based fuels, and when taking into account that LNG has 90% less sulphur content than oil (except low sulphur fuel oil), the sulphur emissions saves could be between 10.5 to 12.5 %. And the PM reduction will reach similar numbers. The NOx will be reduced but its reduction will depend also on the speed of the ships, and the distance travelled. CO2 reduction is around 7% and it may not the reach the required level. LNG provide 20-25% CO2 reduction in general but this percentage is not enough to tackle climate issues especially in China, since it is responsible for 25% of the global CO2 levels.

The results of switching to LNG will enhance air &life quality, lowering overall emissions (GHG, NOx. Sox, and PM), resulting with downsizing the health expenses and cutting back the number of premature deaths caused by oil based fuels.

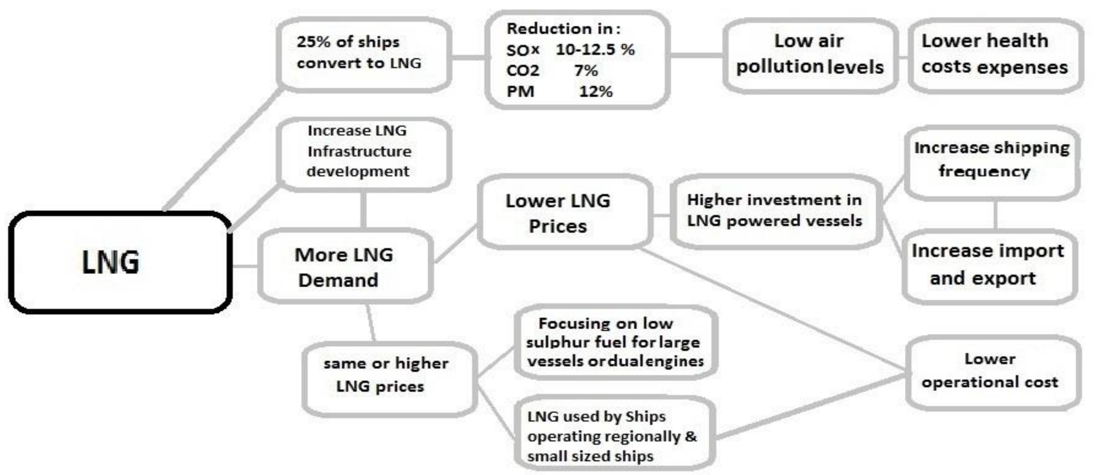

Figure 7, Scenario analysis story map for LNG

5.2.2. Scenario -B- Biodiesel

Biodiesel may be more appealing to ship owners when knowing that biodiesel can be blended easily with petroleum diesel and it works fine on the current engines.

The high cost of switching the engine type is eliminated in case of biodiesel. This is a high advantage over other types of fuel. Ship owners may prefer the possibilities for switching to biodiesel based on technical specifications and environmental performance.

The technical downside represents in its power output variation, engine power generated through burning biodiesel depends heavily on the type of biomass used to produce the fuel. This aspect may lead ship owners to prefer an importing destination over others.

Regarding the environmental aspect, the consequences of applying biodiesel depend strongly on the percentage rate. Moreover, considering that more ships will use biodiesel due to its high flexibility, if 30 % of the Chinese ships use B20, which is the most common percentage blend, the sulphur emissions in the region is approximately decreased by 2.5-3 %, CO_2 3.5%, PM is reduced by 4.5%.NO_x reduction will depend on wither the ships are using after exhaust treatment technologies or not.

Moreover, the amount of emissions saved by each ship when using B20 may be not enough to fulfill the environmental requirement. Increasing the biodiesel percentage is a solution, however, the price of B20 is close to petroleum diesel and increasing the amount of biodiesel will result in very high prices for ship owners which most likely preventing them from using it.

Nevertheless, these emissions saved numbers while using B20 is when considering that biodiesel is able to cover the demand needed by ships. The major problem when considering biodiesel is its availability. It is expected that biodiesel production will account for 20 billion liters in 2020. The main use of biodiesel is in the automotive market. But even if the whole production is dedicated to sea shipping, it will still be not enough to cover the high need for fuel in marine shipping. Increase the biodiesel production may lead to non-environmental consequences in term of GHG emission caused by deforestation and from production plants. Further, increased production will affect food markets and prices as well as draining the freshwater resources.

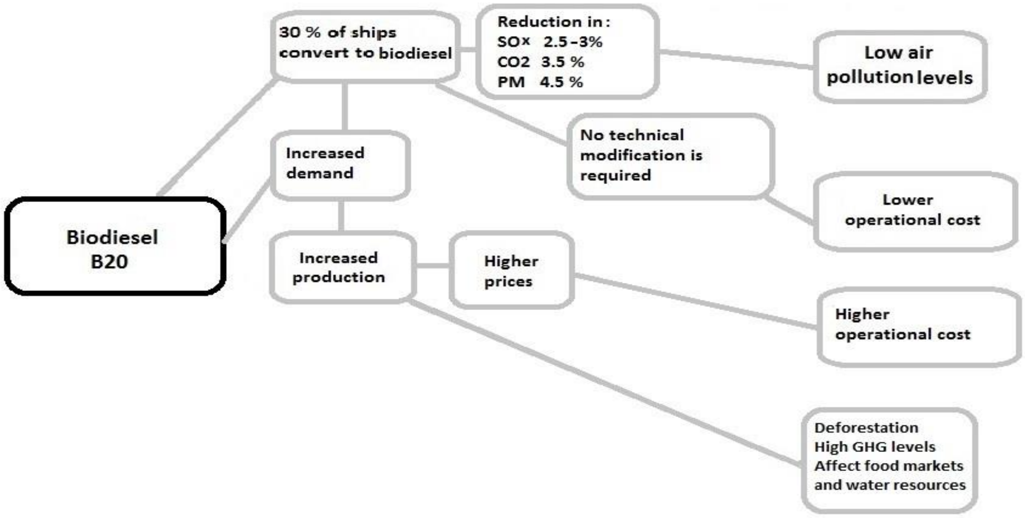

Figure 8, Scenario analysis story map for biodiesel

5.2.3. Scenario -C- Bioethanol

As for the economic part, several aspects decide the economic feasibility of bioethanol. First, Bioethanol is cheaper than petroleum fuels and biodiesel, and also has production cost support from the governments. This makes it more appealing to ship owners in term of fuel prices.

However, this fuel doesn't work on the current engines used in sea shipping unless it is modified. This technical modification for current engines may result in high costs for ship owners and it will affect the total operation cost.

Small ships and all ships that sail regionally may be the sector who would switch to bioethanol more than other sectors. They can benefit from low prices of bioethanol and the cost resulted from technical modification could be brought back over the time since ships are considered to be a long-term investment. In addition, the tax incentives from using cleaner fuel and lowering emission will contribute to the cost savings. Larger ships that operate internationally most likely will prefer other types who doesn't affect the technical characteristics of the ships and they may use low sulphur fuel oil. Older ships that operate internationally may tend to prefer dual gas engines to meet the environmental requirements and also as an upgrade to their engines and ship's technical state. Another reason to eliminate the choice of bioethanol is its low power output. This will result in higher consumption and the prices saved from the cost savings from low prices of bioethanol may be reversed due to the high consumption. The international ships may rather stay with conventional fuel due to the limited availability of bioethanol. Bioethanol may be available in some ports but the production number doesn't seem to be enough to cover international demand for ship fuels.

The environmental impacts of bioethanol also depend on the percentage rate with petroleum fuel. Bioethanol can be blended at any rate with gasoline fuel, but when blending with diesel, an additive package should be added to the mix in order to maintain blend stability. Most common blend rate for Ediesel is 85% diesel and 15% ethanol. Calculating the emission saved is a difficult process due to the complexity of the blend rates. However, considering that 25% of the Chinese fleet would use Ediesel, E15, the emissions saved would approximately result in CO2 reduction by 3%, 1-2 % NOx, 3-4% sulphur and 4-% PM. These numbers are most likely will not meet stricter environmental requirements. Similar to biodiesel, the technology currently exists to produce bioethanol still not enough to cover the high demand expected from ships. Increased production for bioethanol will also create other environmental negative consequences that would increase the emission levels and affect food markets and water resources.

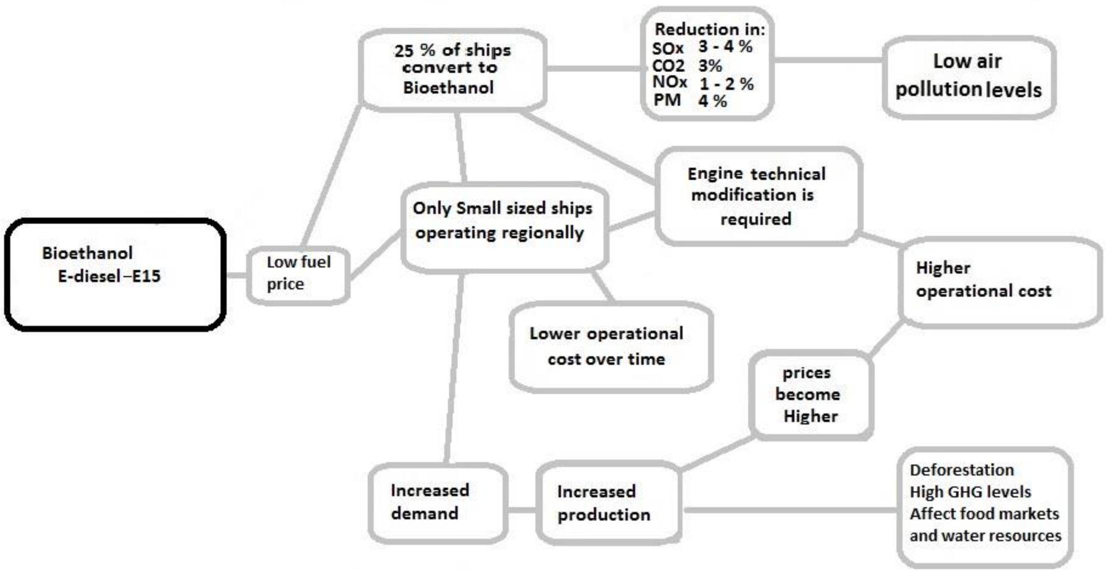

Figure 9, Scenario analysis story map for bioethanol

6. Discussion

When observing the results from the analysis sections, it clearly shows that liquefied natural gas is the best available option among the fuels selected. LNG performance delivers results close to the requirement needed when looking at the comparisons with oil-based fuels and Biofuels.

One of the best benefits of oil is presented in its availability and the easiness of its extraction and refinement. Oil showed over many decades of production its availability and existence, the infrastructure needed for refining and extraction is already in place and in most times, oil production had the ability to meet the required demand. Currently, the world is consuming oil far faster than it is finding it and the world is working on finding another source to generate energy.

When considering switching to another type of fuel, the alternative must prove and show the same ability to supply the huge demand expected in the future, especially when oil production starts to decline and its prices begin to increase.

Biofuels are expected to save approximately 30 billion liters of oil fuels by 2020. These numbers are extremely lower than the global demand for fuel in the shipping industry. Biofuel can be considered to be used in a mix with conventional fuel. Using biodiesel and bioethanol in the mixture has many benefits but it cannot replace conventional oil fuel 100%. On the other hand, LNG availability is growing from gas reserves. It has been used for the last two decades and proved its value as a fuel. In the last two decades, LNG demand increased considerably in vessel market and this demand is expected to keep increasing for the next 10 years. LNG has more potential to become the main fuel in the future since it has the potential to be able to supply the desired amount of demand in the sea shipping industry.

Regarding environmental aspects, oil fuel products such as HFO and Diesel contain a high quantity of different pollutants, high GHG levels, as well as high NOx, SOx, and PM. Biodiesel mixture B20 can eliminate approximately 20% of carbon compared to traditional diesel and could be around 78% when using engine mechanical systems. The amount of PM decreased by 20 % and SOx levels are lowered based on the mix ratio but when burning pure biodiesel it will produce zero SOx emissions. Bioethanol has also more benefits to the environment when burned during the combustion. As the case for biodiesel, the amount of air pollution saved depends on the ethanol percentage in the blend. For instance, E15 can save approximately 5% of NOx emission and about 40% of PM. In both biofuels, (Diesel and Ethanol) the CO2 emission released when the fuel is burned is originally captured from the atmosphere so it doesn't add to the total CO2 emission, but when considering increasing the demand for biofuels, an increased production process is expected to use non-environmental approaches that may contribute to the air pollution levels alongside the impacts expected on food and freshwater resources.

Liquefied natural gas gave better results than oil in terms of environmental performance. Using LNG as a fuel for vessels proved its advantages and confirmed its ability to reduce air pollution. In many investigations, LNG confirmed its ability to decrease the amount CO_2, NO_x, SO_x, and PM and its performance fulfils the Tier III requirement established in MARPOL Annex VI. LNG reduces CO_2 emissions by 25% and NO_x emissions by approximately 85%. Low sulphur level in natural gas helps to diminish 90% of SO_x emission and PM. Methane slip is the main disadvantage but several studies verified that using catalyst systems can lower the methane slip level by 90%.

Crude oil prices are extremely important to ship owners as fuel prices stand for 60% of the total operating costs. This element is very important when analyzing alternative types of fuels. Alternative fuels have several advantages in term of environmental performance and operational efficiency, but when it comes to its prices and production cost some fuels have lower costs than others. Biofuel prices depend on several aspects, the feedstock used in production, the production technology used and the amount of the biofuel used in the blend. Currently, pure biodiesel prices are higher than traditional diesel, B20 mixture ratio cost is little higher than petroleum diesel, and when increasing the amount of biodiesel in the blend the price will increase. On the other hand, the bioethanol prices are generally less than oil-based petrol due to the support given by governments especially in the EU. Nevertheless, increased production of bioethanol and biodiesel may lead to higher costs in term of production as well as affecting the prices of resources used to produce biofuels such as food prices. In contrast, the LNG price rate is more stable and predictable than biofuels. Oil prices have an influence on LNG prices but usually LNG is cheaper, for instance, lower price of LNG and the reduced tax for emissions helped several ship owners in Norway to save a significant amount in the overall operational cost. Moreover, several ports in Europe and around the world offer a tariff discount for vessels uses LNG as fuel. In addition, considering the expected boost for oil prices in the future, LNG is a more feasible option in terms of net energy value.

The internal combustion engine has been used for decades and it proved its effectiveness in turning fuel burned into usable energy and moving large objects and after all these years the awareness and experience level about combustion engine increased significantly and helped to enhance its performance and lower its mechanical issues. The fuel compatibility with the current combustion engines in the shipping industry is an important factor when analyzing alternative fuels.

Biodiesel can be used directly in standard diesel engines and it will not need any technical modification. It has been used before on a few large vessels as a part of an experiment. Mechanical performance for biodiesel varies depending on several aspects, nature of the feedstock used to derive the fuel, and mix ratio, so it is complicated to conclude the mechanical performance unless the previous aspect is specifically determined. The power density of Biodiesel also depends on the feedstock used in production and ratio used in the blend, B20 generally produce less power which can lead to increase fuel consumption by approximately 10%. This would require more storage room on board affecting space used for cargo.

On the contrary, Ethanol requires modifications to the current engines used onboard to give them the ability to burn the mixture of both fuels. Bioethanol has been observed mainly in the automobile market, nevertheless, for the sea shipping industry, not so many literatures evaluated its mechanical performance. However, the chemical components of bioethanol help to reduce the load on the engine parts and lowering the risk of mechanical issues. The power density of bioethanol is less than biodiesel and fossil fuel, thus, leading to higher fuel consumption and bigger tank volumes onboard affecting cargo space.

As regards to LNG, it has different handling characteristics. LNG has several Engine concepts, the dual fuel engines that have the ability to burn LNG and oil (one fuel at a time), and the gas-only engines. The advantage of the dual fuel engines represents in its ability to burn both LNG and conventional fuel which give more flexibility to ship owners. Switching current conventional engines to burn LNG is also another option to ship owners instead of installing new engines, this transformation process is usually used on older ships.

The purity of LNG fuel helps with lowering mechanical issues and enhancing engine performance, thus, reducing operational costs and technical states. The downside of using LNG as a fuel is the lack of LNG infrastructure around the world. In the EU, LNG structure is more extended in other parts of the world. The space required for fuel storage is 2.5-time larger than conventional oil which also affects cargo volume for the ship onboard.

Fuel	Oil-based fuels	LNG	Biodiesel	Bioethanol
Source	*Underground natural reserves*	*Underground natural reserves*	*Edible & non edible crops (peanut oils /waste)*	*Edible & non edible crops (sugar canes/wood)*
GHG emission	*High*	*20-25 % lower than Oil-based fuels*	*Low / Depends on the mix ratio*	*Low / Depends on the mix ratio*
NOx	*High*	*85% lower than Oil-based fuels*	*Low / Depends on the mix ratio*	*Low / Depends on the mix ratio*
Sox	*High / except Low sulphur fuel*	*90% lower than Oil-based fuels*	*None / Depends on the mix ratio*	*None / Depends on the mix ratio*
PM	*High*	*90% lower than Oil-based fuels*	*Low / Depends on the mix ratio*	*Low / Depends on the mix ratio*
Price	*Stable with increasing trend low*	*Similar or cheaper than different types of Oil-based fuels*	*High*	*High*
Availability	*High with decreasing trend*	*High*	*Low*	*Low*
Power output	*High*	*Low*	*Low*	*Low*
Engine reliability	*High*	*High*	*High*	*High*
Impact on cargo space	*No impact*	*High impact/ reducing cargo space*	*High impact/ reducing cargo space*	*High impact/ reducing cargo space*

Figure 10, Alternative fuels comparison.

7. Conclusion

The purpose of this research was to explore the alternative options for fuels in the maritime industry for achieving improved environmental impacts in addition to obtaining better operational and economic performance. This research focused on answering the two main questions asked from the maritime industry and from the public. Which fuel give the best environmental performance and what fuel can replace the absent of oil-based fuels in term of operational and economic performance.

The Oil-based fuels and internal combustion engines have been used in decades for power generation in sea shipping industry and in other sectors. Its performance and reliability is high and the experience level with these types of engines alongside cheap prices makes oil the best option from an economic point of view. Nevertheless, but when realizing that oil is a limited source, the need increases for exploring an alternative to substitute the huge demand for oil products.

This research shows the values and barriers when applying different fuels within the shipping industry and increase the understanding of the main aspects related to each fuel, environmental impacts, operational performance as well as the fuel prices. Oil fuels are used for comparison and the results for each aspect of alternative fuels are based on its performance against oil fuels.

Biofuels (Biodiesel & Bioethanol), both demonstrated their ability to reduce air pollution from marine engines, meeting the environmental regulation, and it gave a fine engine performance, but the high prices and high production costs compared to oil make these options less feasible for sea shipping. The production volume for biofuels is the major barrier when considering using it in the sea shipping industry. Low power density and high fuel consumption also decrease the possibility to apply biofuels on a wider scale. Biofuels may become more viable in automotive transportation but under the current technology available for production, it is hard to consider in deep sea shipping.

When combining all evaluating aspects, liquefied natural gas compared to the other two types has better environmental performance, higher technical efficiency and it can bring great economic outcome. LNG has been labeled by several studies as “the best available choice” to replace oil-based fuels. LNG has been used before in transportation and its environmental performance resulted in a massive cut in the total emissions compared to oil. The methane slip is the main disadvantages of LNG but when applying after treatment methods the methane slip reduced 90%. The availability of LNG as a natural resources place it before other options. Besides the environmental performance, the operational energy efficiency gives LNG an advantage since the operational efficiency is a key element in long term investments such as vessels. LNG price compared to Biofuels and also to oil-based fuels is more competitive in the current economic situation. This gives LNG another merit since fuel prices account for approximately 60% of the total operating costs. The LNG infrastructure is still developing on a global scale but many countries started investing in the port infrastructure in order to comply with the strict environmental laws and to improve the environmental consequences results from oil fuels.

In general, all alternative fuels have their advantages and disadvantages, but most alternatives have better environmental performance than oil-based fuels. The future of alternative fuel is still not clear 100 %. But with more advanced technologies in fuel productions and in power generation, an alternative fuel or several alternatives will be more likely to replace the oil-based fuels in the future.

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