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The Adoption of Liquefied Natural Gas as a Fuel in Greek Passenger Shipping: Possibilities and Limitations

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Abstract

Greece has a unique insular character with almost 6000 islands surrounding its mainland. This trait is the main reason for Greece developing one of the leading passenger shipping industries in Europe. With increasing exhaust emissions brought about by this excessive shipping activity in its waters, Greece having to deal with air pollution, hazardous to populations in its coastal areas and to the country's environment. Taking the above into consideration alongside the International and European regulations on ship air emissions, it is imperative that a combined effort is made by all involved to reduce these ship air emission. For this to succeed, all alternative options should be looked into. This research examines the limitations and possibilities of the adoption of Liquefied Natural Gas (LNG) as an alternative ship fuel in order to reduce air emissions associated with the Greek ferries. Each aspect of the research indicates that the adoption of LNG is feasible provided the existence of bunkering infrastructure and governmental or EU financing for overcoming the large capital costs. Furthermore, the volatility of the price of LNG, which was found to be higher than that of other fuels, could be a drawback for the change of ship fuel from oil to LNG in small ferry companies mainly based in small ports.

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To my parents Michael and Angela.
For all the opportunities they have given me,
their endless love and support.

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1 Introduction

1.1 Background

The world is striving to confront climate change and to mitigate environmental pollution. Countries and institutions are taking actions by forming appropriate regulations to reduce emissions from industries that can have an impact on the environment. The maritime industry is one of the industries subject to this kind of regulations, which aim to control harmful to the environment exhaust emissions created by shipping activity.

In 1948 the United Nations (UN) established in Geneva an agency called International Maritime Organization (IMO). Purpose of this agency is to regulate and monitor the maritime industry (IMO, 2018a). In 1973 IMO established an international regulatory framework, known as MARPOL, for controlling the environmental pollution caused by the shipping industry. MARPOL framework is segmented in several annexes each of them dealing with different sources of pollution, for example oil pollution, garbage pollution, ship sewage pollution etc. (IMOb, 2018b). Through time, new annexes were introduced to the MARPOL framework. In 2005, the sixth annex (*Annex VI*) was incorporated in the overall framework and its purpose is to prevent air pollution from ships (IMO, 2018c). More specifically, *Annex VI* sets limits on the emissions of Sulphur oxide (SO_X), nitrogen oxide (NO_X) and particulate matter (PM). Additionally, it introduces the Emission Control Areas (ECAs) which are designated sea areas in which the previously mentioned emission limits are more stringent (IMO, 2018c). Apart from the international regulations, the European Union (EU) has also introduced its own regulatory framework, referred in the Directive 2016/802[1], in order to control climate change and decrease air pollution caused by ships. It targets at the reduction of the SOx emissions by setting a maximum sulphur content in marine fuel oils at the territorial waters and exclusive economic zones of all EU Member States (EU, 2016).

The international and European regulations mentioned above render essential the investigation of all the practicable alternatives to achieve reduced emissions from ships. The use of Liquefied Natural Gas (LNG) is considered as one of these alternatives due to the fact that it is a cleaner fuel. There are plentiful studies, researches from academia and classification societies, that investigate the use of LNG as a ship fuel since it has been proven to comply to all the above-mentioned regulations. Wang and Notteboom (2014) through their research aim to obtain a better understanding of the current perspectives and challenges for the use of LNG as a bunker fuel. They also identify the gaps and the weak points in the related literature in order to suggest future research. Adamchak (2010) investigates the use LNG as a marine fuel in terms of pros and cons. Balon and Lowell (2012)

[1] Modified version of the Council Directive 1999/32/EC

investigate the prospects and challenges of converting U.S. marine vessels to LNG. Aagesen, Ajala and Nicoll (2012) through their study evaluated the possibility of the wide adoption of LNG as a fuel for deep sea shipping and tried to understand how a global LNG bunkering infrastructure might develop. The MAGALOG study (2008) confirms LNG as a feasible source of large environmental improvement in North European shipping, building on experience gained from using LNG for coastal shipping in Norway and points out the required next steps for its development such as the logistics for making LNG fuel available for the end users.

1.2 Definition of the Problem

The passenger shipping industry has been proven one of the largest Greek industries with one of the highest contributions to the country's Gross Domestic Product (GDP). As listed on the website of the association of the Greek passenger shipping companies, passenger shipping contributes 9.2% (16.1 billion euros) on the Greek GDP. The geographical formation and the insular character of Greece generated the need for the regular connection between inhabited islands and the mainland, causing an increased passenger shipping activity and thus increased volume of exhaust emissions in the Greek seas and coastal areas. In order to control these harmful to the environment emissions and to create a more sustainable industry, measures must be taken. Therefore, based on these facts and in combination with the above-mentioned studies, it can be agreed that the use of LNG as a ship fuel could drastically reduce exhaust emissions from the passenger ship activity in Greece.

Yet, non of the pre-mentioned articles and literature has focused on the use of LNG as a ship fuel in passenger ferries in the Greek seas. There are only few exceptions such as Tzannatos and Nikitakos (2013) and of Tzannatos, Papadimitriou and Koliousis (2013). In the first study the authors examine the use of natural gas as a cleaner fuel alternative compared to heavy and light fuel oils for domestic passenger shipping in Greece and in the second one the authors conduct a comparison analysis between an oil and a natural gas fuelled ferry in the Piraeus - Dodecanese islands line. However, none of these researches are investigating the perspective of those directly involved with the use of LNG as a ship fuel, such as ship owners, nor the effect of the daily fluctuations of the price of LNG in comparison to the other alternatives, to the development of LNG. Consequently, an extensive research on the adoption of LNG as a ship fuel in the Greek passenger shipping must take place, taking into consideration the above gaps in literature.

Based on the above statements, this thesis will be an addition to the small amount of researches investigating the use of the LNG bunker fuel in the Greek passenger shipping industry. Therefore, the main research question of this study can be formed as such.

What are the possibilities and limitations for the adoption of LNG as a ship fuel in Greek passenger shipping?

This research question will be answered with the help of the following sub-questions:

1. To what extent can the existing literature build a better understanding on the feasibility of the use of LNG in Greek passenger shipping?

2. (a) How can the Greek passenger shipping stakeholders provide a more detailed insight to the possibility of adopting LNG as a fuel in the Greek ferries?

   (b) To what extent can the price and price return volatility of LNG in comparison to alternative fuels, influence the decision making of shipowners and particularly Greek ferry owners?

1.3 Reason of the Problem Definition & Objective of this Thesis

Up untill today, MARPOLs more stringent limits of sulphur content in marine fuels are applied only in the areas known as ECAs. However, in 2020 a strict limit of sulphur content will be also applied globally by MARPOL (IMO, 2018d). On the same year, the same strict limits will be applied at the territorial waters and exclusive economic zones of all EU Member States by the EU Directive 2016/802 (EU, 2016). The date of the application of MARPOLs new limits could be deferred to 1 January, 2025, depending on the outcome of further investigation, by IMO, into the global availability of low-sulphur fuel oil for marine use by 2018 (Aagesen et al., 2012). Greece is not yet subject to strict emission regulations due to the fact that the Mediterranean is not yet an assigned emission control area and hence, the absence of adequate literature referred above. Nevertheless, even if the application of IMOs legislation is postponed, Greece will be subject to the European legislation by 2020 and shipowners will be called to take action in order to comply to these regulations in one way or the other. Therefore, the objective of this thesis is to explore whether the use of LNG, as an alternative ship fuel, is a feasible solution for the Greek passenger shipping, as a measure to abide by the upcoming regulations as well as to become a greener and more sustainable industry and to provide valuable information whether LNG is attractive to Greek passenger shipowners in terms of the price stability of LNG compared to that of other conventional oils.

2 Methodology & Structure

2.1 Methodology

This chapter will provide a detailed description of the methodology followed in order to answer the main research question of this thesis (see Figure 1).

Objective	Data Source	Data	Methods
Better understanding of the use of LNG as a fuel in the shipping industry.	Literature News media Real-life examples	Theoretical and empirical findings News & articles	Literature review Content analysis
Better understanding of the possibility of the adoption of LNG in the Greek passenger shipping.	Industry experts	Opinions Timing Conditions	Experts interview and qualitative analysis
Better understanding of the perception of Greek passenger shipping companies on the adoption of LNG bunker and their reaction to the air emission limits.	Greek passenger shipping companies	Opinions Timing Conditions	Questionnaires and qualitative analysis
Examination of the LNG price and price return volatility evolution in comparison to alternative fuels during the last decade.	Bloomberg and online databases.	Fuel prices time series	Quantitative analysis
Interpretation of the effect of the price and price return volatility evolution on the ship owners.	Ship owners	Opinions	Questionnaires and qualitative analysis

Figure 1: Research Strategy.

In order to answer to the first of the two sub-questions presented in section 1.2, an extensive discussion on existing literature, news articles and real-life examples will be provided. This will commence with a presentation of some important academic articles and studies focused on the use of LNG as a ship fuel. This will occur in an effort to collect all of their empirical and theoretical findings in order to understand the main factors that affect the adoption of LNG as a ship fuel. An extensive presentation of those factors will follow, by analyzing the content of studies, articles, news media, etc. Finally, a collection of all the real-life examples where LNG is already being used as a fuel in the shipping industry will take place. All these steps, will provide insights to a better understanding of the possibilities of adoption of LNG as bunker fuel in the Greek passenger shipping and its limitations.

With the objective to better understand the possibility of the adoption of LNG as a ship fuel in the Greek passenger shipping, industry experts will be interviewed and shipowners will be surveyed. This action will give access to their opinion on the possibility and the timing of the LNG adoption in the Greek passenger shipping and the current state of the market. More specifically, by surveying Greek passenger shipowners, it will become feasible to offer insight on how they are planning to react to the imminent ship air emission regulations and on their perception of LNG as an alternative cleaner for their ships.

In order to answer the next sub-question 2b, two steps will be taken. The first step will be to examine the evolution of the price and price return volatility of LNG in comparison to other alternative fuel oils the past decade. Using price time-series that will be extracted from Bloomberg and other databases, an analysis of the prices and the volatility will be performed. The latter will become possible with the application of the time varying volatility GARCH model (Engle, 1982 and Bollerslev, 1986) on the LNG price returns and on its competitive fuel oils. The estimation of the GARCH model parameters will be done through the Maximum Likelihood (ML) methodology. The second step in this process, will be to present the results of the previous analysis to Greek passenger shipowners via questionnaires in an effort to collect their opinions and therefore, to understand whether the price and price return volatility of LNG compared to those of alternative fuels, could affect their decision making in adopting LNG for their ships.

Finally, by performing a qualitative analysis to all of the above findings, it will be possible to answer the research question and understand the possibilities and limitations on the adoption of LNG in the Greek passenger shipping industry.

2.2 Structure

This thesis research consists of eight chapters. The third chapter will present a detailed presentation of the findings of several articles and studies focused on the use LNG as a ship fuel. The fourth chapter will present the main factors that could influence the wide adoption of LNG as a fuel in the shipping industry. The analysis of the price and price return volatility of LNG and other fuels will take place in the same chapter, as a potential factors that could affect the adoption of LNG. The fifth chapter will refer to the cases where LNG is already adopted in the shipping sector and most importantly in the passenger shipping. In the sixth chapter, the Greek passenger shipping will be introduced as a potential market for the LNG as a fuel by taking into consideration all of the above discussions and arguments. The seventh chapter will elaborate, in detail, on the findings from the questionnaires to the shipping companies and the interviews with the industry experts. Finally, the eighth chapter will summarize the findings from all the previous chapters and draw conclusions on if, when and how will the Greek passenger shipping adopt LNG fuel.

3 Literature Review

3.1 Natural Gas as a Ship Fuel

Wang and Notteboom (2014) seek through their research, to provide a broader understanding of the current perspectives and challenges of LNG as a ship fuel. By performing a systematic review on a significant amount (33) of researches/studies, published from 2008 to 2012. The authors collected the findings from the studies and they investigated the consistency, divergence and the complement between them. The overall results of their review were presented in a structured way as follows.

From the perspective of the regulatory framework availability, they concluded that there are regulatory gaps in the application of LNG as a ship fuel. However, they also state that regulations on gas-fuelled ships are under construction, such as the IGF code of IMO. When it comes to LNG bunkering regulations, they emphasize the fact that the lack of such regulations is a major barrier that slows down implementation of LNG as a ship fuel. However, some of the latest studies point out that ISO is working to close that gap. Finally, another mentioned barrier is the absence of regulation associated to the use of LNG on inland vessels in Europe and it is strongly suggested that such regulations must be developed.

From the economic viability perspective, the authors found that the literature agrees on the higher investment cost of LNG fuelled ships relatively to an oil fuelled vessel due to the high costs of the advanced LNG engines and the specialized fuel tanks. It is supported that this high required capital cost for LNG fuelled ships will be reduced if the demand for this technology will increase. Some researches, e.g. Ruud Verbeek et al. (2011), de Ruiter (2010), support that LNG is more feasible for newly built ships due to the higher costs to convert an existing ship. Regarding the LNG price it is found that it is relatively lower than other conventional ship fuels and it can cause significant cost savings for ship-owners who face a high pressure of low freight rates. Nevertheless, the opinions about the future LNG price differ, the majority of the reviewed studies e.g. Ashworth (2012) and Karlsen (2012), expect that LNG will retain its price advantage while others e.g. Baumgart and Olsen (2010), expect that the increased future LNG demand might cause its price to increase. Furthermore, others (Aagesen et al. (2012)) support that the final LNG price, which includes several supply logistic costs could be uncertain due to the lack of bunkering infrastructure and a logistics network. This price uncertainty is a major reason for the slow development of the application of LNG as a ship fuel. Finally, another economic advantage of the LNG use is being stated which is the low maintenance cost of its engine and the long-life feature of the LNG technology.

From a technological perspective there are some challenges that need to be confronted. First and foremost, the sizable space needed for the LNG tank fuels which has a negative effect on ship productivity and freight earnings. The use of a smaller fuel tank and frequent refueling as well as a hull-type integrated tank is supported by a few (DNV, 2010; Alvestad 2011) of the reviewed studies as a way to tackle this capacity issue. In the case of retrofitting ships and the issue of the large fuel tank, many studies claim that LNG is more feasible for new ships and some others after performing researches on the feasibility of ship conversion conclude that the possibility of conversion depends on ship age and configuration. Another technical challenge that requires attention is the emissions of one of the greenhouse gases (GHG), the unburned methane(CH_4) which can weaken the environmental performance of LNG fuelled ships. Finally, although many studies are positive when it comes to the safety risks of LNG fuel on board others believe that more studies need to focus on safety concerns about the use of LNG as a ship fuel.

From the perspective of infrastructure availability, it is found that there is a lack of appropriate bunkering infrastructure and distribution networks for delivering LNG fuel to ships. This causes the so-called "chicken and egg problem", where bunker suppliers are unwilling to invest in infrastructure due to the lack of sufficient demand and on the other hand, shipowners who are reluctant in investing in LNG ships due to the almost non-existing supply of LNG fuel.

They argue that the "chicken and egg" problem can be settled with the intervention of governments with subsidies, funding etc. While it is also argued, that the public financial support from governments to promote infrastructure development is poor, it is stated that the public awareness is moving upwards. Another matter that undermines the use of LNG as a bunker fuel, is the negative perception of LNG from the public, which by many studies is believed to be caused by the lack of communication between the general public, project developers, and authorities. Establishment of better communication is crucial at this point for the faster establishment of LNG as fuel.

In terms of LNG availability, the authors support that there are plentiful global natural gas reserves and its world trade is growing fast. From the systematic review the authors concluded that LNG fuel can be supplied from either large LNG terminals that are close to the LNG ships or from piped gas which is turned to LNG through the liquefaction process. The need for small scale liquefaction plants renders the second option more expensive than the first one and it is only preferred in sites where the gas is inexpensive and in ample quantity.

From the findings of the reviewed studies it can be concluded that the initiation of the LNG use as ship fuel is more suited in the shipping segments that are characterized by a regular sailing pattern, by high fuel consumption per ship, when they operate in regions with stricter environmental standards, e.g. ECAs and when the LNG fuel system does not interfere with the rest of the operations on-board.

Although there are many clean alternative fuels discussed in the reviewed studies, such as, nuclear power and bio-fuels, there are many constraints that hinder their application to the maritime industry and therefore it is concluded that LNG seems the most feasible solution.

Finally, through this extensive literature review it was concluded that the LNG in comparison to its competitive solutions, i.e. scrubbers and LSFO like MGO, is the only fuel that can comply to the upcoming strict SO_X and NO_X emission standards without any abatement technologies.

Adamchak and Adede (2013) also discuss the use of LNG as a bunker fuel and by analyzing some of its aspects, they elaborate on the advantages and the challenges associated with its use.

The authors report two main reasons that make LNG seem a better alternative in order to comply to the Annex VI regulations. The first is the fact that LNG complies to the Annex VI regulations due to its negligible sulphur content and to the fact that it reduces NO_X emissions without after treatment.The second one is LNGs competitive price in comparison to residual and distillate fuel prices in some markets. Subsequently, the authors mention the price differences of natural gas and LNG to alternative fuels (IFO 380 and MDO) in different geographical areas (U.S., Europe and Asia) and highlight the importance of infrastructure and supply costs to the final LNG price, which can sometimes affect its competitiveness to other fuels.

Additionally, an attempt to develop an estimation of the demand of LNG as marine fuel was made. By taking some assumptions e.i. the global limit of 0,5% sulphur content in marine fuels will be implemented in 2025 and focusing in ships operating in ECA to ECA trades in major international routes it is concluded that the consumption of LNG as a marine fuel will rise to 1 million tonnes in 2020 and in 2025 it will quickly increase to 8.5 million tonnes. It is also believed that when the date of aforementioned global sulphur limit is made known it will cause the orders for LNG fuelled ships to increase. A brief reference is also being made to other published demand projections and the assumptions that affected them.

Furthermore, this paper identifies some uncertainties that affect the decisions of the shipowners, the bunker fuel providers, and therefore the development of LNG as a bunker fuel. First, the unknown date of the enforcement of the 0,5% global sulphur limit, which is subject to the IMOs review in 2018. Second, the uncertainty on the possible new ECAs under the 0,1% sulphur cap, whose increase would speed the adoption of LSFO. Third, the lack of an International regulation for the use of LNG as fuel that would cause confusion in international trades. Moreover, the uncertainty shipowners and infrastructure developers face on whether there will be adequate LNG fuel supply for their ships and sufficient LNG fuel demand, respectively, that causes them to be reluctant to take the initiative to enter the LNG market first, and the unawareness if spot and short-term supply of LNG would offer some sort of security an eradicate their reluctance. Finally, the authors refer to the uncertainty of LNG supply and place emphasis on the fact that it should display the same increase as the projected LNG fuel demand.

3.2 Natural Gas as Ship Fuel in the Greek Passenger Shipping

In their paper Tzannatos and Nikitakos (2013) examine the use of natural gas as a cleaner alternative fuel in the Greek domestic passenger shipping and to do so they perform a comparison of its the external (damage) costs with those of heavy and light fuel oils. They also focus on important parameters that would have an impact on the fuel shift to natural gas.

Their paper starts off with general information on the regulations for the control of climate change, air pollution and the need for cleaner fuels, on the emissions from ships, possible ways of reducing them, and the possibility of LNG as ship fuel, and finally they provide brief description of the Greek coastline morphology, insular character, and the characteristics of its domestic passenger shipping. On the second part the authors break down the already existing and the upcoming International regulatory framework by IMO (Annex VI of MARPOL) and European legislation (Directive 2012/33/EU) for the control of the exhaust emission form ships.

Subsequently, they present their top-down methodology where they use various sources (national submissions to United Nations Framework Convention on Climate Change by Greece, major Greek bunkering companies' records) to estimate the fuel consumption of the Greek passenger shipping for the time period 2001-2010, and to later list the amount of exhaust emissions linked with the burning of fuel oil and natural gas using the emission factors of SO_2, PM, NO_X and CO_2 and their corresponding external costs factors (effects of emissions on human mortality and morbidity, acidity on buildings and crop yield reduction) they found in other researches.

From the authors' analysis, it was found that the Greek passengers shipping produces 37.5 thousand tons of exhaust pollutants per year and a shift to natural gas would reduce that amount to 3.56 thousand tons per year. It was also found that SO_2 emissions would be completely removed, and NO_X would be reduced by 91.1%, PM by 84.5% and CO_2 by 34.2%. In terms of external costs, the use of natural gas was found to reduce the current estimated 256.7 million euros per year by 85%. Later, the authors state that the marine diesel engine technology is more favorable option due to the high private costs of the gas engine technology but simultaneously they observed the significantly lower price level of LNG relatively to the one of crude oil and sometimes to light fuel oil. Moreover, they mention the importance of incentives created by the government for a shift to LNG fuelled vessels. Finally, they highlight the importance of an international regulatory framework in order to boost LNG shipping, and of LNG bunkering facilities, whose absence in Greece render the LNG shipping development unfeasible.

In the following research a cost (fuel, technical, and external) comparison analysis between an oil and a LNG fuelled ferry in the connection of port of Piraeus and the Greek Dodecanese Islands was conducted by Tzannatos, Papadimitriou, and Koliousis (2013).

Their paper follows almost the same structure as the previously mentioned paper as they start by presenting the same general information on the matter and by breaking down the technical and economic aspects of LNG compared to those of oil as marine fuels.

Later on, the methodology of the analysis is described where they estimate and compare the total fuel costs (fuel costs at sea + fuel costs in ports), the total pollution costs (air pollution at sea + air pollution in ports), and the technical costs of an oil fuelled ferry to those of a LNG one. To do so they use data (emission and fuel consumption factors, technical costs etc.) from similar researches, and other important variables which are thoroughly described in the paper, such as characteristics of the ferry, the route stages (time spend at main and small ports and at sea), and the operating profile of the main and auxiliary engines under investigation (engine load factor in each stage of the trip).

From their analysis the authors found that the total annual fuel costs of a LNG fuelled ferry is 48.6% less than that of an oil fuelled one (3.7 and 7.2 million euros, respectively). The resulted annual technical costs were in favor of the oil fuelled ferry (0.4 million euro per year) in comparison to that of a LNG fuelled ferry (0.7 million euro per year). Therefore, the total private costs (fuel and technical costs) were found to be lower for the LNG fuelled ferry (by 42.8%). The total air pollution costs of the LNG fuelled ferry were found to be overwhelmingly lower (almost 90%) those of the oil fuelled ferry. Finally, summing up all the above it was found that the total (private and pollution costs) annual costs were 65.6% lower for the LNG fuelled ferry.

Ultimately, the authors highlight the need of a life-cycle analysis methodology regarding the emissions in order to additionally account the indirect impacts of the alternative fuel technologies, and the importance of the state support to adopt friendlier to the environment ship technologies.

3.3 Natural Gas as a Ship Fuel in Deep Sea Shipping

Aagesen et. Al were assigned through Lloyd's Register to conduct a study in order to asses the possibility of the wide adoption of LNG as a ship fuel for deep sea shipping and to grasp the possible growth of LNG bunkering facilities around the world.

Firstly, the authors surveyed dominant shipowners, and bunkering ports on deep sea trades in order to collect information, on their intentions for complying to the regulations, and to determine essential locations for LNG bunkering facilities, respectively. Subsequently, they developed an LNG bunker demand model which was based on various assumptions i.e. bunker fuel oil and LNG prices, date of regulation implementation, propensity to select LNG fuel, etc., in order to obtain an approximation of the demand for new deep sea ships that will use LNG as a fuel, up to 2025 and the corresponding LNG bunker demand.

After surveying the shipowners on the deep sea trade (cruise ship, container shipowners etc.), the authors found that the first perceive the LNG as a solution that could take place within ten or more years in order to reduce their emissions, and the use of low-sulphur fuels and scrubbers more of a short term and medium term solution, respectively.

From the bunkering ports survey it was concluded that LNG bunkering will more likely begin in short sea shipping in ECAs and later pass on to the deep sea shipping, and that the price of LNG and its price difference from other alternative fuels (HFO, MGO), are significant factors that affect LNG bunker demand.

Following the surveys, the demand model explored three scenarios, giving different prediction outputs for the period up to 2025, for the deep sea trade. According to the first base case scenario, where it is assumed that the LNG prices will be kept low, the 0.5 sulphur limits will come into force in 2020, 50% increase in propensity and that the ECAs are the current ones, the outcome was a forecast of 653 new LNG-fuelled deep sea ships and a 24 million tonnes of LNG bunker demand. In the high case scenario, it is assumed that there will be a 25% decrease on the base case LNG prices, the ECAs are the current ones with the addition of some other hypothetical ones, and a 75% increase in propensity. In this scenario, the outcome was, 1,963 LNG-fuelled new-buildings, and a demand of 66 million tonnes of LNG bunker. Finally, the assumptions of the low case scenario were, a 25% increase in LNG bunker prices and propensity, compared to the base case, and 2023 as the year of the global sulphur limit. In the low case scenario 13 LNG-fuelled newbuilds were forecasted and LNG bunker demand is presumed to be 0.7 million tonnes.

An additional study on LNG as a ship fuel in deep sea shipping and more specifically in container vessels was performed by Sames, Clausen and Andersen (2011) on behalf of Germanischer Lloyd (GL) and MAN Diesel and Turbo. In this study the authors focus on the costs and possible benefits of different technologies (LNG, scrubbers, and waste heat recovery systems) on the engine systems of five container vessels of different size and route profile (therefore different ECA exposure) and compare them to those of a reference vessel which uses fuels required by the existing and the upcoming regulations.

Eventually, the authors concluded that the payback time for each technology is diminished with higher ECA exposure. For smaller vessels the payback time can be less than 2 years when their route is 65% within an ECA. For 2,500 TEU vessels, the LNG technology payback time is less than that of the scrubber, even with high LNG tank costs (as long as LNG is as expensive as or cheaper than HFO) and the use of a waste heat recovery (WHR) system only increases the payback times in both cases. However, in the case of larger vessels (14,000 TEU) that usually operate for a smaller percentage within ECAs, it is concluded that the LNG system has an even shorter payback time when a WHR system is implemented. Additionally, it is noted that the payback time for larger vessels, that have inevitably larger LNG system costs, depends on the LNG price to the end-users and therefore, would be affected by any variation of the LNG distribution costs (as a consequence of the current absence of LNG bunkering facilities).

3.4 Natural Gas as a Ship Fuel Across the World

Balon et al. (2012) prepared a report for the American Clean Skies Foundation with the objective to explore the limitations and opportunities of natural gas as a marine fuel in the U.S.

In this report the authors highlight that the two most important drivers for the adoption of LNG as a marine fuel in the U.S. are, the fact that marine vessels that operate within the North American and Caribbean ECAs are called, due to regulations, to reduce emissions (of SO_X, NO_X and PM), as well as the price advantage of LNG in comparison to the traditional marine fuels that are used in the U.S. which can consequently cause high fuel savings for a ship owner after converting to LNG.

Additionally, they mention that although LNG is plentiful in the U.S., it is only stored in carefully chosen areas and it is not always available for sale to potential customers.Therefore, the inaccessibility of LNG and the absence of LNG infrastructure in many ports of the U.S., in addition with the high capital cost of the LNG technology are major factors that hinder the process of adopting LNG in marine vessels in the U.S..

They also propose U.S. flagged tug boats, medium sized ferries, and Great Lake bulk carriers as good candidates to convert to LNG fuel as they could achieve such cost savings (by maximizing their cost savings due to their high utilization and annual fuel use) that would provide them a rational payback time for the rather high vessel conversion cost.

Moreover, they suggest that the use of already existing LNG facilities close to the ports would improve the cost savings as the development of new facilities in order to serve LNG fuelled ships could actually double the price of LNG delivered to the ships. Finally, they give examples of such facilities around the U.S. coast that could support the conversion of marine vessels and they call attention to the necessity of U.S. government intervention to encourage LNG as a fuel for ships.

4 Factors that would Affect the Adoption of LNG as a Ship Fuel.

From the research conducted by each of the studies presented in the literature review, someone could conclude that there are numerous factors that could influence the implementation of LNG as a fuel in the shipping industry. The following chapter will examine those factors in detail, by quoting more specific statements from the existing literature and other sources such as news articles, IMOs website, maritime companies' researches, etc., in order to formulate a better understanding on the perspectives and challenges that these factors pose on the adoption of LNG in the Greek passenger shipping industry.

4.1 Regulations on Air Emissions from Ships

Globalization and global-scale trade has caused the transportation of a tremendous amount of products around the world. A vast proportion of these goods is transported by ships and this proportion will probably continue to increase as global-scale trade increases. This form of transportation is considered to be cleaner in comparison to other (Viana et al., 2014). However, exhaust emissions from ships can considerably contribute to the deterioration of the air quality on a global scale (Wang et al., 2008) as well as to the global anthropogenic emissions (Tzannatos, 2010). According to Endresen et al. (2003), nearly 70% of ship air emissions are estimated to occur within a distance of 400 km from land. This means that ships have the potential to contribute significantly to the air quality degradation in coastal areas. According to Tzannatos (2010) these ship exhaust emissions have a direct effect on the human population, the built environment and the natural resources of many urbanized ports.

4.1.1 A Brief Introduction of Ship Air Emissions

As stated by Han (2010), bunker costs represent 50% of the operational expenses of a ship and therefore for economic reasons ship operators around the world use low quality residue heavy fuel oil (HFO) with high sulphur content[2] due to it's price advantage. The burning process of these type of fuels in marine diesel engines[3], can produce significant amounts of particulate matter (PM), nitrogen oxides (NO_X), sulphur dioxide (SO_X), volatile organic compounds (VOC), that contribute to the environmental pollution,

[2] The sulphur content of standard marine fuel is 2,700 times higher than that of conventional diesel for cars (Miola et al., 2010)

[3] Marine diesel engines have been dominant in the production of main and auxiliary power for merchant ships, mainly because of their high thermal efficiency, the low cost of fuel oil and their operational reliability (Tzanatos and Nikitakos, 2013).

and carbon dioxide (CO_2) and other green house gasses (GHG) that have an impact on climate change (Magalog Project, 2008).

According to the Third IMO GHG Study (2014), the shipping industry is responsible for approximately 3.1% of the annual global CO_2 emissions and roughly 2.8% of the annual GHG emissions, on average, for the period 2007-2012. This study estimates multi-year (2007–2012) average annual totals of 20.9 million and 11.3 million tonnes for NO_X (as NO_2) and SO_X (as SO_2) from all shipping, respectively. Global NO_X and SO_X emissions from all shipping represent about 15% and 13% of global NO_X and SO_X from anthropogenic sources, respectively. Finally, international shipping NO_X and SO_X represent approximately 13% and 12% of global NO_X and SO_X totals, respectively (IMO, 2018c).

These aforementioned ship exhaust emissions can have a great deal of harmful effects in populations and the natural environment. They can contribute to many serious health problems including premature mortality, morbidity, heart failure, and respiratory diseases such as, asthma attacks and bronchitis. In addition, these pollutants can cause acid rain and directly affect the natural environment that can consequently result in crop yield reduction and cause acidity in inland waters and on buildings (IAPH, 2007, Tzanatos, 2010). Finally, they can diminish the ozone layer and enhance the green-house effect (Bin and Cheung-Yuan, 2006).

These negative effects, rendered the control and reduction of these emissions inevitably imperative. While air emissions from shore-based industries were under regulation, ship air emissions were not. In general, governments have made laws to achieve huge cuts in sulphur from cars, buses, lorries, factories and power stations but not for the shipping industry (Magalog Project, 2008). A representative case is that of Europe, which has made large efforts to reduce emission from other type of sources (industrial, power generation, etc.), but this resulted in an increase of the relative weight of shipping emissions to the total of anthropogenic emissions (Viana et al., 2014).

However, few years ago the International Maritime Organization (IMO) and the European Union (EU) intervened and have put regulations into action for the control and reduction of emissions from ships. These regulations will be presented in the following part.

4.1.2 International Regulations on Ship Air Emissions

In 1948, in Geneva, IMO was established as a specialized agency of the United Nations. Its objective would be the safety and security of shipping and the prevention of marine pollution by ships. In 1973, IMO, with the purpose to create a main international regulatory framework for the decrease and prevention of pollution generated by ships, developed the International Convention for the Prevention of Pollution from Ships, the so called MAR-

POL convention. MARPOL consists of six Annexes, each of which is designed for a specific type of ship pollution. The following Table (Table 1) provides a brief description of the Annexes and the types of emissions they aim to regulate (IMO,2018b).

Annexes	Description	Entered into force
Annex I	Regulations for the Prevention of Pollution by Oil	2 October 1983
Annex II	Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk	2 October 1983
Annex III	Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form	1 July 1992
Annex IV	Prevention of Pollution by Sewage from Ships	27 September 2003
Annex V	Prevention of Pollution by Garbage from Ships	31 December 1988
Annex VI	Prevention of Air Pollution from Ships	19 May 2005

Table 1: Description of MARPOL Annexes (IMO, 2018b)

This research will focus on the MARPOL *Annex VI* since it is the one that introduced regulations in order to limit air polluting and ozone depleting emissions.

***Annex VI* of MARPOL** was adopted in 1997 with the aim to reduce main air pollutants contained in ship exhaust emissions. Those targeted air pollutants are, sulphur oxides (SO_X), nitrogen oxides (NO_X) and ozone depleting substances (ODS). Additionally, it regulates the shipboard incineration, and the emissions of volatile organic compounds (VOC) from tankers. *Annex VI* was put into force on May 2005 and during the following three years it was continuously improved and adjusted, according to the technological improvements, by the Maritime Environmental Protection Committee (MEPC) which made stricter the already existing limits. More specifically, according to those adjustments, a global progressive reduction of the emissions of SO_X, NO_X and particulate matter (PM) was initiated, and the emission control areas (ECAs) were introduced (IMO, 2018d).

ECAs are designated marine areas in which even tighter airborne emissions limits are applied. Until today there are four established ECAs. In May 2006, the Baltic sea was the first designed ECA which was followed by the North sea and North America (US and Canada) in 2007 and in 2011, respectively, and finally the US Caribbean sea in 2013. In the future, new ECAs might be designated. The Figure below (Figure 2) demonstrates the already existing ECAs as well as the other areas around the world most likely to become one in the upcoming years. The implementation of new ECAs it is not an IMO initiative but it rather depends on Parties submitting a proposal to IMO to designate a new ECA (Adamchack and Adede, 2013). Currently, no proposals have taken place to IMO in order to establish the Mediterranean as an ECA. Nonetheless, a year ago France was the first to push for the designation of the Mediterranean as an ECA. Soon after that, a group of environmental organizations (e.g. Birdlife in Malta, NABU from Germany and other from Greece, Italy, Spain, etc.) followed by forming an alliance and adopted a declaration to designate the Mediterranean Sea an

ECA to limit air pollution from ships (Birdlife Malta, 2017; HSN, 2017). Consequently, the pressure imposed by Mediterranean countries and non-governmental organizations to policy makers might result in the creation of a Mediterranean ECA in the following years. Additionally, Andreola and Schmill (2011) state that the Mediterranean sea could also become an ECA in the near future.

Figure 2: MARPOL *Annex VI* Existing and Possible Future Emission Control Areas (DNV,2013)

In order to reduce SO_X emissions from ships, MARPOL *Annex VI* sets a limit in ship fuel sulphur content. The following Figure (Figure 3) depicts this permitted sulphur content in ship fuel, globally (green area) and in the ECAs (yellow area). On the global scale the limit was kept at 4.50% from 2008 to 2012. Later on, it was reduced to 3.50% which will be effective until the first of January 2020, where the sulphur content cap will plummet to 0.5%. However, the date of the implementation of this crucial stricter limit is subject to the outcome of a study conducted by IMO on low sulphur fuel availability which is due to be completed in 2018, and therefore it might be deferred until 2025.

In the ECAs, the limits are more rigorous. From 2008 until 2010, the sulphur cap was 1.5%, then it dropped to 1%, and in 2015 it was shifted to 0.1%.

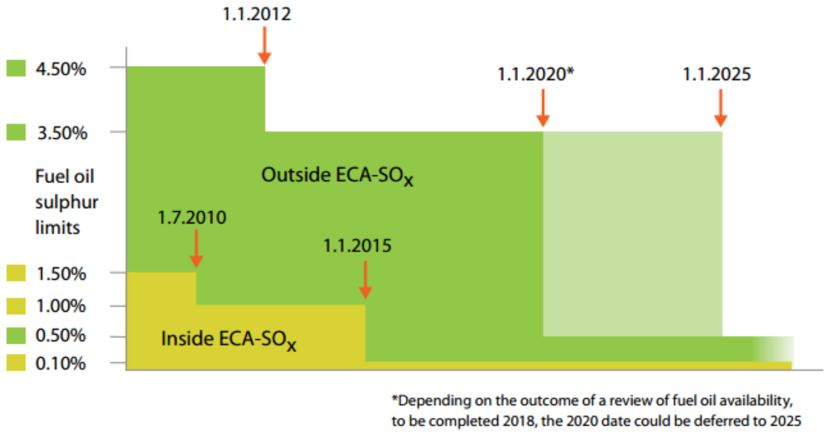

Figure 3: MARPOL *Annex VI* regulations and enforcement of sulphur limits with respective timelines (Aagesten et. al., 2012).

NO_X emissions depend mostly on engine design and operating conditions (Magalog Project, 2008). Therefore, regulations on NO_X emissions were set in marine diesel engines installed on ships and they depend on the engine speed and the ships construction year. More specifically, marine diesel engines installed on a ship which is constructed on or after 1 January 1990 but before 1 January 2011 and on or after 2011 are required to comply with "Tier I" and "Tier II" emission standards, respectively. Engines installed on a ship constructed on or after 1 January 2016 operating in the North America and US Caribbean ECAs are subject to a more stringent "Tier III" emission limit. "Tier III" will be enforced for ships operating in the Baltic and North sea if they are constructed on or after 1 January 2021. *Annex VI* NO_X emission limitations are expressed in g/kWh and they decrease when the speed engine (in revolutions per minute) increase (Figure 4).

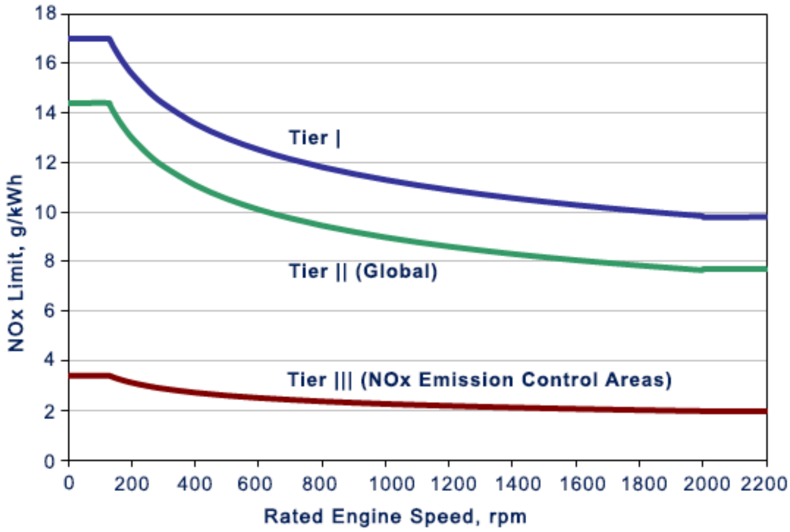

Figure 4: MARPOL *Annex VI* NO_X emission limits as a function of engine speed (DNV GL a, 2015).

As for the control and reduction of the GHG generated by the shipping industry, IMO's MEPC aimed to optimize the energy efficiency of ships by creating, in 2009, a combination of technical and operational measures, which where included in *Annex VI*. The Energy Efficiency Design Index (EEDI) is the technical measure which works towards encouraging the use of more energy efficient equipment and engines, and consequently producing less pollution. The Ship Energy Efficiency Management Plan (SEEMP) is the operational measure that sets techniques that would better the energy efficiency of a ship in a cost-effective way. EEDI and SEEMP measures entered into force and became mandatory in 2013, together with the adoption of MARPOL *Annex VI*, for new ships and all ships of 400 gross tonnage and above, respectively. More recently, in April 2018, IMO adopted a strategy with the aim to reduce GHG emissions from international shipping and as soon as possible in this century and gradually to phase them out (IMO, 2018c).

Two other climate change treaties is the Kyoto Protocol and the Paris Agreement. Both of them are International agreements linked to the United Nations Framework Convention on Climate Change, which commit their state parties to reduce GHG emissions and keep the global temperature rise below 2 degree Celsius. Kyoto Protocol will be effective until 2020 and after that the Paris agreement will come into effect (UNCC, 2018a&b). International shipping emissions has been excluded from both treaties. However, domestic shipping is included in the estimation of the national carbon footprint and therefore, it is a source of GHGs that a State party should control

(Tzanatos And Nikitakos, 2013).

4.1.3 European Regulations on Ship Air Emissions

With the purpose to reduce sulphur dioxide emissions generated by the combustion of certain fuel oils and consequently reduce their detrimental effects on man and the environment, EU constructed the *Directive 1999/32/EC* which has been significantly amended several times and is now repealed by the *Directive 2016/802* of the European Parliament and of the Council of 11 May 2016, relating to a reduction in the sulphur content of certain liquid fuels. In order to accomplish such an objective the EU imposed a limit on the content of sulphur in fuel oils used in ships operating in within Member States' territory, territorial seas and exclusive economic zones or pollution control zones.

According to the *Directive 2016/802*, from 1 January 2020 all ships that operate in territorial seas and exclusive economic zones shall not use marine fuels with sulphur content that surpasses 0,5%. Until that limit comes into force, passenger ships that are operating on regular services to or from any Union port should use marine fuels that their sulphur content is not more than 1,5%. It is of significant importance to note that irrespective of the outcome of IMO's low sulphur fuel availability study in 2018, ships operating in the EU waters will be subject to the regulations of the *Directive 2016/802* and therefore would have to conform to the 0,5% sulphur limit on 1 January 2020. For the marine fuels used the territorial seas, exclusive economic zones and pollution control zones falling within the MARPOL's SO_X Emission Control Areas, the limits in their sulphur content remains the same as those addressed in MARPOL *Annex VI*.

Additionally, since 1 January 2010, all ships that remain for more than two hours at EU berths are required to use marine fuels with sulphur content of not more than 0,1% or to switch off all engines and use shore-side electricity facilities (EU, 2016).

4.1.4 Solutions Towards Meeting Air Emission Limits

The previously mentioned international and European regulations on ship air emissions pose a challenge to the shipping industry. Shipowners are compelled to consider all the alternatives, such as cleaner new fuels and new technologies, in order to produce cleaner energy, reduce their air emissions and therefore comply to the underlying requirements of the regulations. Shipowners have three complying alternatives. They can either shift to low-sulphur fuels, such as, marine diesel oil (MDO) and marine gas oil (MGO), or they can continue using HFO, but they would have to install an exhaust treatment technology, such as scrubbers, or switch to natural gas engines for the use of LNG as fuel.

Scrubbers is an exhaust gas treatment system that washes the sulphur and PM from the engine's exhaust gas with sea water and it has been proven to almost completely remove the corresponding emissions. Nevertheless, the use of scrubbers does not reduce CO_2 emissions, but can reduce NO_X emissions with an additional abatement technology i.e. Selective Catalytic Reduction (SCR). The installation of scrubbers will burden the shipowners in the sense that it requires a capital investment and the ships off-hire time for the conversion. Additionally, scrubbers occupy space from the ship's cargo capacity, demands high maintenance costs and finally, they produce waste that should be handled in ports which takes time and requires waste handling facilities in ports. However, shipowners can benefit from the fact that they can carry on with using residual fuels[4] (i.e. HFO) which have an established market, with bunkering facilities and therefore are available, and they won't have to retrofit their ships and replace their engines (TEN-T, 2012; Notteboom and Wang, 2014; Adamchak et al., 2013)..

Distillate fuels[5] (i.e. MGO), just like scrubbers, can meet the sulphur and PM emission limits, CO_2 emissions remain the same as when using HFO, and in order to reduce NO_X emissions and meet "Tier III" limits, SCR is necessary. In order to shift to MGO, no retrofitting of the ships or investment costs are required. However, MGO prices are rather high and it is expected to rise even more due to limited supply as refineries are not obligated to produce low-sulphur fuels (TEN-T, 2012; Notteboom and Wang, 2014; Adamchak et al., 2013).

The use of LNG as an alternative solution will be discussed in the following section.

4.1.5 LNG as a Solution to the Regulations on Ship Air Emissions

The use of LNG as a ship fuel is considered by many studies (i.e. Balon et al., 2012; Adamchak et al., 2013) as a feasible solution that can meet the reductions in air emissions (e.g. SO_X, PM and NO_X Tier III) as instructed by all the aforementioned regulations. LNG is natural gas which has been cooled and become liquid at a temperature of -162°C while kept at atmospheric pressure. The primary component of natural gas is methane with some ethane and small amounts of heavy hydrocarbons and according to Shell (published on its website) it is the cleanest-burning hydrocarbon. Once it is cooled and liquefied it becomes 600 times less in volume than its original gaseous state, which makes it easier to store and transport as

[4] The heaviest oil fraction from the oil refining processes and is often called heavy fuel oil (HFO). It is the traditional marine bunker fuel and has a high sulphur content (Aagesen et al., 2012)

[5] Lighter oil fractions from the oil refining process. They typically have a low sulphur content(Aagesen et al., 2012).

well as to store on a ship as a bunker fuel. LNG is a clear colourless, non-toxic liquid and in comparison to other traditional marine fuel oils it has a significant advantage due to the fact that is produces very low emissions of SO_X, NO_X and PM. More specifically, the replacement of conventional fuel oils with LNG, reduces SO_X and PM emissions by almost 100%, NO_X emissions up to 85% and finally CO_2 emissions around 20% (Notteboom and Wang, 2014; DNV GL, 2015b). Further to the advantage of LNG on low emissions, the low price of natural gas and LNG compared to residual and distillate fuel prices in the U.S and Europe the past years is an additional factor that renders LNG an attractive alternative marine fuel.

According to Balon et al. (2012) LNG has somewhat higher energy density, which means that a pound of LNG produces more energy than a pound of other marine fuels. However, LNG takes almost twice the space that other marine fuels would take in order to produce the same amount of energy. For that reason, the LNG system and storage tanks require more space than those of conventional fuels and will consequently reduce cargo capacity and affect productivity and freight earnings. The installation of the LNG system and tanks require a significant amount of capital investment and a long off-hire time for the retrofitting of the ship. Both investment costs and off-hire time for the installation of the LNG system is larger than installing scrubbers. However, LNG being a cleaner fuel, requires significantly less maintenance costs than the scrubbers. An additional concern raised by the use of LNG as a ship fuel is the fact that there are no established bunkering infrastructure and distribution networks for delivering LNG to the ships (TEN-T, 2012; Notteboom and Wang, 2014; Adamchak et al., 2013; DNV GL, 2015b).

All these advantages and disadvantages of LNG as a ship fuel, act as important factors that would affect its adoption in the shipping industry . The most significant factors will be described in more detail in the following sections.

	MDO/MGO	Scrubbers & HFO	LNG
Positive	• Low or no investment for engine retrofitting. • No extra volume required for fuel storage tanks. • Existing bunkering facilities.	• Scrubbers are used in combination with the current high Sulphur bunker fuels. • Low HFO fuel price. • Existing HFO bunkering facilities. • No retrofit of the engines.	• Meets all air emission regulations. • Low LNG fuel price.
Negative	• High fuel price. • Additional abatement technology required to reduce NO_X emissions. • No CO_2 reduction. • Availability: Oil suppliers are not committed by any law to provide low Sulphur bunker fuels.	• Capital investment and off-fired time for scrubber installation. • Additional abatement required to reduce NO_X emissions. • No CO_2 reduction. • Waste handling and disposal facilities. • On board space consumption.	• LNG consumes significant on board space. • Requires high capital investment. • Lack of LNG bunkering facilities and distribution network.

Figure 5: MARPOL *Annex VI* compliance solutions.

4.2 Price of LNG in Comparison to Alternative Fuels

According to Poten & Partners, LNG does not only have the advantage of being a cleaner fuel that meets the air emissions limits posed by MARPOL *Annex VI* on a global and ECA scale, but it may also have an economic advantage. They argue that this economic advantage of LNG in comparison to conventional fuels is one of the primary drivers that makes LNG an attractive alternative and gives an economic incentive to adopt it. Likewise, Notteboom and Wang (2014) support that it is widely recognized that the low price of LNG compared to the conventional oil fuel is a main economic driver for its application as a ship fuel as it can yield significant fuel cost savings for shipowners who are challenged to achieve low freight rates, and that the adoption of LNG as a ship fuel depends on the price difference between LNG and low sulphur fuel oil (LSFO). Balon et al. (2012) state that the conversion of a vessel from using traditional marine fuels to LNG, would give the opportunity for significant fuel cost savings due to the relative low price of LNG and therefore that is one of the two main drivers of the potential for LNG to be used as a marine fuel.

We can therefore conclude that the historically low price of LNG is one of the most significant factors that would affect shipowners on their decision to adopt LNG in order to comply to the regulations. The researches and studies reviewed for this thesis research cover a period until 2014. Therefore, in order to comprehend the price advantage LNG and investigate whether it is maintained until today, this research will provide an analysis of the price of natural gas and of other alternative fuels for the time period from the beginning of 2010 until the end of 2017.

The following part provides a detailed description of the dataset that was used in this price analysis. It consists of eight time series. The first two are the Henry Hub (HH) Daily Spot Price Index (i.e. closing daily prices), and the UK National Balancing Point (NBP) Natural Gas One Day Forward Index[6]. The second and the third times series are the 180 Intermediate Fuel Oil[7] Centistoke Rotterdam Spot Price (IFO 180) and the 380 Intermediate Fuel Oil Centistoke Rotterdam Spot Price (IFO 380). The fifth and the sixth time series are the ones of Brent Crude Oil Spot Price Index and West Texas Intermediate (WTI) Crude Oil Spot Price Index. Finally, the last two series are the Marine Diesel Oil (MDO) Spot Price Index and the Marine Gas Oil (MGO) Spot Price Index.

As listed on the website of S&P Platts both HH and NBP prices are highly linked to the pricing process and the final pricing of LNG. Therefore,

[6]Due to unavailability of National Balancing Point (NBP) Daily Spot Price Index, the one-day future index was used as an approximate. The one-day future price is the price that someone pays to buy a product today, which will be delivered the next day. These NBP one day future prices have been compared to reported prices in the previously mentioned literature (for the time period 2010-2012) and they are at the same level.

[7]A mixture of residual and distillate fuel oils and one of the basic marine bunker fuels.

natural gas prices are used as approximates of the LNG price in many of the existing academic literature, such as in the study of Adamchak and Adede (2013). Furthermore, HH and NBP are the prices of the extracted fossil fuel, natural gas. Hence, it is logical to include in the comparison those of crude oil prices (Brent and WTI). At the same time, since the objective of this section is the investigation of the price of LNG compared to the prices of alternative marine fuels, it is reasonable to include the prices of several other traditional marine fuels that are broadly used in the industry, the IFO 180, the IFO 380, the MDO and the MGO.

The time series mentioned above were retrieved from various sources. HH, NBP, IFO 180 and IFO 380 were downloaded from Bloomberg. Brent and WTI prices were downloaded from the US Energy Information Administration (EIA) official website. Finally, MDO and MGO closing spot index prices were downloaded from the Bunker Index official website.

One important aspect of these data is that each one of them were expressed in different units of measurement when they were downloaded. Therefore, in order to be able to compare all the different fuel prices it was necessary to convert the downloaded data to the same unit of measurment. Numerous academic studies, e.g. Balon et al. (2012), presented bunker fuel prices in terms of dollars per million British thermal units (MBtu or MMBtu). Following their example, all the data were converted to dollars per MMBtu ($/MMBtu). HH was downloaded in terms of dollars per MMBtu therefore, no changes were necessary for these series. NBP was downloaded in terms of GBp per Therm (which equals to 100,000 Btu). Hence, these prices were initially converted to MMBtu by simply multiplying them by 0.1 and then to dollars by using the corresponding date's exchange rate [8]. Both IFO 180 and IFO 380 were downloaded in unit terms of dollars per Metric Tonnes. Both of them are residual fuels and in order to be transformed to Btu, they are transformed initially to barrels by dividing the price by 6.7 and then to Btu by dividing them by 5,812,800. The result was then multiplied by 1,000,000 in order to reach the dollar per MMBtu units. Both Brent and WTI crude oil spot prices were downloaded in terms of dollars per Barrel. In order to transform this latter unit to Btu, the prices were divided by 5,535,600 and then the result was transformed to MMBtu by multiplying it by 1,000,000. Finally, the two last time series of MDO and MGO were also downloaded in terms of dollars per Metric Tonnes. These two bunker fuels are distillate oil fuels, hence in order to be transformed to dollars per MMBtu, they were initially transformed to dollars per barrel by dividing the downloaded prices by 7.5 and then to Btu by dividing by 5,405,400. Multiplying the latter final result by a 1,000,000 gives the final dollars/MMBtu prices. All the necessary ratios for the above conversions where found at Iowa State University's official website (Hofstrand, B., 2008).

[8]Also downloaded from Bloomberg.

All eight time series cover a period of eight years i.e. from the 5th of January 2010 until the 29th of December 2017. This means that each of the time series consists of 2,036 observations and the whole dataset consists of 16,288 observations.

4.2.1 Price

In this section the investigation of the historical performance of both HH and NBP prices with respect to the rest of the selected commodity prices will take place.

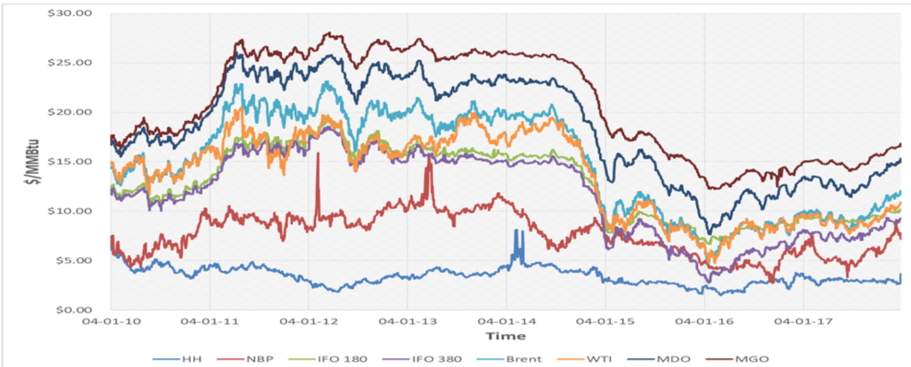

Figure 6: Fuel Oils and Natural Gas Prices.

Statistic \ Series	HH	NBP	IFO 180	IFO 380	Brent	WTI	MDO	MGO
μ	\$3.41	\$7.60	\$12.79	\$11.62	\$14.85	\$13.55	\$18.34	\$20.70
σ^2	\$0.80	\$4.71	\$13.08	\$18.34	\$26.24	\$18.05	\$27.19	\$27.12
σ	\$0.90	\$2.17	\$3.62	\$4.29	\$5.12	\$4.25	\$5.21	\$5.21
Max	\$8.15	\$15.90	\$19.73	\$18.59	\$23.15	\$20.48	\$26.10	\$28.07
Min	\$1.49	\$2.71	\$6.65	\$2.75	\$4.70	\$4.73	\$7.62	\$12.21
$Observations$	2,036	2,036	2,036	2,036	2,036	2,036	2,036	2,036

Table 2: Descriptive statistics of each price time series.

Figure 6 depicts the price performance, of each of the selected commodities, for the last eight years. Table 2 presents some of their basic statistical features of the price time series. Starting with HH, it is the commodity with the lowest price, relatively to all the rest, for the whole period of the last eight years. This is also verified in Table 2, as it has the lowest average price and the lowest range of prices i.e. [$1.49,$8.15]. NBP is shown to be the commodity with the second lowest price, in comparison to the others, for the majority of the last eight years, except for the period between mid-2015 and mid-2016 where the NBP price surpassed the IFO 380 price. In a nutshell, it is more expensive than Henry Hub and cheaper than the rest of the commodities. This can be also be seen in Table 2, where NBP's average price is the second lowest which is also the case with its minimum and maximum prices i.e. [$2.71, $15.90]. Regarding the IFO 180 and IFO 380 bunker fuel prices, for the majority of the underlying period, with some exceptions, they seem to be at the same level and more expensive from both LNG approximates (HH and NBP) and at the same time less expensive than Brent, WTI, MDO and MGO. This is also obvious in Table 2 where both average prices of IFO 180 and IFO 380 are at a higher level from those of LNG approximates and below those of the crude (Brent and WTI) and distillate oils (MDO and MGO). The latter ones are clearly the most expensive fuels in this comparison with the highest averages and price ranges i.e. [$7.62,$26.10] and [$12.21,$28.07], respectively.

The main conclusion that can be drawn from Figure 6 and Table 2 is that the LNG prices approximates (Henry Hub and NBP) are the lowest ones relatively to all the rest of the fuels presented in this research, which indicates clearly the price advantage of LNG. At this point there are two observations worth mentioning. The first is the prices decrease starting from the mid-2014. This downturn is more clearly observed in the IFO 180, IFO 380, Brent, WTI, MDO and MGO as their prices move at an entirely different price level. This decrease is not so obvious for the two LNG approximates as their prices at that period do not deviate significantly from the past levels. The main drivers of this sharp drop were mainly, the reduced demand from major oil consuming countries (e.g. China, India and Brazil), the combination of reduced oil imports and increased domestic production of USA and Canada, and finally the decision of Saudi Arabia to keep their low cost oil supply stable and at relatively low prices (DePersio, 2018). The second observation is that both HH and NBP have displayed few extreme peaks at the beginning of 2012, 2013 and 2014 (see Figure 6). Regarding HH, the sharp increase observed in the first months of 2014, was a result of the increased residential and commercial demand of natural gas due to the colder than normal temperatures in the United States, which led to high natural gas storage withdrawals. The same weather conditions, in the United Kingdom, were the reason of the NBP pikes, observed at the beginning of 2012 and 2013 (Cunningham, 2018; U.S. Energy Information Administration website).

These two observations will add great interpretation value in the next paragraph of the volatility analysis .

4.2.2 Volatility of Prices

It would have been ideal for this research to be able to provide a forecast analysis of the future natural gas prices in comparison to future fuel oil prices in order to provide an insight to the reader and shipowners whether natural gas will maintain its price advantage. Such a projection of the price of these commodities however, could prove challenging. Instead, in order to provide a detailed analysis and better understanding of the behavior of natural gas prices in comparison to the other conventional marine bunkers throughout the years, this research will examine how they behave on a day to day basis through investigating the volatilities of their prices' returns. As the daily spot price fluctuation of the fuel prices might affect the operational costs and the fuel cost savings of a shipping company and therefore their decision for which fuel to use. Moreover, Aagesen, Ajala and Nicoll (2012) stated, that if shipowners can obtain LNG fuel cheaper than HFO or MGO and at a less volatile price, they may be more convinced to shift to LNG as the preferred fuel in the future. Therefore, the following analysis will shed light on how volatile the LNG price is and consequently, to what extent can this attribute of the price, affect the decision making of shipowners.

In the previous paragraph, the main drawn conclusion was that both LNG price approximates i.e. HH and NBP were the relatively lowest prices for the last eight years. Although, there is another aspect of the commodities' prices that should be considered by the shipowners. That is the variability of the percentage changes of the prices. In other words, it is desirable that the price remains at low levels and at the same time the percentage changes of the prices to remain small in absolute terms and stable. Dramatic percentage changes are not desirable because this would consequently mean dramatic price changes. Purpose of this paragraph is the investigation of the volatility of the prices' percentage changes. More specifically, for this variability analysis a conditional time varying volatility model is used. That is the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model of Engle (1982) and Bollerslev (1986).

The first step of this volatility analysis is to calculate the percentage changes. The percentage changes or returns of the closing prices are calculated as

$$r_t = \frac{P_t - P_{t-1}}{P_{t-1}} \tag{1}$$

for each of the selected eight fuels. Each of the next plots displays the percentage changes of the two LNG approximates with respect to those of the rest of the selected fuels, while Table 3 presents the basic statistical features of the percentage changes time series.

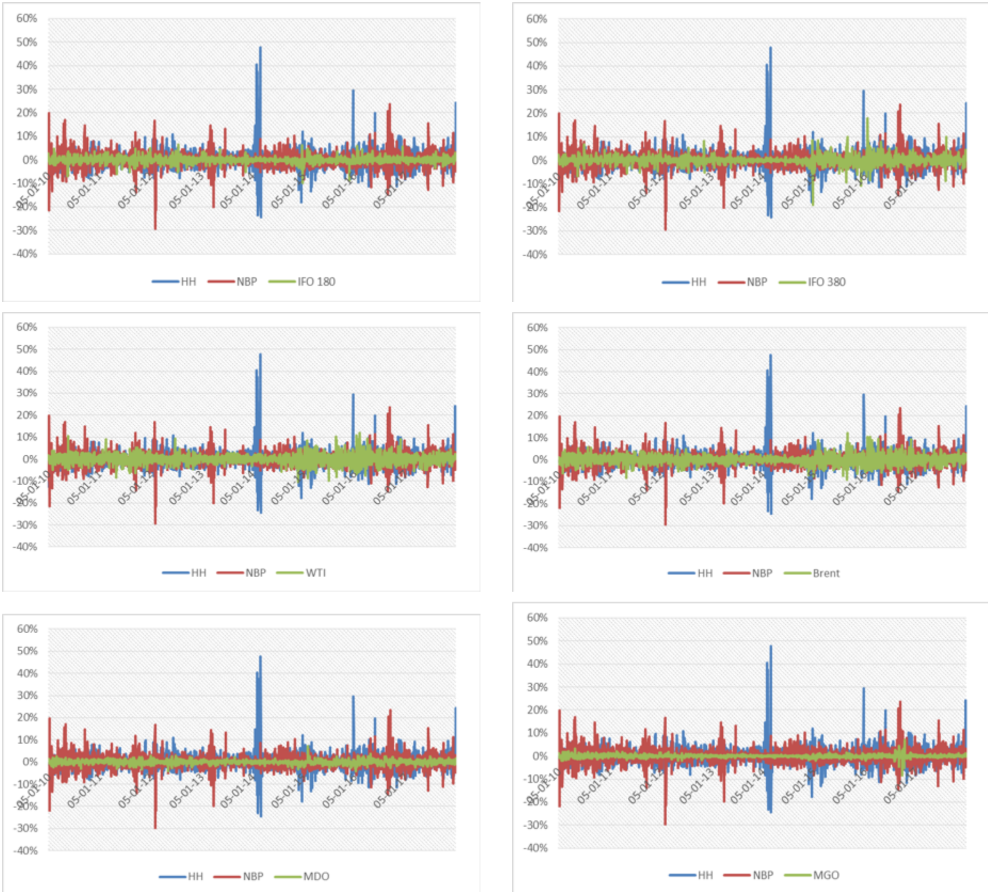

Figure 7: Returns of the prices of each fuel oil compared to HH & NBP.

Statistic \ Series	HH	NBP	IFO 180	IFO 380	Brent	WTI	MDO	MGO
μ	0.04%	0.06%	0.00%	0.00%	0.01%	0.01%	0.00%	0.00%
σ^2	0.14%	0.11%	0.01%	0.03%	0.04%	0.04%	0.01%	0.00%
σ	3.69%	3.35	1.11	1.66	1.94	2.12	0.85	0.59
Max	47.71%	23.51%	6.41%	17.70%	12.11%	11.95%	7.22%	6.96%
Min	-24.30%	-29.37%	-9.84%	-18.83%	-9.26%	-10.53%	-4.26%	-7.99%
$Observations$	2,035	2,035	2,035	2,035	2,035	2,035	2,035	2,035

Table 3: Statistical features of the percentage changes.

It can be concluded from the above complex of graphs (Figure 7) and Table 3, that both LNG price approximates display larger percentage changes. The difference seems significant for the cases of IFO 180, IFO 380, MDO and MGO. For the cases of Brent and WTI, the difference is clearly visible before 2015 while after that year, the magnitude of the crude oil returns increase to the levels of the two natural gases. These visual findings are also verified by Table 3, where someone can see that both HH and NBP have larger averages than the rest of the fuels, far larger unconditional variances, unconditional volatilities, and value ranges i.e. minimum and maximum.

In order to obtain a more proper graphical insight in the variability of the prices' percentage changes, a volatility model will be applied on the returns' time series. That is the GARCH model of Engle (1982) and Bollerslev (1986) applied on the percentage changes time series of the selected bunker fuel prices. The GARCH model consists of the following equations

$$\begin{aligned} r_t &= \sigma_t z_t \\ \sigma_t &= \omega + \alpha r_{t-1}^2 + \beta \sigma_{t-1}^2 \\ z_t \sim \mathrm{N}(0,1), \quad t = 1,2,3,..., \quad & \omega > 0, \alpha > 0, 0 < \beta < 1 \end{aligned} \tag{2}$$

where, r_t are the percentage changes, σ_t is the volatility term which is allowed to evolve in time t by having its own equation (second equation in the above system) and z_t is the error term which is assumed to follow a normal distribution with zero mean and unit variance. The terms ω,α and β are the strictly positive parameters of the model which are estimated via the Maximum Likelihood methodology[9]. By applying the model to the data the following graphical summary emerges.

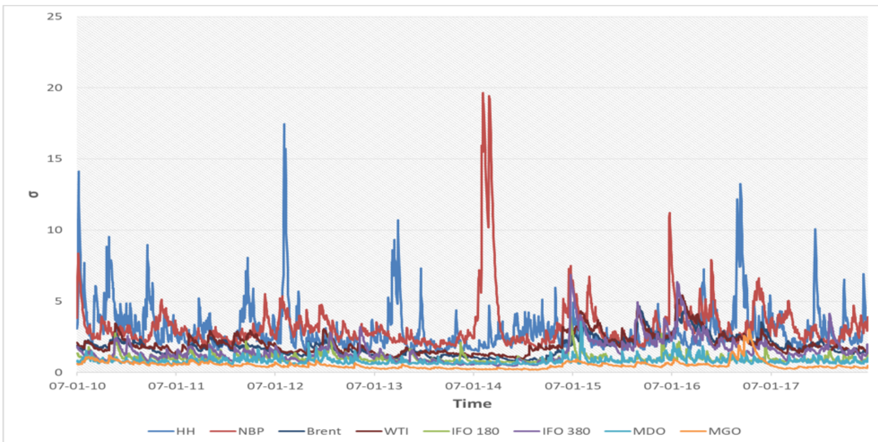

Figure 8: Volatility of the prices of natural gas and other fuel oils.

Parameters \ Series	HH	NBP	IFO 180	IFO 380	Brent	WTI	MDO	MGO
$\hat{\omega}$	0.265	0.529	0.099	0.012	0.014	0.038	0.093	0.001
$\hat{\alpha}$	0.127	0.244	0.097	0.098	0.057	0.062	0.199	0.086
$\hat{\beta}$	0.861	0.724	0.921	0.910	0.941	0.931	0.679	0.917

Table 4: Estimated parameters.

[9]For reasons of brevity a detailed and analytical explanation of the Maximum Likelihood methodology is not provided in this research. For more details please look at Engel (1982) and Bollerslev (1986).

In the above graph it is clear that the estimated time varying volatility of the percentage changes of the two LNG approximates are almost continuously at a higher level than those of the rest of selected commodities. The only exemption is the period 2015-2016 where it can be seen that some of the rest time varying volatilities (Brent, WTI and IFO 380) reach and on a few occasions surpass the levels of HH and NBP. It must be stated that the percentage changes of both HH and NBP are highly volatile which means that their prices could display heavier (relatively to the rest of the fuels) changes in the short-term horizon, both positive and negative. This implies uncertainty regarding the short-term future. This conclusion has an intuitive explanation. The main reason that the natural gas price displays more radical changes from day to day is that it is a significantly smaller market and thus more sensitive to the laws of supply and demand (U.S. Energy InformationAdministration website), than that of oil. In the oil time series of this analysis, long term trend changes can be seen, but not extreme changes from day to day. Contrary, this is something that it is observed in the natural gas time series such as the two pre-mentioned examples at the beginning of 2012, 2013 and 2014, from which it was observed how sensitive the natural gas price is, to an increase in demand caused by the lower weather temperature conditions. From this explanation, an additional conclusion can be drawn. Since natural gas market is relatively small and highly sensitive from the demand and supply of several industries, then LNG price will be sensitive to these factors as well since it is highly linked to the natural gas prices.

Consequently, Natural Gas has unquestionably a price advantage over the alternative bunker fuels. Yet, its price returns are highly volatile relatively to those of the others and therefore more unpredictable. However, Sames (2011) and Ashworth (2012), observe that although LNG has a competitive price advantage, this price does not represent the final price of the ship fuel payed by the shipowners. The final LNG price includes costs such as the distribution costs and the costs of the LNG bunkering operations (Magalog Project, 2008).

4.3 Availability of Bunkering Infrastructure

The superiority of LNG as a cleaner fuel that meets all regulation limits, and its price advantage in comparison to other marine bunker fuels mentioned in the previous sections are the two main factors that would play a beneficial role to the development of LNG as a ship fuel. In additions to these two factors, many studies (e.g. Lasse Karlsen, 2012; Aagesen et al., 2012 and Sames et al.,2011) agree that the existence of LNG bunkering facilities and distribution networks for delivering LNG to ships, would influence the expansion of LNG fuel in the shipping industry.

Traditional marine bunker fuels are available and have an established market, with established fuel distribution networks and bunkering facilities, which enables them to be supplied to shipowners in a safe, cost-efficient and reliable manner. LNG however, lacks such scale of network and infrastructures and creates a barrier for its development. This challenge is represented with the *chicken-and-egg* problem. Natural Gas suppliers will not make the necessary investments to provide the infrastructure needed, to make LNG available to shipowners, if they are not confident that there will be adequate demand for LNG fuel, and shipowners on the other hand will not put money into building LNG-fuelled ships or converting their existing fleet if LNG is not yet available. As stated by Balon et al. (2012) and in the Magalog project (2008), government intervention, might resolve the first mover disadvantages, by funding or subsidizing, the construction of bunkering facilities and the retrofitting or construction of LNG-fuelled ships. Such intervention could prove catalytic to the wide development of LNG as bunker fuel.

It is pointed out by TEN-T (2012), that in order for shipowners to become interested in adopting LNG as a fuel for their ships, the continuous development of a sufficient LNG infrastructure network is necessary. The same study explains that an LNG bunkering infrastructure has two dimensions, a “soft” dimension focusing on regulations and industry standards, and a “hard” dimension focusing on the physical system such as bunkering terminals, bunker ships and tank trucks. Both dimensions are not yet developed in many countries around the world. Currently, LNG bunkering facilities are concentrated in the areas that are under strict air emission limits, that have access to LNG from regasification (import terminals) or liquefaction (export terminals) facilities. (GIE, 2015). This phenomenon may be observed due to the fact that, the development of a new LNG production facility to support the LNG demand from LNG-fuelled vessels could almost double the price of the LNG, delivered to the vessel. Therefore, taking advantage of the already existing LNG import or export terminals close to the call port of the LNG-fuelled vessels can be proven to be more economic as it could reduce LNG delivery cost and as a result, shipowners will be able to achieve higher annual vessel fuel cost savings (Balon et al., 2012).

4.3.1 Types of LNG Bunkering Solutions

LNG can be supplied by two alternative ways, in order to become available as a ship’s fuel. Those are the small scale, and the large scale LNG. Small scale LNG denotes the production of LNG from natural gas sources that is located close to the bunkering facilities. On the other hand, large scale LNG refers to the provision of LNG from imported natural gas from sources further away (Magalog Project, 2008). Subsequently, LNG bunker can become available at ports, for LNG-fuelled ships, in four different modes (Figure 9).

Tank-Truck to ship: LNG is transported by road and the filling takes place directly at the port from a LNG truck. This mode is relatively easy to establish and inexpensive to invest for small amounts of LNG, but it is not practical or cost effective for larger quantities.

LNG Terminal-to-ship via Pipeline (TPS): The supply of LNG happens through the transfer of LNG from a terminal to a ship via a pipeline and a loading arm.

Ship-to-Ship: LNG bunkering occurs alongside quays, but it is also possible to bunker at berth or at sea, by using a LNG bunker vessel. This option is considered as the most practicable long term option due to its flexible operation in terms of bunkering place and time (e.g. bunkering during cargo handling at berth), but it requires a sufficient volume of LNG traffic and good weather conditions.

LNG Containers Loaded On Board: Portable LNG tanks loaded on board and used as fuel, which is regarded as a viable solution especially for inland waterway transport.(Notteboom and Wang, 2004)

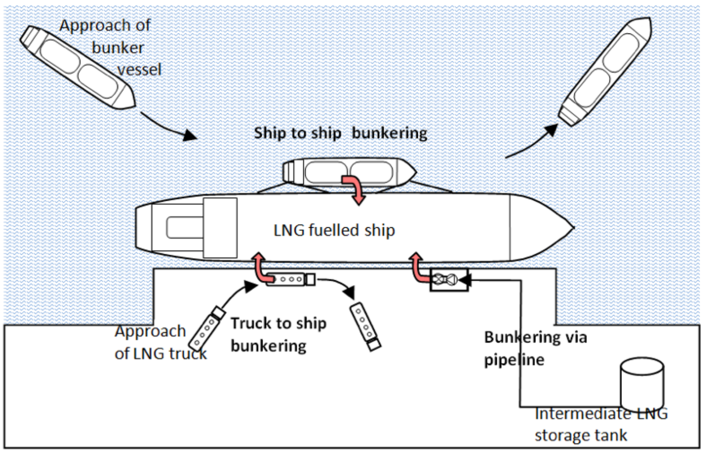

Figure 9: LNG bunkering modes (TEN-T, 2012).

4.4 Investment Cost for the Adoption of LNG as a Ship Fuel.

Another important factor that would influence the growth of LNG is the high capital costs needed, to convert an existing vessel to LNG-powered or to order a new LNG-powered vessel. According to Notteboom and Wang (2014) the high costs play a crucial role to the decision of shipowners and to construct an LNG-fuelled vessel is estimated to be between 20 to 25% higher in comparison to an equivalent oil-fuelled vessel, According to Balon et al., the high capital costs is one of the two major impediments for the use of LNG as a fuel. He states that it can cost almost 11 million dollars to convert a passenger/car ferry to LNG-powered. It was estimated that in a course of ten years a medium-sized ferry can save about 11 million dollars and pay back the investment costs. Both articles support, that the decision of shipowners to adopt LNG as a fuel, regarding the significant capital costs, will depend on the potential fuel cost savings, due to the low LNG price, the lower fuel use, and the lower operational costs, and therefore benefit from a desirable payback time of the large capital expenses. Additionally, many studies (Verbeek, 2011; Balon et al., 2012; Magalog Project, 2008) they state that the costs for a LNG-fuelled newbuilding is less than the cost needed to convert a similar existing vessel. LNG is therefore more feasible for new ships.

4.5 Secondary Factors that would Affect the Adoption of LNG as a Ship Fuel

The adoption of LNG as a ship fuel on a wide scale relies on the main factors described above. Nonetheless, there are many other elements that would have an effect on the decision making of the shipowners who consider the adoption of LNG for their ships, and the general development of LNG as a fuel, and therefore need to be examined.

Such an issue that would affect the decision of shipowners in some parts of the world is the undeveloped 'soft dimension' of the LNG bunkering infrastructures. The lack of a regulatory framework in some countries for the handling and bunkering operations of LNG could prevent shipowners from adopting LNG. However, in the beginning of 2018 the European Maritime Safety Agency (EMSA) issued a guideline in cooperation with the European Union, its member states and the industry within the context of the European Sustainable Shipping Forum. This guideline intents to support port authorities and administration for backing the use of LNG as a ship fuel, in an effort to increase safety and sustainability (EMSA,2018).

Additionally, a factor that shipowners need to take into consideration when deciding whether to adopt LNG, is the characteristics of the candidate ships. There are some shipping operation attributes in which the use of LNG as a marine fuel is more suitable. These attributes are, according to Andreola and Schmill (2001) and Notteboom and Wang (2014) are:

1. The sailing pattern of the ship, e.g.regularity, with high frequency, steady route, and short hauling. As it is important to understand whether the vessel has a stable refuelling port and the chance to refuel often. Due to the substantially large space required by the LNG system and tanks, LNG is more compatible with this sailing pattern, that would not require to store large amounts of LNG fuel.

2. The fuel consumption and intensive engine utilization. It is more eco-

nomically beneficial when fuel consumption and engine utilization are high, as it is a way to maximize annual fuel cost savings and counteract the high costs of LNG technology investment.

3. The life-cycle of the vessel and the fleets renewal potential, in order to valuate whether it is economically feasible to convert a ship or to replace it.

According to the above service characteristics, LNG will, most probably, be firstly adopted in ferry routes, as the passenger shipping industry is the best candidate for the application of LNG as a fuel (Notteboom and Wang, 2014; Tzanatos and Nikitakos,2013). Therefore, passenger shipowners could be more willing to adopt LNG in comparison to shipowners of other ship categories.

5 The Current Use of LNG in the Shipping Industry

The use of LNG as a ship fuel goes back more than 40 years. LNG carriers were the first to use natural gas as part of their ship propulsion. More precisely, in order for these tankers to carry natural gas, it is liquefied at a temperature of -163°, which is close to its vaporization temperature. From the transferred LNG cargo there is always a small evaporated amount, despite the specialized tank design for heat insulation. This small evaporated amount is known as *boil-off* and it has to be removed from the cargo tanks for maintaining the tank pressure. Hence, LNG tankers were, and still are, able to use this boil-off natural gas to power their ships (Notteboom and Wang, 2014 and Babicz, 2015). In 2000 however, LNG was used to power the first ship besides LNG carriers.

A Norwegian domestic ferry named *Glutra*, owned by the ferry company *Fjord 1*, was the first non-LNG tanker that ever used LNG as a fuel. In the following three years, two Platform Supply Vessels (PSV) were constructed and from 2006 and onward, the Norwegian LNG-fuelled fleet kept growing, reaching today's number of more than 58 LNG-fuelled vessels.

There were many reasons observing this increased adoption of LNG in Norway. The most important, is that Norway has one of the largest reserves of oil and natural gas on the European continent (Magalog, 2008). In order to set these reserves in production, Norway established several LNG production plants along with multiple LNG receiving terminals. The transportation of LNG from the production to the receiving terminals is done by trucks or LNG carriers. In addition to the above mentioned abundance of natural gas, Norway was concerned about its NO_X emission levels during the last decades, which caused the implementation of Norway's domestic NO_X fund. These last two facts, triggered the development of LNG-fuelled vessels in Norway (Latarche, 2017). The NO_X Fund was established in 2008, with the purpose to reduce NO_X emissions in Norway. Vessels would be taxed a certain amount on every kilo of NO_X emissions and the amount of the taxes would be added to the fund. This fund was used to finance investments that had the objective to reduce NO_X. Switching to LNG fuel, which reduces NO_X emissions by more than 85%, such an investment was. The fund granted support for many LNG-fuelled ships, converted or newbuilds (Andreola and Schmill, 2011).

It is clear that the last 18 years, LNG is gradually gaining ground as a ship fuel in various vessel types, beyond LNG tankers around the world, further than Norway. In 2013 other countries followed Norway's example by constructing LNG-fuelled vessels. The first LNG-powered vessels outside of Norway were found in the Baltic Sea and in Uruguay. From 2014 and onward, an increase in LNG-fuelled vessels was observed in Europe and a year later in North America. More specifically, currently, there are nearly 118 LNG-fuelled ships in service and more than 100 on order. It is significant to note that out of the 118 vessels in service only 6 are retrofittings while the rest are newbuildings, and 5 out of the 100 ordered vessels are vessels under the conversion process. Hence, we can conclude that LNG is mostly gaining momentum in newly-build ships than in already existing vessels.

Almost 70% of the in-service fleet operates in the European Economic Zone, 14% in America, 8.5% operates globally and the rest 7.5% operates in Australia, Middle East, and Asia (see Figure 10).

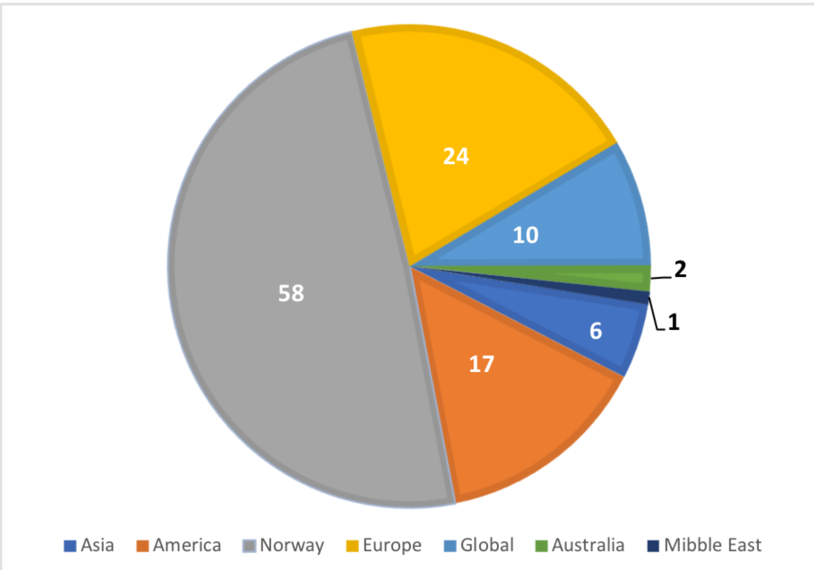

Figure 10: LNG-fuelled ships in service around the world.

From Figure 11 it is clear that the cumulative number of LNG-fuelled ships in operation and on order increases exponentially over time. At the same Figure, the two columns of 2018, the darker blue and lighter blue, represent the LNG-fuelled ships that are in service today and the number of LNG-fuelled ships expected to be active by the end of 2018, according to orders that are due to be delivered in 2018, respectively. Assuming that all ships due to be delivered in 2018, are delivered on time, an almost 52% increase in the active LNG-fuelled fleet will be observed from the end of 2017 until the end of 2018. A similar growth rate of 43%, will be observed to the existing fleet from the end of 2018 until the end of 2019 assuming again that all orders are delivered on time. Someone could agree, that this growth rate of the number of LNG-fuelled ships is impressive.

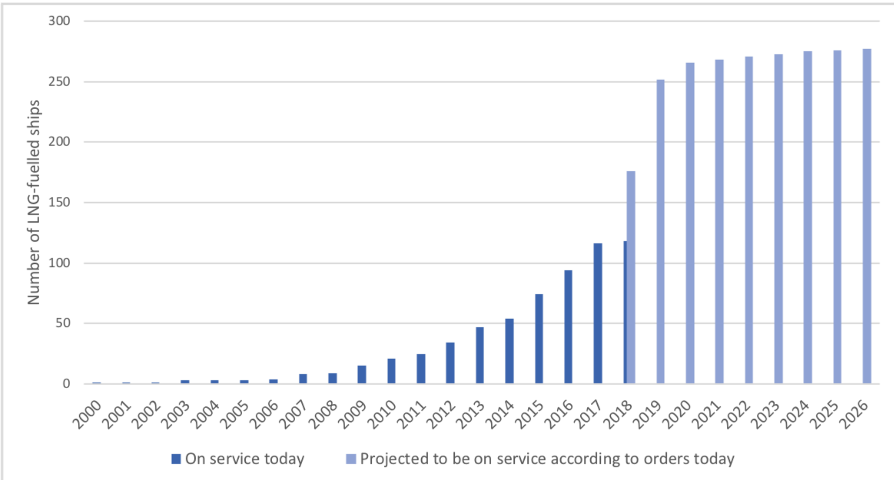

Figure 11: LNG-fuelled ships in service according to orders in 2018.

Furthermore, it is also important to look into the different vessel types that use LNG as fuel, in order to understand in which vessel type segments LNG is thriving and what implication this may have to the evolution of LNG as a fuel in the future. Figure 12 depicts the sum of LNG-fuelled vessels in service and on order for each ship type. The most important information derived from this Figure is that the type of ship with the highest number of ships in service and on order in the passenger one. Passenger shipping accounts for almost 34% of the total existing and ordered LNG-fuelled vessels. The second in line vessel type, which accounts for 25.5% of the total, is the service & supply vessels. However, the increase in demand for new LNG-fuelled vessels has been considerable for tankers and bulkers. The number of ordered LNG-fuelled tanker and bulk carriers approaches the corresponding number of passenger ships.

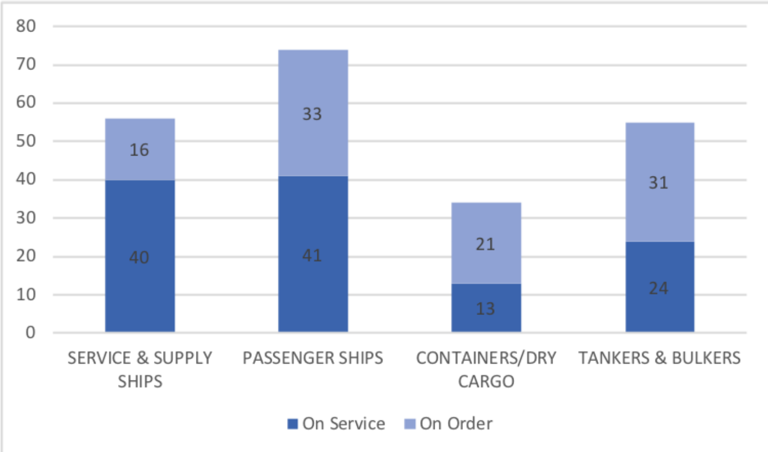

Figure 12: LNG-fuelled ships in service and on order by ship type.

Information on the number of LNG-fuelled vessels in service and on order where extracted from a list, posted on the website of LNG world shipping, by Corkhill (2017a&b). Adjustments where made on the list as some vessels on order have been delivered and some shipping companies have ordered LNG-fuelled vessels since then (CMA-CGM and Carnival Corporation website, accessed April 2018). The areas on which these vessels operate were found by extracting information of each vessel from the Marine Traffic website.

Finally, regarding the LNG bunkering facilities, as stated in section 6.3, it is observed that they are all concentrated in areas under strict ship air emission limits and most importantly in areas that have direct access to LNG regasification or liquefaction facilities. Additionally, LNG bunkering operations are planned to begin or have already taken place in areas that are not ECAs but have access to LNG terminals, such as, in Italy and Spain (GIE, 2015).

6 Greek Passenger Shipping as a Potential Market for the Adoption of LNG as a Ship Fuel

The most important characteristic of Greece is its morphology. Greece consists of almost 6.000 island and islets, scattered in the Aegean and Ionian sea, 227 of them are inhabited (visit Greece website, 2018). The coastline of Greece is 14,880 km (of which 7.500 km is the seaside) which is 92.80% of the country's overall perimeter (16,040 km) (as listed in geofylakto website, 2013). The extensive coastline and the impressive insular character of Greece and due to the fact that many islands can be reached only by ship, rendered the country to be one of the leading countries of the EU in passenger shipping. As listed in the website of the Greek passenger shipping companies association (SEEN), as of 26 November 2017, Greece represents

17% of the total number of passengers traveled by sea in Europe, with Italy leading, as the country accounts for the 17.3%.

Greek passenger shipping consists of 350 vessels of various types and sizes (including those of less than 400 tonnage and pleasure boats) which offer connection from the 40 mainland to 100 island ports. Due to the seasonal (summer) arrival of tourists and residents in the Greek coastline, the population within 2 and 50 km from the seaside, can increase from 35% of the country's total population, which is the permanent population of the coastline, to 85%. This extensive domestic shipping operations contributes significantly to the air emissions of the country and consequently has a direct effect on the pollution and the environment and can harm the Greek coastal population and visitors (Tzanatos and Nikitakos, 2013).

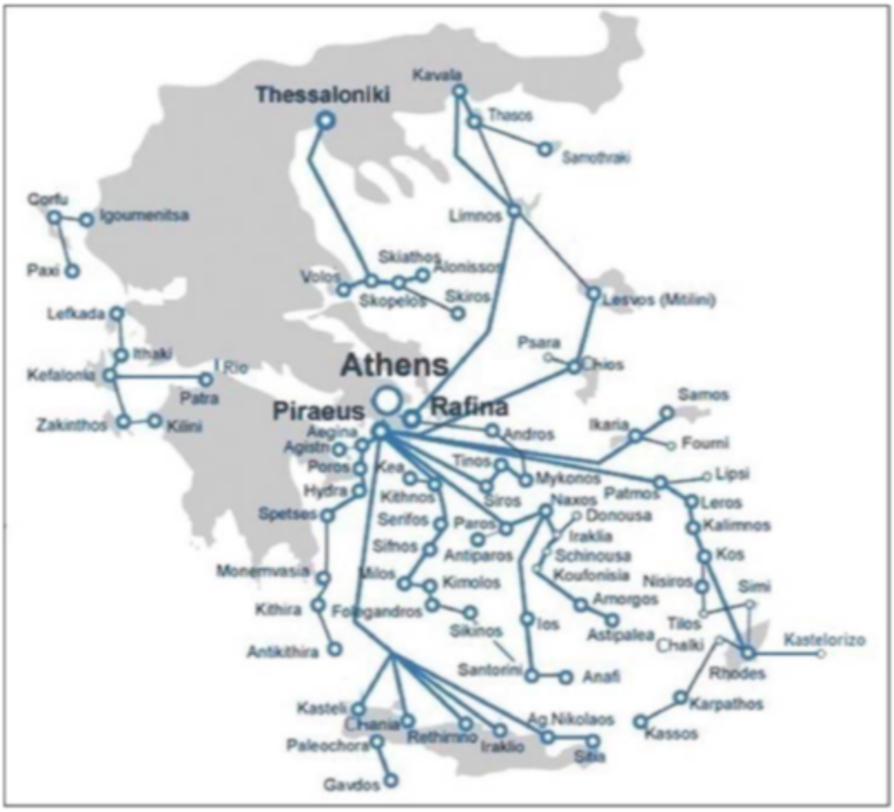

Figure 13: Passenger shipping network in Greece (Tzanatos and Nikitakos, 2013).

Furthermore, while the date of the implementation of the regulations of MARPOL *Annex VI* (referred in chapter 4) is subject to change and be postponed to 2025, Greece will be subject to the air emission regulations of the EU Directive 2016/802 in 2020. Additionally, Greece is a member state of the Kyoto protocol and the Paris agreement and hence is committed to achieve the GHG reduction target, by reducing its national carbon footprint.

As stated in section 4.1.2, domestic shipping is included in the estimation of the national carbon footprint. Therefore, the Greek passenger shipping industry has to consider all the alternatives for the sustainable operation of its fleet, in order to reduce its exhaust emissions and consequently comply to the air emission regulations in 2020.

At the same time, it was concluded in the previous chapters, that the passenger shipping industry is one of the best candidates to adopt LNG as a cleaner fuel for its ships, and in addition, LNG-fuelled passenger ships are thriving in other countries. Therefore, LNG can also be considered as an alternative fuel in the Greek passenger shipping industry.

Tzanatos and Nikitakos (2013), who examined the use of LNG in comparison to oil in Greek passenger shipping, found that the exhaust pollutants (SO_2 , PM and NO_X) produced by the passenger shipping in Greece, were on average equal to 37.5 thousand tons per year, and they also found that changing from fuel oil to natural gas, would reduce their annual contribution to the country's air pollution to 3.56 thousand tons. Regarding the GHG they found that Greek passenger shipping produces on average 1.2 million tons per year, however, a change of fuel to natural gas would reduce CO_2 emissions by 34.2%, resulting in an annual average level of around 800 thousand tons.

Additionally, as stated in chapter 4 in the section of bunkering facilities, the use of LNG as a fuel in shipping can benefit from the existence of a natural gas regasification of liquefaction facility, close to the ports where LNG-fuelled ships will operate and refuel. Since 1999, a LNG import (regasification) terminal operates in Greece at the island of Revithoussa, located almost 20 km west from the main port of Piraeus. Revithoussa's LNG terminal is operated by DESFA (Hellenic gas transmission system operator) and as they have listed on their website, it consists of two tanks of total capacity of 130.000 cubic meters and currently a third storage tank is planned which will have capacity of 95.000 cubic meters of LNG. Moreover, according to GIE small scale LNG database posted on GIE's website, more services are planned to be offered at Revithoussas LNG terminal. Such services are, truck loading, due to commence by 2019 and reloading small and large scale LNG. These additional services, can hasten the provision of LNG bunkering services in the port of Piraeus and other ports in the close proximity, by reloading LNG bunker barges and tank-trucks, for the ship-to-ship and the truck-to-ship mode, respectively. Finally, a new LNG facility is planned to be built in north Greece, at the city of Alexandroupoli. The existence of Revithoussas terminal, and the possibility of the construction of a new one can prove to be a driver for the LNG adoption in the Greek passenger shipping.

7 Greek Passenger Shipping Findings & Discussion

7.1 Research procedure & Findings

In the first chapter, two sub-questions where set under investigation in order to answer the main research question of this thesis, which aims to understand the possibilities and limitations of the adoption of LNG as a ship fuel in Greek passenger shipping. This chapter attempts to answer the second sub-question which explores, firstly, how can the Greek passenger shipping stakeholders provide a more detailed insight to the possibility of adopting LNG as a fuel in the Greek ferries and secondly, to what extend can the LNG price and its returns' volatility in comparison to those of alternative fuels, affect the decision making of the Greek passenger shipowners.

In order to investigate these questions, a two-sided research was conducted. Firstly, a questionnaire was designed targeting Greek passenger shipping companies. Consequently, a set of questions was created with the intention to interview entities related to the Greek passenger shipping and to LNG adoption projects. Both questionnaire and interviews were designed according to the findings from the literature. The questionnaire consisted of 15, both open and multiple choice, questions (the questionnaire can be found in the Appendix). It was send to 21 Greek passenger shipping companies, which practically represent the total number of such companies in Greece, taking into consideration that there are many joint ventures. The companies received the questionnaire for the first time on the 19th of March upon a notification over the phone. The responses were collected in a time-frame of 7 weeks. During this period the companies were receiving the questionnaire and notifications over the phone in order to collect as many as responses as possible. Out of the 21 companies only 10 responded to the questionnaire. The fact that more than half of the Greek passenger shipping companies were reluctant to give out information through answering the questionnaire, poses a limitation to the purpose of this research. However, it is important to note that the Greek passenger fleet consists of 97 ships (as listed on the website of the association of the Greek passenger shipping companies), and the companies who responded have a total number of 67 ships. Therefore, the respondents represent the 69% of the total number of the Greek passenger fleet.

Regarding the interviews, an attempt was made to come in touch with industry experts, such as academics, consultancy companies to the maritime and energy industry, classification societies, passenger shipping associations and projects for the adoption of LNG in the Mediterranean. Due to the disclosure of information policy of some companies and the reluctance of others to participate in the interview, made it possible to only interview three entities. Those are, the association of Greek passenger shipping companies

(GPSA), a classification society (CS) and a European project (EP) for the adoption of LNG in the Eastern Mediterranean sea which is coordinated by a natural gas supplier in Greece.

As it was discussed above, out of the 21 Greek passenger shipping companies that received the questionnaire, 10 have responded. Some of the findings from their answers will be discussed below.

Figure 14 illustrates the answers the companies gave when they were asked how they will respond to the stricter limits of fuel sulphur content of 2020. 90% of the companies see low-sulphur distillate fuels as their short term solution and the rest 10%, will opt a combination of LSFO (up to 0.5% sulphur content), and MDO (0.1% sulphur content) at berths. Most companies (50%), perceive scrubbers as their long term solution, while 30% and 20% chose the combination of LSFO and MDO/MGO, and distillate fuels, respectively. Regarding LNG as a compliance solution to the regulations, 50% responded that they have no intention of using it and 40% are not sure if they would use it.

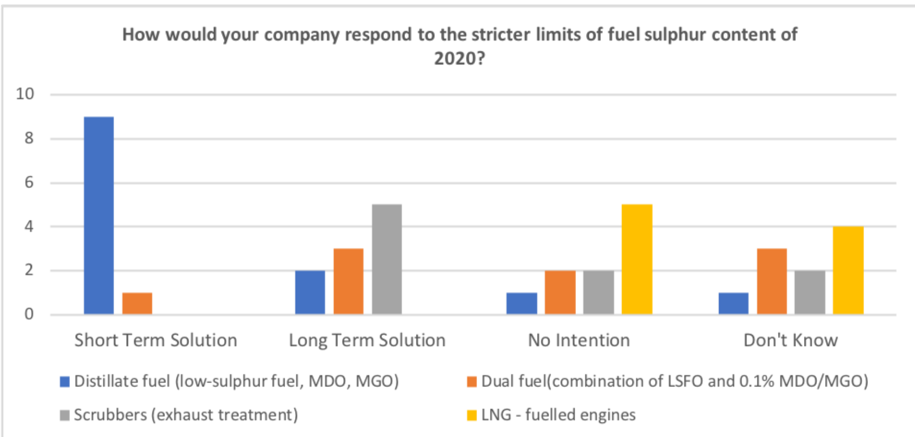

Figure 14: Intentions of Greek passenger shipowners for regulation compliance.

To the question of what they consider the most important factors for adopting or not LNG as a fuel for their ships, the majority responded that they consider of high importance the price of LNG in comparison to other fuels, the cost to install the LNG technology, the availability of bunkering facilities at local ports, the governmental support and finally, their compliance to the regulatory framework regarding air emissions. The availability of a regulatory framework for the use of LNG and their company's positive perception from the public, are viewed as factors of slightly less importance (see Figure 15).

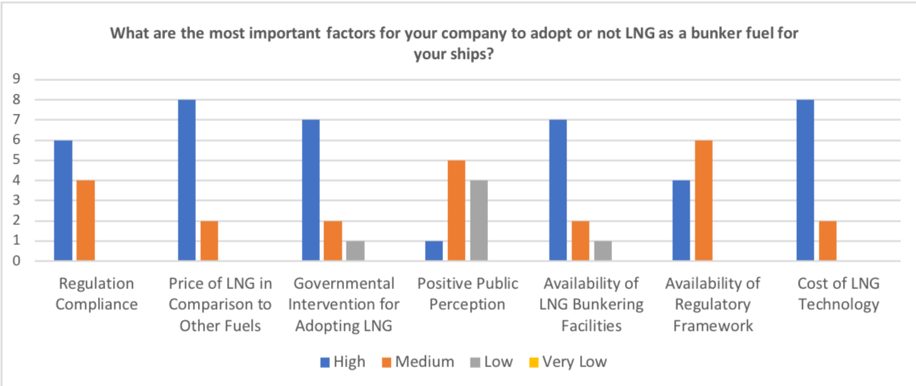

Figure 15: Factors that affect the adoption of LNG according Greek passenger shipping companies.

Finally, in order to understand to what extend will the LNG price and its price return volatility affect shipowners on their decision to adopt LNG, companies were asked whether they would consider the adoption of LNG, from the implications of Figure 6 on the price of LNG in comparison to the other fuels, and whether the results on the price return volatility of the different bunker fuels in Figure 8 would affect them negatively and cause them to reconsider adopting LNG. 100% of the respondents were affirmative on the first question. Regarding the volatility of the prices' returns however, 50% responded that they would not reconsider the adoption of LNG and the rest 50% said that they would (see Table 5).

Companies	Number of Ships	Positively affected by LNG price	Negatively affected by LNG volatility	Scale (1-5) of negative effect of volatility
1	4	Yes	No	
2	15	Yes	No	
3	3	Yes	Yes	4
4	1	Yes	Yes	2
5	3	Yes	Yes	3
6	3	Yes	Yes	3
7	2	Yes	Yes	3
8	18	Yes	No	
9	7	Yes	No	
10	11	Yes	No	

Table 5: Responses to questions 4, 12, 13 and 14 of the questionnaire (see Appendix).

In an attempt to achieve one of the purposes of this thesis research, the answers to the open questions asked in the shipping companies' survey and the experts' interview will be presented, and analyzed together with the above findings, in the following part.

7.2 Research Analysis

7.2.1 Insight to the Possibility of the Adoption of LNG as a Fuel in Greek Ferries

According to the EP the most important factor for the adoption of LNG in the Greek passenger shipping is divided in two dimensions. These dimensions are the supply and demand of LNG, the so-called "chicken-and-egg" problem. Supply is regarded as the existence of infrastructure at Greek ports that would make LNG available for the delivery to LNG-fuelled ships. Demand of LNG, is interpreted as the existence of adequate LNG-fuelled ships. The CS supported that shipowners have to take action and choose an alternative that abides by the regulations, and LNG, being a cleaner fuel that offers full compliance to the air emission limits, is the way to do so.

All three interviewed entities strongly believe in LNG as an alternative cleaner fuel and that it is feasible in the Greek passenger shipping industry, but they point out that there are some pending issues that need to be resolved. All of the shipping companies seem to agree with that statement, but most of them expressed their concern about two significant impediments for them to adopt LNG as a fuel for their ships. Five out of ten respondents referred to the lack of LNG bunkering facilities in Greek ports, and eight out of ten, that the investment costs needed to retrofit their ships are rather high (three out of ten referred to both). Additionally, four of the respondents noted that the adoption of LNG would become feasible with European or governmental financial support. Nevertheless, the CS and the EP argued that the most significant impediment is the high investment costs necessary to adopt LNG since there will be a bunkering facility in Greece before 2020. More specifically, the CS speculates that this facility will be located at the port of Patras and LNG will be supplied with feeder vessels, most probably from Revithousa's LNG terminal. The EP estimates that in addition to the first facility before 2020, multiple facilities will be constructed across Greece until 2025. Moreover, according to the CS and EP, in order to tackle the barrier of the high investment costs, that concerns shipowners, efforts are being made to receive financial support from both the European Union and the Greek government. Both entities were optimistic that such financial contribution will be achieved shortly. Finally, a shipping company and the CS referred to the need of a legislative framework for bunkering operations and safe refueling while loading and unloading passengers and or vehicles. The CS reassured that the European Maritime Safety Agency (EMSA) has issued a guidance on LNG bunkering which will be used by those concerned in Greece in order to issue a national legislative framework by 2020.

As a solution to the regulations on ship air emissions, it can be concluded from Figure 14, that the majority of the existing passenger fleet will use, as a short term solution, distillate fuels such as MDO/MGO and scrubbers as a long term solution. This was also confirmed by the CS, and the GPSA who stated that the majority of the ships in the association will use scrubbers as their long term solution.

Not one of the Greek passenger shipping companies plans to adopt LNG in the following years. Nine respondents claimed that they would only consider the adoption of LNG in new buildings. Similarly, new buildings are considered more suitable to use LNG as a ship fuel by the EP and the CS. The first however, is conducting studies for the design of two Greek ferries to be converted to LNG-powered, and the later believes that once financial support is offered, there is a possibility that the retrofitting of some ships will take place. Otherwise, without the financial intervention, shipowners would only consider the adoption of LNG for their new ships. It is rather challenging for them to say when the first LNG-fuelled passenger ship will operate in Greece. The EP was categorical that there won't be any before 2020, and the CS stated that shipowners have adopted the wait-and-see strategy and it is believed that from the moment the first shipowner will adopt LNG as a bunker fuel, many more will follow. All three interviewed entities, are confident that in the long term, the Greek passenger fleet will definitely consist of many LNG-fuelled ships.

7.2.2 Insight to the Effect of Price and Price Return Volatility of LNG on Shipowners

There are many factors that would affect the adoption of the LNG by the Greek passenger shipping companies. As discussed above shipowners consider the high investment costs and the lack of bunkering infrastructures as two significant barriers for them to move on with the adoption of LNG for their ships. However, as stated by the CS and the EP the latter barrier will be tackled before 2020 and therefore, shipowners who are considering the alternative of the LNG will only worry about the high costs of the investments.

From Figure 15 it can be seen that shipowners perceive the relative price advantage of LNG, and the cost of investments as the most significant, positive and negative, factors for them to adopt LNG. Supposing that LNG holds its low price advantage, it can prove to be a mean of achieving a more rapid payback time on the high LNG technology investment. It is perceived that the low price of LNG can compensate for the high investment costs. Therefore, it is essential that the price of LNG remains at the same low levels and that it does not manifest an unpredictable behavior. Additionally, from Table 5 in the section 6.1, it is clear that all shipping companies surveyed, would consider the adoption of LNG due to its price advantage in comparison to the other alternative fuels.

At the same time, the shipping companies were asked whether the high LNG price volatility in comparison to the alternative fuels, would affect them negatively and make them reconsider the adoption of LNG for their ships. Half of them responded that they would reconsider their decision and half of them responded that they wouldn't be affected by the factor of the volatility. It is worth mentioning that the companies that won't be affected by the high volatility of the LNG price are the companies with the most ships on their fleet. More specifically, two of them have more than 15 ships each. These five passenger shipping companies are considered to be the biggest passenger shipping companies in Greece, they occupy more that thousand employees each and they are based in major Greek ports. Regarding the five companies that would reconsider due to the highly volatile price of LNG, those are smaller shipping companies, with three or less ships, and most of them are based in small Greek islands. From all of the above it could be implied that there is a relation between whether they are affected by the daily fluctuations of the price, and the size of a company and the place where they purchase bunker fuel for their ships. If a company is based on a major port and the more ships it has the less they are exposed to the volatility of the price of a fuel such as LNG.

Bigger companies have, most probably, dedicated personnel that deals with monitoring the oil/gas market and have access to the financial industry. Therefore, they would be able to make predictions of the bunker prices and determine whether it is preferable to buy bunker for immediate operational need, when the prices are high, or to buy with derivative contracts such as futures, when the bunker price is low. For a smaller company it could be of no interest to employ resources in order to have dedicated personnel for such a purpose. Similarly, a company that is based at a major port might have more options from where to acquire bunker fuel, as there are more suppliers and therefore more competition. This makes it possible for them to purchase bunker fuel in lower prices. On the other hand, shipping companies based in small Greek islands have less options as there are not many suppliers and therefore, they could be more exposed in daily bunker price fluctuations.

It is also worth mentioning in this part, that the EP which is coordinated by a natural gas supplier in Greece argued that the high volatility of LNG's price returns couldn't be considered as an inhibitory factor before 2015, for the reason that the price difference of the LNG with the other fuels was rather big (see Figure 6), but after 2015 that the crude oil price dropped dramatically and its difference with the LNG price reduced, the high LNG price volatility of LNG would indeed have some effect on its adoption. It can therefore be concluded that the LNG price volatility may have a greater effect when the price of LNG is close to the price of alternative fuels. Furthermore, the GPSA said that shipping companies create their own fuel price indexes in order to come up with an estimate of the future fuel price level. This can be challenging most of the times due to the crude oil price volatility. Therefore, this can be more challenging in the case of LNG due to its high price volatility.

Consequently, from this research there are indications that the volatility of the LNG price, in comparison to other alternatives, could act as a factor that would influence the decision for the adoption of LNG by certain categories of passenger shipping companies. Nevertheless, due to the fact that not many companies answered the questionnaire, it was not possible to draw a more definite conclusion. For that reason it is suggested that more research is focused on the matter, in order to better understand to what extend this factor affects the decision making of shipowners.

8 Conclusions

This research focuses on the scenario of the implementation of LNG as a ship fuel in the Greek passenger shipping. The limitations and possibilities of this scenario were explored through several methods. Through an extensive content analysis of the literature, news media, and of real-life cases where LNG is already being used as bunker fuel, it was made possible to better understand whether LNG could be feasible in the passenger shipping industry in Greece. Subsequently, with the purpose to provide a better insight to the possibility of the adoption of LNG by Greek passenger ship owners, industry experts and shipowners were interviewed and surveyed, respectively. Finally, along with other factors that would influence the bunker change from fuel oil to LNG, the price and the price return volatility of LNG in comparison to those of other fuels were examined and an effort was made to understand how these factors can affect the LNG adoption in the Greek ferries.

For the fist part of this analysis, the literature review indicated that the two main drivers affecting the LNG adoption are the low natural gas prices relatively to the rest bunker fuel options and the superiority of LNG as a cleaner fuel that offers full compliance to the imminent air emission limits. However, there are also two major impediments that could hinder LNG's development as a fuel. These are, the high investment costs for the conversion/construction of LNG-powered vessels and the lack of LNG bunkering facilities in many countries. At the same time, it was concluded that LNG could thrive as a bunker fuel in many types of ship vessels but most importantly in passenger/car ferries and additionally, it is more feasible with new buildings and not retrofittings. Finally, shipowners who plan to adopt LNG as a bunker fuel for their ships, could benefit from the existence of LNG import/export terminals close to the port where their ships re-fuel, since, it is cost efficient to build LNG bunkering facilities in a close proximity to these terminals. These main drivers, impediments and generally positive and negative factors for the LNG adoption, could also apply to the passenger shipping industry of Greece.

By surveying shipping companies, it is found that Greek passenger shipping companies consider the price as the most important driver. Nevertheless, the high capital costs required for adopting LNG, and the lack of LNG bunckering facilities in the main ports of Greece, discourages them to take this decision. Regarding the regulation compliance offered by LNG, it is not considered as such an important factor as e.g. price advantage, as they are planning to use other alternatives towards meeting the regulations i.e. distillate fuels and scrubbers. Furthermore, they would consider LNG technology installation only in new built ships.

Industry experts support that LNG is an alternative cleaner fuel that it is feasible Greek passenger shipping. They also acknowledge the high investment costs related to the LNG technology installation but they believe that this drawback can be overcome by governmental or EU financial support. They are also confident that the problem of the absence of the LNG bunkering facilities will be resolved by 2020.

While all of the market participants consider the competitive advantage of LNG's price an important factor, there is an aspect of the price that has not been investigated. That is the LNG price returns' volatility, which might influence negatively the decision of LNG adoption, as it is found to be rather high in comparison to that of competitive fuels. This research makes a vague conclusion that it actually does affect negatively shipowners of smaller fleets based in smaller Greek ports. However, more research is required to be focused on that aspect of the price of LNG, such that a more definite conclusion is drawn.

This research concludes that, Greek passenger ship owners are reluctant to adopt LNG due to the limitations posed by the high investment costs and the lack of bunkering facilities. Nevertheless, there is an overall optimism that the possibility of governmental or European financial intervention that would promote the LNG adoption in Greek ferries and the planned designs of LNG bunkering facilities by 2020, facilitated by the existence of Revithousa's LNG terminal, will counteract the previously mentioned limitations and therefore render the adoption of LNG as a fuel in existing vessels and newbuildings of the Greek passenger shipping fleet more feasible especially after 2020. It will take one of the shipping companies motivated enough to make this pioneer change to using LNG as a fuel for their ships, to lead the way for others to follow in its path.

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Appendix

Shipowners' Questionnaire

1. **Your company's name (please note that this will be confidential)**

2. **In which department of your company do you belong?** *
   Mark only one oval.
   - Administrative
   - Technical
   - Financial - Accounting
   - Operation
   - Other:

3. **Which routes does your company service?**

4. **How many ships does your company's fleet consist of?** *

5. **How old are the ships in your company's fleet ?** *
   Check all that apply.
   - Less that 10 years
   - 10 - 20 years
   - 20 - 30 years
   - More than 30 years

6. **Does your fleet consist of ships of 400 gross tonnage or more?** *
   Mark only one oval.
   - Yes
   - No

7. **Are you aware of the MARPOL Annex VI and the EU Directive 2016/802 regulations on ship emissions?** *
Mark only one oval.

- ◯ Yes
- ◯ No

8. **How would your company respond to the stricter limits of fuel sulphur content of 2020?** *
Mark only one oval per row.

	Scrubbers (Exhaust treatment)	Distillate fuel (low - sulphur fuel, MDO, MGO)	Dual fuel	LNG - fuelled engines
Short term solution	◯	◯	◯	◯
Long term solution	◯	◯	◯	◯
No intention	◯	◯	◯	◯
Don't know	◯	◯	◯	◯

9. **Is it in your company's future plans to adopt LNG as a fuel for your ships? If yes, at which vessel age would you consider LNG as an alternative fuel?** *

____

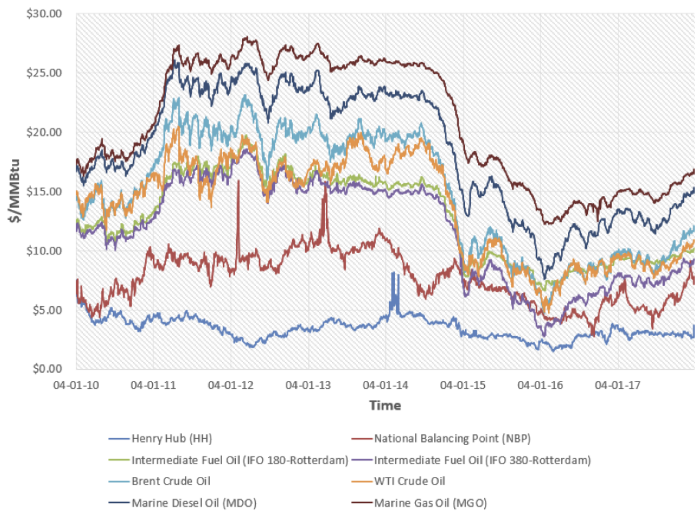
10. **What are the most important factors for your company to adopt or not adopt LNG as a bunker fuel for your ships?** *
Mark only one oval per row.

	High	Medium	Low	Very Low
Regulation compliance	◯	◯	◯	◯
Price of LNG in comparison to other fuels	◯	◯	◯	◯
Government intervention (financing) for adopting the LNG technology	◯	◯	◯	◯
Positive public perception	◯	◯	◯	◯
Availability of LNG - existence of LNG bunkering facilities at the port of call	◯	◯	◯	◯
Availability of a regulatory framework for the application of LNG a ship fuel	◯	◯	◯	◯
Cost of LNG technology (engine and fuel tank)	◯	◯	◯	◯

11. **What do you consider as the most significant impediment for your company in order not to adopt LNG as a ship fuel?**

____

LNG pricing is based on the natural gas prices, they are highly related and their prices are close. The following graph shows the price fluctuations of two natural gases (HH & NBP), two crude oils (WTI & Brent), two residual oils (IFO 180 & IFO 380) and two distillate oils (MDO & MGO) for the period 2010-2017. The graph indicates that for this time period, the two natural gases have a cost advantage in comparison to all the rest.

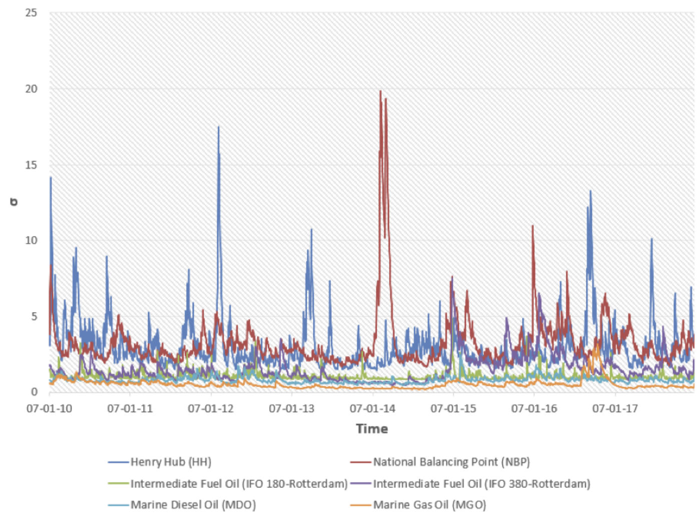


12. **Taking into consideration the above graphical indication of natural gas cost advantage, would your company consider the adoption of LNG as a fuel for your ships?** *

Mark only one oval.

- Yes
- No

The following graph presents the volatility (that changes over time) of the prices' percentage changes of the two natural gases (HH & NBP), the two residual oils (IFO 180 & IFO 380) and two distillate oils (MDO & MGO) for the period 2010-2017. The graph indicates that the natural gas prices are highly volatile and therefore, they could display significant changes (both positive and negative) from day to day in comparison to the rest of the fuels.



13. **Taking into consideration the findings of the above graph, would you reconsider the adoption of LNG as a bunker fuel, in terms of price? (In other words, would it influence you negatively in adopting LNG?)** *

Mark only one oval.

- ◯ Yes
- ◯ No

14. **If yes, on a scale of 1 to 5 how much would it influence you against adopting LNG as a fuel for your vessels?**

Mark only one oval.

	1	2	3	4	5	
Very low	◯	◯	◯	◯	◯	High

15. **How do you see LNG as a ship fuel in the Greek passenger shipping industry and do you believe it will be feasible?**