11-5-2017

LNG as a marine fuel in Malta: case study : regulatory analysis and potential scenarios for LNG bunkering infrastructure

Mark Philip Cassar

WORLD MARITIME UNIVERSITY

Malmö, Sweden

LNG AS A MARINE FUEL IN MALTA

Case Study: Regulatory Analysis and Potential Scenarios for LNG Bunkering Infrastructure

By

MARK PHILIP CASSAR

Malta

A dissertation submitted to the World Maritime University in partial fulfilment of the requirements for the award of the degree of

MASTERS OF SCIENCE

In

MARITIME AFFAIRS

(MARITIME ENERGY MANAGEMENT)

2017

Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

Signature:

Date: 19th September 2017.

Supervised by: Fabio Ballini

Lecturer

World Maritime University

Acknowledgements

I would like to thank the respective personnel from Transport Malta, especially Mr Ivan Sammut, Registrar-General of Shipping and Seamen. I would also like to thank the Sasakawa Peace Foundation, for giving me this golden opportunity to study at the WMU, and for their assistance throughout this fourteen month journey.

I wish to express my gratitude to Professor F. Ballini, my main supervisor and Head of Faculty Professor A.I. Ölçer, for their constant support during the program and for their assistance throughout this study. I am proud to be part of the MEM Faculty, and to have served as the first MEM class course representative. It was an opportunity for me to collaborate with you all. To Professor D. Dalaklis, thank you for assisting me with valuable information and for your expertise on LNG. To the I.T. and library staff, thank you for your kind assistance and the useful library class.

I would like to thank those personnel who have dedicated some of their time to reply to my questionnaire, including the few dedicated people from the respective government agencies in Malta which are involved in structuring the LNG bunkering analysis project.

A special thanks goes to Dr. Kevin Ghirxi, Head of Marine Safety Investigation and former WMU student, for his assistance throughout my study period.

Last but not least, to my family, especially my parents, for their constant support from far away. To Josianne Vella, thank you for being part of this journey with all its drawbacks of being apart for long periods of time. May this opportunity provide us with a bright future together.

Abstract

Title of dissertation: **LNG as a Marine Fuel in Malta. Case Study: Regulatory Analysis and Potential Scenarios for LNG Bunkering Infrastructure**

Degree: **MSc**

With the issues of emissions from ships, regulations have been pushed forward by the International Maritime Organisation (IMO). The European Union (EU) has also adopted stricter regulations for its Member States. This has brought forward the switch to cleaner fuels and their availability. The EU has opted for a region wide infrastructure to make the provision of gas more available. Liquefied natural gas (LNG) proves to be an effective clean fuel; however, it still has it pros and cons.

This study explores the case of Malta, a country that, in addition to the global targets of the IMO, also has the directives of the EU to abide to as a member state. As a small island state at the heart of the Mediterranean Sea, it has a strong maritime industry, with good oil bunkering business opportunities. In the coming years, as we approach the year 2020, the demand for LNG as a ship fuel is expected to increase in the Mediterranean region.

In view of the growing LNG bunkering infrastructure in Northern Europe, and in the Mediterranean still at an early stage, what opinions do people from the LNG field have on its use, and the way it is being implemented? Considering possible LNG availability in Malta after 2024, would it be viable to create an LNG bunkering infrastructure? What regulatory amendments are required to allow the use of LNG within the Maltese ports? Is there a possibility of local demand from the maritime vessels operating solely from the Maltese ports, and would it be viable for these small vessels to switch to LNG? Will small vessel owners be able to make profit from fuel savings? From the country’s perspective, what emission reductions can be achieved by decreasing the use of diesel oil and switching to LNG?

In this dissertation, views on LNG from various countries were gathered and analysed. A regulatory gap analysis on the Maltese legislation regarding bunkering was also carried out. Scenarios that help illustrate the viability of LNG in Malta have been created, suggesting answers to the questions mentioned in the previous paragraph. In addition, a net present value (NPV) is calculated for a potential LNG infrastructure scenario.

KEYWORDS: LNG, regulations, legislation, MARPOL, EU Directives, Malta, ferries, small ships, emissions, fuel savings, infrastructure, NPV.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ABS	American Bureau of Shipping
Bcm	Billion cubic meters
BIMCO	Baltic and International Maritime Council
BLEVE	Boiling Liquid Expanding Vapour Explosion
CNG	Compressed Natural Gas
COSTA	CO_2 & other Ship Transport Emission Abatement by LNG
DMA	Danish Maritime Authority
DNV GL	Det Norske Veritas Germanischer Lloyd
EEA	European Economic Area
ETS	Emission Trading Scheme
EU	European Union
FOB	Free On-Board
GHG	Greenhouse Gases
GNL	Gas Naturale Liquido
HAZID	Hazard Identification
HAZOP	Hazard and Operability
IACS	International Association of Classification Societies
IAPH	International Association of Ports and Harbours
ICS	International Chamber of Shipping
IEA	International Energy Agency
IEC	International Electro technical Commission
IGC Code	International Code for Construction and Equipment of ships Carrying Liquefied Gases in Bulk
IGF Code	International Code of Safety for Ships using Gases or Other Low Flashpoint Fuels
IMO	International Maritime Organization
ISGOTT	International Safety Guide for Oil Tankers and Terminals

ISO	International Standards Organization
LCA	Life Cycle Analysis
LNG	Liquefied Natural Gas
LR	Lloyds Register of Shipping
MARPOL	International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978, as amended
MEPC	Marine Environmental Protection Committee
MMBtu	Million British thermal units
NECA	NO_x Emission Control Area
NCV	Non Convention Size Vessel
NG	Natural Gas
NPV	Net Present Value
PM	Particulate Matter
PTS	Port To Ship
QRA	Quantitative Risk Assessment
RPT	Rapid Phase Transition
SECA	Sulphur Emission Control Area
SGMF	The Society for Gas as a Marine Fuel
SIGTTO	Society of International Gas Tanker and Terminal Operators
S.L.	Subsidiary Legislation
STCW	International convention on Standard of Training, Certification and Watch keeping
STS	Ship To Ship bunkering
TTS	Truck To Ship
WACC	Weighted Average Costs of Capital
WTW	Well To Wheel

1 INTRODUCTION

Life on Earth is a self-sustainable natural cycle in which various organisms survive by consuming nutrients released from other creatures. Human kind, however, has always been trying to dominate other beings and to improve its lifestyle. This brought many inventions, increasing the global trade and introducing an industrial revolution. The need for more efficient ways to secure energy and transportation was necessary. The burning of fossil fuels did satisfy these requirements (Gruber & Galloway, 2008). However, the natural lifecycle was not able to make up for the air pollution and emissions produced, leading to climate change (Maione et al., 2016; Martinez, 2005). Humans grew concerned when they became aware of climate change and its devastating effects (Li, 2016). “Concerned that human activities have been substantially increasing the atmospheric concentrations of greenhouse gases”, and that they “may adversely affect natural ecosystems and humankind (UNFCCC, 1992)”.

At present, the world is acting to control the release of harmful emissions, with targets set until 2040 (Cozzi, 2016). Within the shipping industry, the Kyoto Protocol has indicated that it is the responsibility of the International Maritime Organisation (IMO) to monitor the emissions from the shipping sector and act accordingly (“Kyoto Protocol”, 1998). As an abatement method to reduce emissions from shipping, a drive to use cleaner fuels has been implemented. Liquefied Natural Gas (LNG) provides potential positive outcomes.

The use of LNG leads to reduced emissions. It does not have any particulate matter (PM) and can achieve less fuel consumption when compared to oil fuels. Some of the challenges LNG has are its low temperature making it a cryogenic liquid, requiring expensive storage and handling equipment. However, under the right procedures, it can be handled in a safe and efficient manner.

1.1 Background - A drive towards cleaner fuels

Following a global drive towards the use of clean fuels, the IMO has established new regulations to reduce the greenhouse gases (GHGs) and other harmful gases emitted by ships. Limits have been set for Nitrogen Oxides (NO_x), Sulphur Oxides (SO_x) and Carbon Dioxide (CO_2) emissions, while certain regions have been selected as emission control areas (MARPOL, 2013; Thomson, Corbett, & Winebrake, 2015). According to the Third IMO Greenhouse Gas Study (2014), it was estimated that between 2007 and 2012, the international shipping transportation industry accounted for 2.1% of the GHG produced worldwide. This is equivalent to 816 million tonnes of GHGs. Despite being a small percentage when compared globally, it still represents a large quantity of emissions (Larkin et al., 2014).

In October 2008, IMO Resolution MEPC.176(58) was adopted. This brought into force amendments to the International convention for the Prevention of Pollution from Ships, 1973 as modified by Protocol of 1978, as amended (MARPOL) Annex VI, where sulphur content was regulated to 0.1% for marine fuels used in sulphur emission control areas (SECA). During the Marine Environmental Protection Committee's (MEPC) 70th session, it was decided that as from 1st January 2020, the sulphur content in marine fuels outside SECA cannot exceed 0.5%. The year 2020 was agreed upon, following a review presented during the meeting which indicated that marine fuels compliant to the mentioned sulphur content will be sufficiently available due date (Kennedy et al., 2011; "Shipping 2020", 2012).

With the introduction of new sulphur emissions regulations, it is estimated that around 70,000 ships will be affected by 2020 ("Global Sulphur Cap 2020", 2016). Taking this date as a target, it is a main concern for ship owners to identify which technology they should adopt by the date of regulation implementation (2012/33/EU, 2012; Nicoll, Aagesen, & Ajala, 2012).

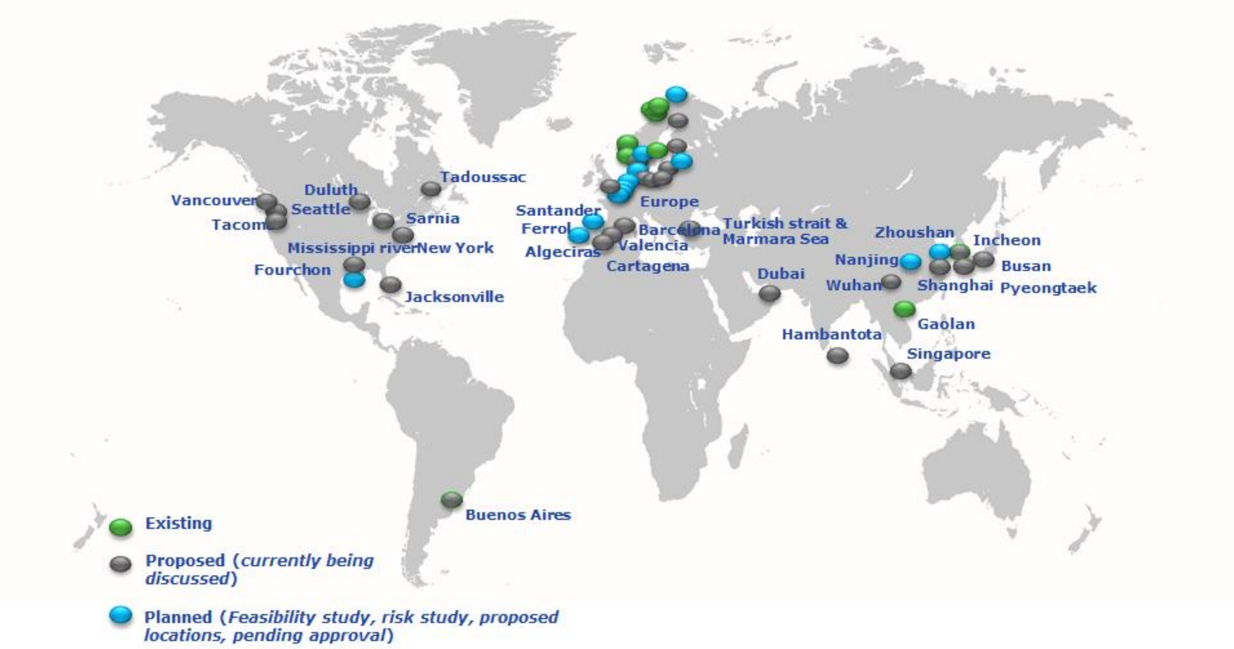
With respect to NO_x emissions and NO_x Emission Control Area (NECA) limitation, IMO has its regulations based on MARPOL Annex VI, regulation 13 and the NO_x Technical Code, 2008. NO_x emission regulations apply to marine diesel engines with an output power of 130kW or more. These are calculated in terms of g/kWh and, depending on the date of construction of the ship, the limits are regulated by three different levels known as tiers. For ships constructed after 1st January 2016 and operating within NECAs, tier III limits are applicable, requiring NO_x to be less than 3.4g/kWh for a speed of 130 rpm (Backer, 2016; MARPOL, 2013).

Few regions around the world have taken the initiative to lead the industry and implement an LNG bunkering infrastructure. SECA regions and areas with a supply of LNG were among the first interested in LNG bunkering. These include four North American ports, fifteen European ports and three Asian ports. Industry research shows that European ports, especially Northern ports, are leading the LNG bunkering to shipping (Benito Luis, 2014; Wang & Notteboom, 2015). A recent study by Det Norske Veritas Germanischer Lloyd (DNV GL) indicates that 54 LNG bunkering infrastructure are in operation, while 71 locations are in discussion or in progress of implementation *(*"LNGi status update", *2017)*.

Singapore offers a large bunkering service to shipping. To promote the development of LNG bunkering, the Maritime Ports Authority of Singapore (MPA) has opted to fund $2 million for a facility ("Taking the LNG lead", 2016).

With a view to switch to energy supply that is low in carbon emissions (He, 2015), the European Union (EU) is working towards a continent-wide gas infrastructure to supply gas to all EU countries by 2035. The International Energy Agency (IEA) estimates that an investment capital of €12bn/year will be invested on gas transportation networks and user facilities by 2035 (GTE, 2016). The principle behind having a gas network is to provide increased competition and to reduce prices, reduce the carbon emissions and ensure energy supply security. In certain European countries such as Norway, Sweden, Denmark, The Netherlands and Belgium, LNG bunkering to ships is already available through port terminals or truck supply (Wang & Notteboom, 2015).

Figure 1: The LNG bunkering stations available or planned around the world.



Source: ("Global LNG bunkering", 2014).

The primary area in Europe, focusing on the bunkering of LNG to ships is the Baltic region. Since the Baltic Sea is an ECA, countries in this region are driven to invest in LNG bunkering (Benito, 2014). Here, various countries have joined forces and embarked on projects to provide LNG to ships. It is the only area in Europe where LNG bunkering is provided also by ship-to-ship transfer, and where ships are being constantly fuelled by LNG (Nugraha, 2009). Other countries in Southern Europe are now implementing LNG bunkering infrastructure following EU directives. Spain, Portugal, Italy, Greece and Crete are studying investments in the LNG bunkering infrastructure (Calderón, Illing, & Veiga, 2016). The Mediterranean Sea has been selected as a region with the possibility of a future SECA (Meech, 2005).

1.2 Problem Statement – Malta and the provision of LNG

With the IMO setting stricter regulations into force for the exhaust emissions of ships, (Resolution MEPC.280(70), 2016), and the EU focusing on building a wide infrastructure for LNG supply (2014/94/EU, 2014), Malta, a small island at the heart of the Mediterranean Sea, has great potential. To date, Malta has invested in an LNG fuelled power plant where its infrastructure comprises of a floating storage unit (Aplin, 2016; Gap analysis, 2016). Currently, Malta is carrying out a study to build an LNG pipeline to connect the island to the European infrastructure (Mallia et al., 2015). In the LNG bunkering sector, Malta is currently at the implementation phase of a feasibility study focusing on legislation, infrastructure options with respective cost-benefit analysis, risk assessments and training requirements (CT3017/2017, 2017).

Results of the subsidiary legislation analysis related to bunkering in Malta clearly show the lack of regulations regarding the service for LNG bunkering (S.L.499.12, 2015). With the implementation of the alternative fuel directive and projects dedicated to widening the LNG bunkering infrastructure, Malta, as a member state of the EU has to consider its actions in regulating LNG as a ship bunker (2014/94/EU, 2014). This would allow service providers to gain their license and supply fuel.

Due to its geographical position, Malta has potential in international trade by shipping that may lead to higher bunkering demand. In the container business, Malta is used as a hub for cargo exchange reaching North Africa and Europe, thus increasing the number of ships arriving in port. When it comes to bunkering, the island has possibility of offshore ship anchoring areas due to seabed depth so that ships can bunker on anchor without the need to enter into port. In 2015, 130 oil bunker operations were carried out within port. 2695 oil bunker operations have been carried out outside port limits in the bunkering areas designated around the island. These values have been approximately constant for the past five years ("Shipping movements in Malta", 2017).

With respect to fuel for shipping, Malta is required to comply with both international regulations and EU directives. Looking ahead at the future of fuels available for shipping, and at Malta's potential in the bunkering industry, actions to provide cleaner alternative would indeed be beneficial. Being a leading maritime trade country in the Mediterranean region might also be a competitive advantage. With little LNG demand before 2020, and with uncertainties from the industry regarding the switch to LNG, it is essential to conduct a broad analysis of factors related to the LNG bunkering industry. Regulations, safety, infrastructure, and potential demand and supply are essential information to provide an efficient service to the industry.

1.3 Aims and Objectives

Malta should take advantage of its geographical position and be a leading country in providing LNG bunkering service for ships crossing the Mediterranean. This would surely necessitate more knowledge on LNG bunkering. Research has noted that there are still gaps limiting the business interest in providing LNG bunker service. The lack of regulations and national prospects for LNG bunkering is critical (Xu, Testa, & Mukherjee, 2015). The application of international emission regulations in the Mediterranean by 2020 is also a key player in what fuel to use (2012/33/EU, 2012). Ship owners' choice of technology on vessels depends not only on the available selection of emission reduction alternatives, but also on whether they consider investing in new building or retrofitting equipment, meeting the necessary requirements. Continuous improvements in this kind of equipment will also affect the time taken by ship owners to install the right technology. Decisions taken by ship owners are also affected by fuel price stability and competitiveness *(*"LNG bunkering in the Mediterranean", n.d.*)*. With constantly changing fuel prices, especially low oil prices, owners might prefer a smaller monetary investment for HFO exhaust cleaning, then high investments in LNG equipment. The choice of equipment will affect the running costs of the ship, as they vary with fuel price and equipment running power. This leads to higher or lower trading prices by the company, affecting their competitiveness.

In view of the information and the situation described above, the aim of this research is to:

- understand and gain knowledge on LNG bunkering and the associated factors required to achieve the functioning of the system;

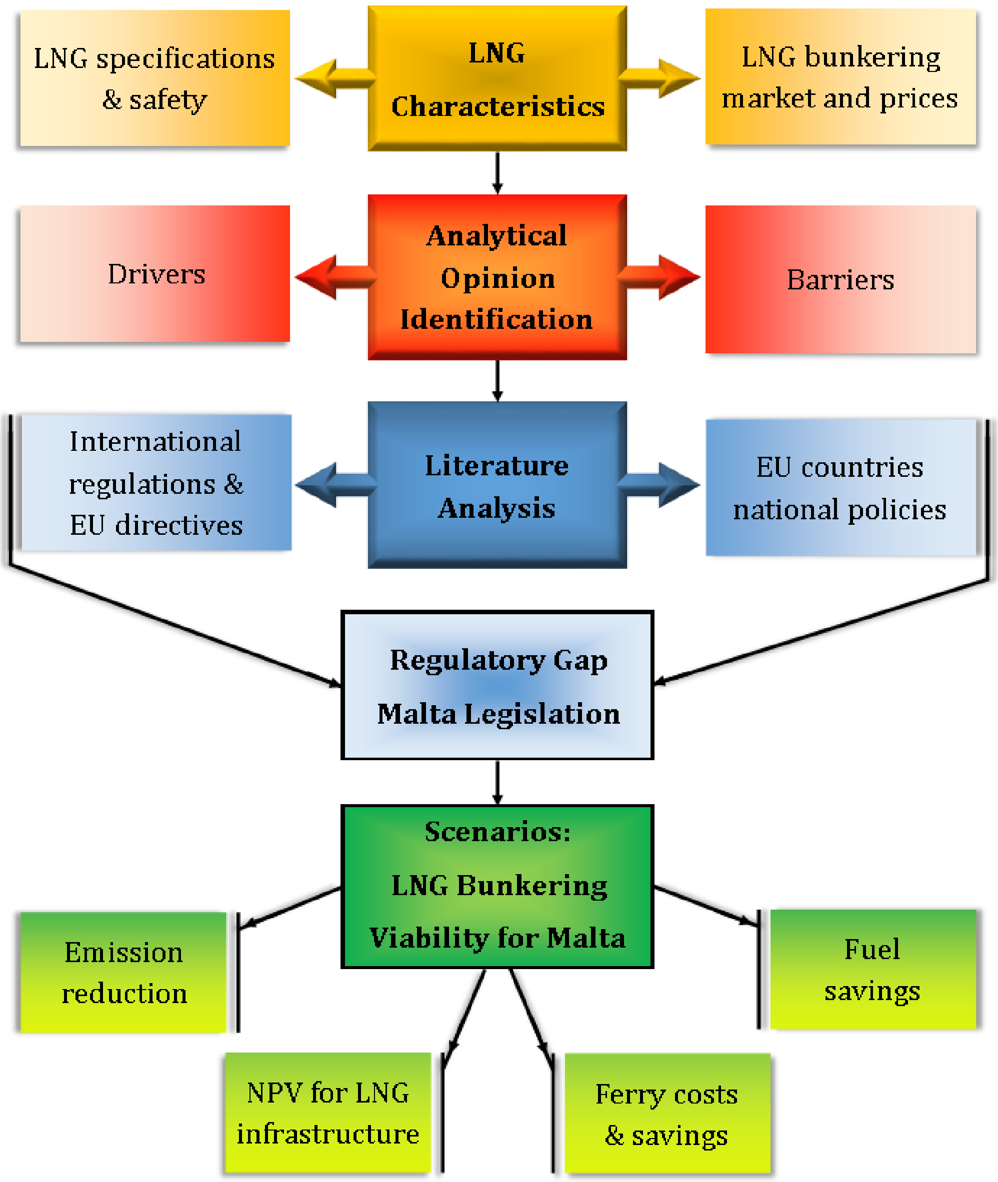
- analyse the regulatory instruments in order to perform LNG bunkering;
- analyse potential LNG viability as ship fuel in Malta; and
- analyse the issue that Malta has to address in order to meet the requirements to provide such services.

1.4 Methodology

This dissertation uses qualitative research to provide deeper insight of the topic, to investigate developments within the industry. It also uncovers the opinions of the author in relation to the literature, discussing trends within current issues, while proposing possible solutions for the future (Klenke, 2016). Quantitative data provides real examples through the scenarios. The research approach is shown in Figure 2, and applies the following methodology:

- Questionnaire –Prepared for communication with the LNG industry and maritime administrations. The aim is to gather information and opinions on the subject;
- Literature review analysis – Analysis of the latest studies and reports from IMO, EU, ISO and classification societies to determine what is already in force and what is required to proceed with LNG bunkering. Maltese legislation in relation to the topic is identified and analysed; and
- Scenario analysis – With knowledge gained from other reports and projects of already implemented LNG bunkering infrastructures, small potential scenarios for Malta were created and analysed for potential result.

Figure 2: A flowchart indicating the research approach used and the scenarios analysed in the case of Malta.



Source: (Author).

1.5 Assumptions and Limitations

The research might be limited due to certain circumstances noted below:

- Due to lack of technical information, this study does not describe safety issues and risk assessments due to scenario sensitivity.

- Information related to private entities and subjective information from authorities is mentioned in a general perspective to avoid public and political conflicts;

- Certain data was restricted in respect of data protection policies of the private companies consulted;

- With respect to Malta, limited information is available in line with the LNG upbringing or any related data; and

- Information related to scenarios is limited and so the hypothesis used are based on other projects and regions.

1.6 Structure of Study

The research analysis and findings will be structured according to the following layout:

- Chapter 2 – A review of LNG characteristics, its use as a marine fuel, and current fuel pricing.

- Chapter 3 – An analysis of the views collected in the questionnaire in terms of factors related to LNG, with additional information from the literature.

- Chapter 4 – A description of international LNG regulations, EU directives, national policies and other studies, serving to identify information that could be essential to the case of LNG bunkering in Malta.

- Chapter 5 – A gap analysis of Maltese subsidiary legislation related to ports and ship fuels. Essential directives for the development of an LNG infrastructure are also mentioned.

- Chapter 6 – LNG as ship fuel and infrastructure NPV scenarios related to Malta are described, and a structure of the methodology used is provided.

- Chapter 7 – Results from the scenario methodology are given and analysed, pointing out the potential of LNG as ship fuel in Malta.

- Chapter 8 – Recommendations and Conclusion.

- Appendices – Questionnaire and scenario calculations.

2 LNG SPECIFICATIONS AND THE MARKET

The first commercial use of natural gas is said to have been made by the Chinese. This was followed by the British in the 17th century, where natural gas was produced from coal and was used for lighting in houses and streets. Later, in the 18th century, gas fulfilled the same objective in the United States. The first commercial viable natural gas well was drilled in the U.S. by William Hart, and this discovery lead to the formation of the first commercial gas lighting company (Kidney & Parrish, 2006).

Between the 18th and late 19th centuries, natural gas was used solely for lighting. In 1885, the invention of the Bunsen burner introduced vast opportunities for gas. This led to new pipeline infrastructure in the 20th century where, in the period following World War II, gas came to be used continuously in heating and cooking appliances, factories, boilers and also in power generation plants ("A Brief Histroy of Natural Gas", 2017).

Nowadays, natural gas is a major supply to the world's energy. In 2015, the worldwide gas production was 3590Bcm. This reflected on the price of gas import by pipeline, which fell by 27.2% for EU countries, while in the U.S., prices fell by 45.6% when compared to that of 2014. Import of gas in Europe increased by 21Bcm during the previous year. The global demand for natural gas in 2015 was of 3600Bcm ("Key Natural Gas Trends", 2016).

2.1 Characteristics of LNG

The composition of LNG is dominated by methane gas (see Table 1). However, depending on the source area, other hydrocarbon gases are present in small percentages in terms of molecular content. LNG also contains traces of nitrogen, sulphur and carbon dioxide.

Table 1: The composition of LNG separated by the content of each gas. Content indicated as a percentage range as it various due to origin of the gas.

		mol % content
Oxygen	O_2	0-0.2
Nitrogen	N_2	0-5
Carbon Dioxide	CO_2	0-8
Hydrogen Sulphide	H_2S	0-5
Methane	CH_4	70-90
Ethane	C_2H_6	0-20
Propane	C_3H_8	0-20
Butane	C_4H_{10}	0-20
Pentanes, Helium & others		negligible

Adapted from: ***(Mokhatab, Mak, Valappil, & Wood, 2014; Kidney & Parrish, 2006).***

Since gas is extracted from rocks, water is a main impurity that needs to be removed for proper liquefaction of natural gas. In situations where the Hydrogen Sulphide percentage is higher than 3%, this compound must be removed from the content as it reacts and forms hazardous by products at a later stage. Other impurities which can be found in very small content in natural gas are mercury and naturally occurring radioactive material (Kidney & Parrish, 2006).

As with every other substance that exists, LNG has properties that make it unique. These properties also vary depending on its state. The common properties for LNG are:

- odourless;

- colourless;
- non-corrosive cryogenic liquid at atmospheric conditions;
- non-toxic. yet causes asphyxiation in unventilated areas;
- LNG is normally kept at atmospheric pressure less than 5 PSI gauge;
- it has a boiling point of -162°C; and
- its density is in the range of 430-470Kg/m^3, depending on its composition (Mokhatab, Mak, Valappil, & Wood, 2014).

2.2 LNG as ship fuel and the bunkering market

In 2014, it was estimated that 84% of the bunkered fuel to the shipping industry was HFO with a Sulphur content of 2.5% (Janoska, 2017). However, IMO is seeing a potential increase in the switch to LNG fuel. It is expected that on a voluntary basis, 5-10% of the marine fuel used will be LNG by 2020. 25-50% of the vessels which operate solely in ECAs such as coastal vessels, and also 10-20% of oil tankers trading globally are expected to change to LNG by 2050. 20% of the total ships are expected to make use of synthetic oil fuel by 2050 (Cazzola et al., 2009; Smith, et al., 2015).

Despite being relatively new type of fuel in shipping, LNG is the cleanest fossil fuel for combustion. It drastically reduces air pollution from ships in terms of PM, it limits levels of SO_x as required by regulations, it reduce NO_x levels by 90%, and decreases CO_2 emissions by up to 20% ("The Future of Shipping", 2014).

In the near future, fuel oil is expected to be the main fuel source for shipping (Wuersig & Chiotopoulos, 2015). However, the potential of LNG as ship fuel is expected to increase at a fast rate, especially for ships under certain criteria such as ECA operating vessels, region bound or coastal vessels, conversions, or aged ships about to be replaced, the investment in reduced emissions, and vessels on fixed routes. The availability of bunkering infrastructure and the differences in fuel prices are sensitive factors that also play an important role in the decision to switch to LNG ("Studies on the", 2016).

Since the turn of the millennium, LNG has been used as a ship fuel at an increasing rate. Motivated by Government measures, Norway was a pioneer with the aim of cutting emissions from ferries. With increase in European gas infrastructure, other regions, especially in Northern Europe, implemented projects for LNG as ship fuel as gas supply grew more feasible (Baltensperger, Füchslin, Krütli, & Lygeros, 2015). DNV was the first classification society to set rules for LNG fuelled ships (Blikom, 2012). To date, there are 107 LNG fuelled ships in operation and another 115 on the order book until 2020 ("*LNGi status update*", 2017).

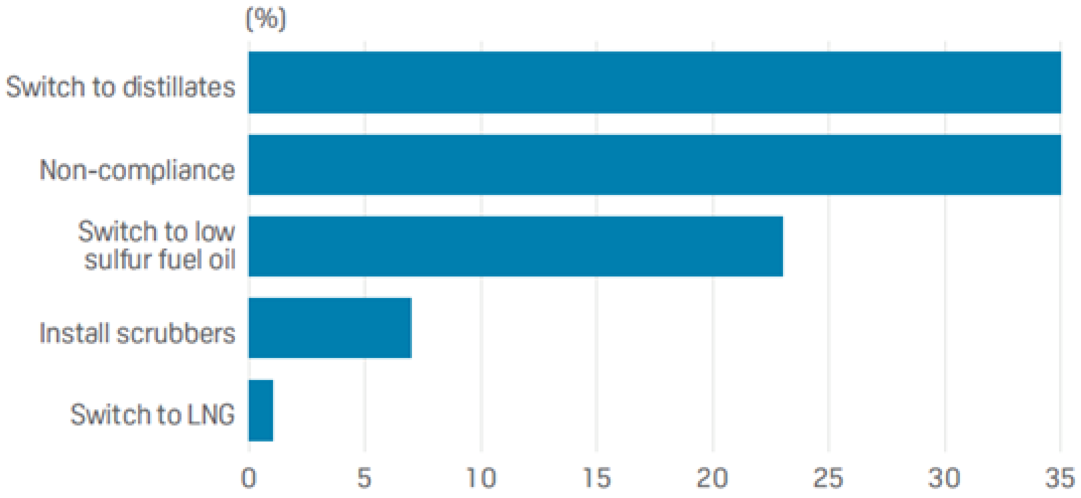
The IMO's action to reduce global sulphur emissions to 0.5% by 2020 is considered an incentive for ship owners in the Mediterranean to switch to LNG fuel. There is currently no environmental enforcement which incentivises LNG for shipping in the Mediterranean. If the EU were to impose stricter regulations on its member states in the Mediterranean, ships would just sail closer to the North African coast ("LNG bunkering in the Mediterranean", n.d.). In relation to this, the EU has an emission trading scheme (ETS) to incentivise companies and countries to reduce their emission levels, and where targets are not reached, penalties are enforced. This includes regional countries which are not part of the EU but are part of the EEA ("The EU emissions", 2016).

2.3 LNG bunkering market in Malta

Due to its geographical position, Malta benefits from a strong shipping trade pattern that passes through the Mediterranean and is estimated to form around 19% of the global seaborne trade. Almost 12,000 ships called in Maltese ports in 2015, and of these, 2695 bunker operations for fuel oil were requested. A total of 60,440,192 GRT of fuel oil was bunkered. This volume reflects operations both in port and at Hurds Bank ("Annual report 2015", 2015; Buonfanti, 2013).

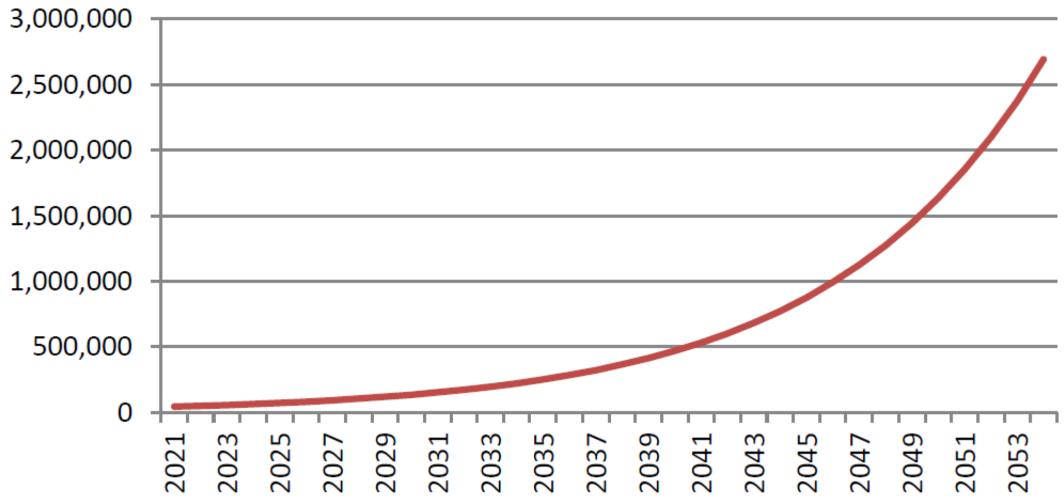
With this potential bunkering business, one would expect that over the years, fuel oil for ship bunkers may reduce in quantity while LNG fuel increases in demand. With the enforcement of emission regulations in 2020, ship owners might either take abatement measures to reduce emissions, or choose to switch fuel (see Figure 3). Considering Malta is situated in the Mediterranean, that is a member of the EU and that it will potentially be identified as a SECA area, shipping traffic might be reduced due to incompliance (2012/33/EU, 2012; Meech, 2005). However, ships might be incurring more expenses due to longer voyages, as the Mediterranean Sea offers a shorter route. Therefore, LNG ships that are fully compliant in SECAs are expected to increase in this region (Gerrish & Listowska, 2017). Through other gas related projects in Malta, LNG bunkering demand in Malta is forecasted to carry an upward trend (see Figure 4).

Figure 3: Data collected from the FUJCON bunker conference, March 2017, on how ships are expected to be in relation to the sulphur cap regulations.



Source: (Gerrish & Listowska, 2017).

Figure 4: The potential future LNG demand for bunkering purpose in Malta. Units in m^3



Source: (CT3017/2017, 2017)

2.4 LNG prices

The reserve and supply chain of LNG makes the price competitive (Ashworth, 2012). In Europe, the supply of gas by pipeline provides more competitive prices compared to imports by ship while the LNG supply infrastructure is becoming more liberalized (“Studies on the”, 2016).

Fuel prices, is a factor that can drastically affect the rate and quantity of ships that do switch to LNG fuel. Fuel prices is a volatile market, and difference in prices has a large impact on the profits made by shipping companies. This will also determine the payback period for an investment companies do implement in order to change the on-board machinery to LNG (Ge & Wang, 2016; Schinas & Butler, 2016).

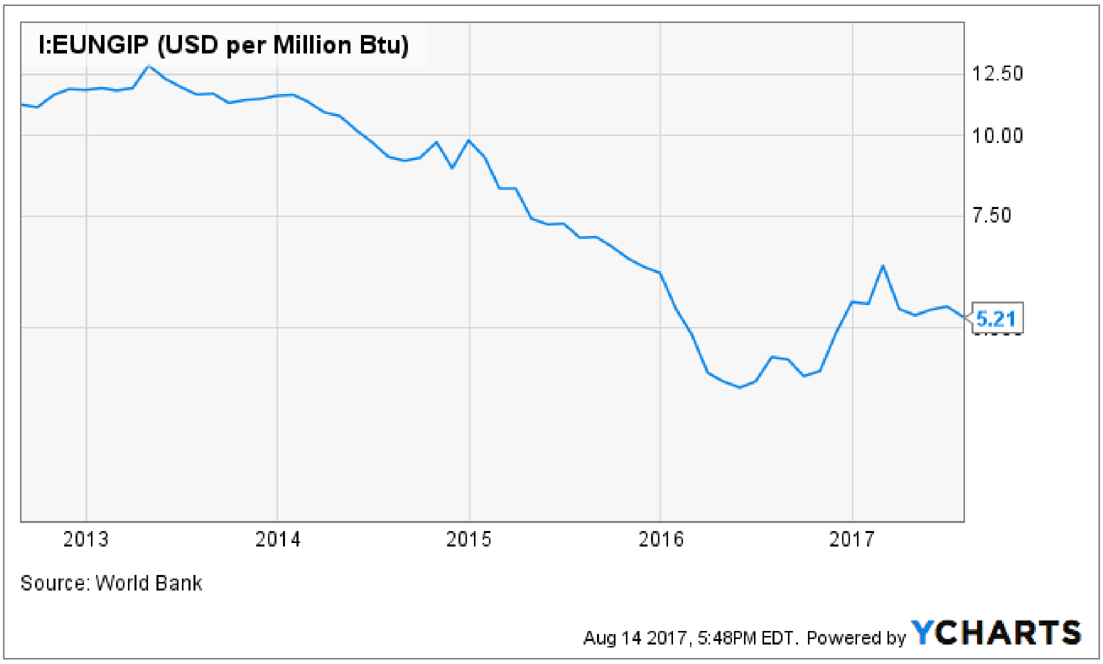
An unanticipated oil price drop in 2015 (see Figure 5) did affect the rate at which ships switch to LNG. Whereas high oil prices produced high probabilities of ships switching to LNG, low oil prices increased profits and therefore did not encourage ship owners to do so (Stern, 2014). By 2018, it is expected that the global quantity of LNG liquefaction will increase by 36%, which in turn is expected to produce a decrease in the LNG price over the next five years (Almeida, 2014). In 2016, oil prices were expected to increase again. Although there was only a slight increase in comparison with previous years, the market is still promising that oil prices will boost again in the coming future (Nikhalat-Jahromi, Angeloudis, Bell, & Cochrane, 2015).

As a result of better infrastructure for the importation of gas, and in relation to low oil prices, the price of LNG has fallen from 441.76 €/tonne to 176.7 €/tonne (see Figure 6) after 2014 (Crook, Vidas, Coffey, & Amarin, 2017). With such a change, ship owners will be cautious about what technology to use. In the figures below, one can note that the LNG price was always less than that of oil. This means that following an investment in LNG fuelled equipment, one can always benefit from cheaper fuel prices.

Figure 5: Five-year price for the Brent Crude Oil Spot Price Chart.

Source: (Brent crude oil spot price chart, 2017).

Figure 6: Five-year price for the European Union Natural Gas Import.



Source: ("European Union natural", 2017).

Table 2 tabulates the prices of crude oil and natural gas if a conversion is done in terms of Euro per tonne.

Table 2: The fuel prices according to the latest estimate from the above figures in €/tonne.

	€/tonne
Crude Oil	312.63
Natural Gas	230.85

Source: ("Brent crude oil", 2017; "European Union natural", 2017).

Considering the price of LNG as ship fuel, it is estimated that the infrastructure cost would increase the LNG price by 50%, depending on the size of the infrastructure and the demand (DMA, 2012). A study on the feasibility and commercial considerations of LNG-fuelled ships suggest an intermediate cost of 97-170€/tonne (Algell, Bakosch, & Forsman, 2012; Schinas & Butler, 2016).

3 Analytical Data Collection & Literature Analysis

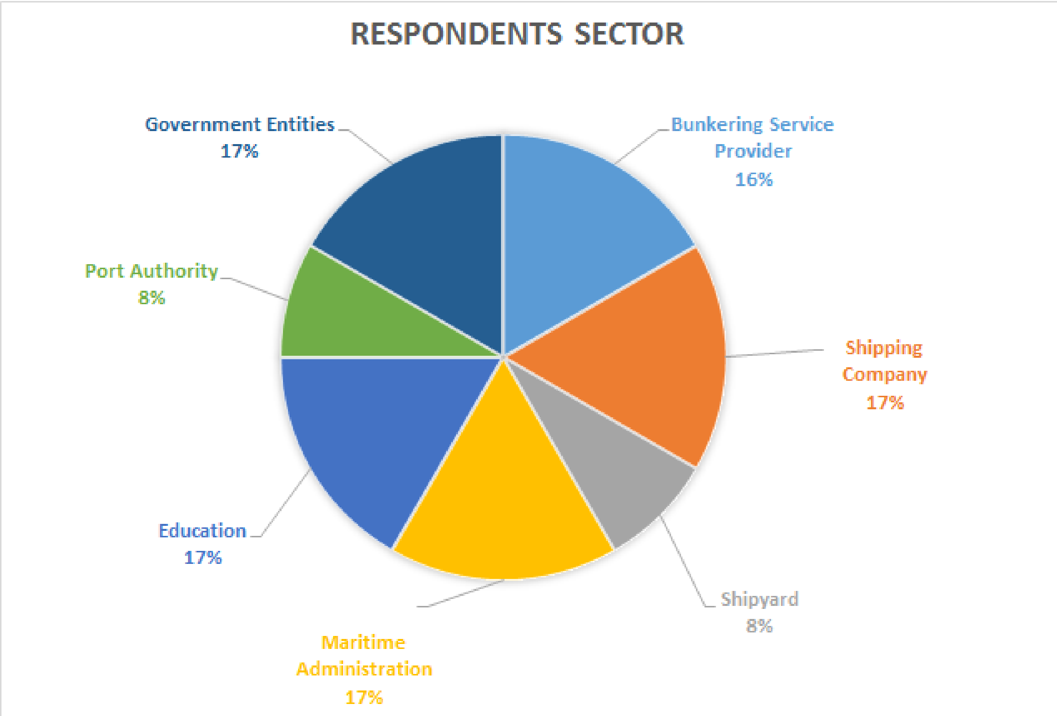
Countries across Europe are evolving in the LNG bunkering sector, each implementing the best practice for the respective country (Calderón et al., 2016). In order to determine what changes are taking place, data was collected directly from field personnel. A questionnaire[1] (see **Error! Reference source not found.**) was created a nd distributed to companies and authorities related to LNG. The main replies received are from LNG operators, port authorities and maritime administrations. The rest were obtained from a university, a ferry company, a ship builder and a bunkering trading platform. Twelve replies were received in total, representing seven countries from the North and Baltic Seas area and the Mediterranean region.

Although the number of participants in the study was small, 42% of the answers were received from the authorities. 25% of the replies were direct from users of LNG as fuel, namely shipping companies and shipyards, while bunkering service providers represent 16% of the respondents. Service providers experience the LNG bunkering sector from the regulatory perspective, the ship-owners' requests, and profits. 17% was represented from the education sector. The collected data also shows that respondents have been working in the LNG field. Despite being few in number, respondents had a

1 The questionnaire was approved for viability by Prof F. Ballini, who supervised the research and was submitted to the ethics committee at the World Maritime University for verification. The committee commented that the questionnaire was well structured, reaching multiple LNG related issues and able to obtain effective results, while specific information could have been collected on consent and availability from the respondent.

strong enough technical background to provide effective replies, with scope for discussion in this chapter.

Figure 7: The percentages above show the weighted percentage of the respondents of the questionnaire according to their sector of origin.



Source: (Author).

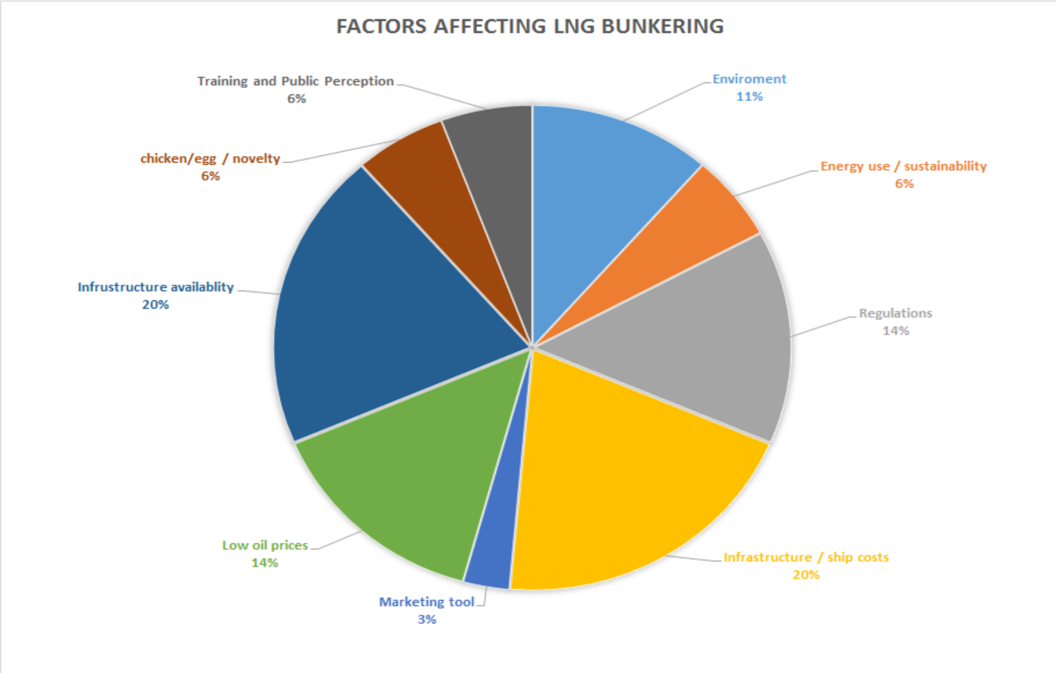
The concept of collecting qualitative data allows for direct expression of opinions. It can be said that latest updates and opinions was collected. Qualitative data "are a source of well-grounded, rich description and explanation of processes in identifiable local context", (Miles & Huberman, 1994). Drawbacks due to the direct response based on opinions through qualitative data can be based on the interaction of the respondent with LNG, that is the gain a company is having within the LNG sector. One word answers which leaves room for unclear massage is also a drawback which may lead to wrong interpretation of the reply.

The questionnaire was carried out using Google forms. These were considered appropriate as they allowed the questionnaire to be sent out by email, which makes the process less time consuming for participants. The questionnaire was also used to gather documents and information relating to policy from different countries, and any LNG bunkering related costings and specifications. The questionnaire consisted of a wide general view of the LNG bunkering sector, safety and technical aspects, training, environmental, policy and infrastructure.

3.1 Results and analysis

Following a brief overview of the replies on LNG bunkering, the data received was collected in a frequency table to allow the listed terms to be weighted. Figure 8 shows the points established from the results as common factors affecting the development of LNG. These issues trigger other factors affecting the whole system chain. Seeing this in a social, economic and environmental context, LNG as a shipping fuel is has its external effects outside the ship boundaries. As will be discussed throughout this chapter, LNG as a marine fuel can be an opportunity to ship owners and the general through indirect benefits like reduced emissions from ports, improved air quality reducing health risks, fuel competition, and more employment.

Figure 8: Issues which have been mentioned in the questionnaire replies relating to LNG bunkering and its infrastructure.

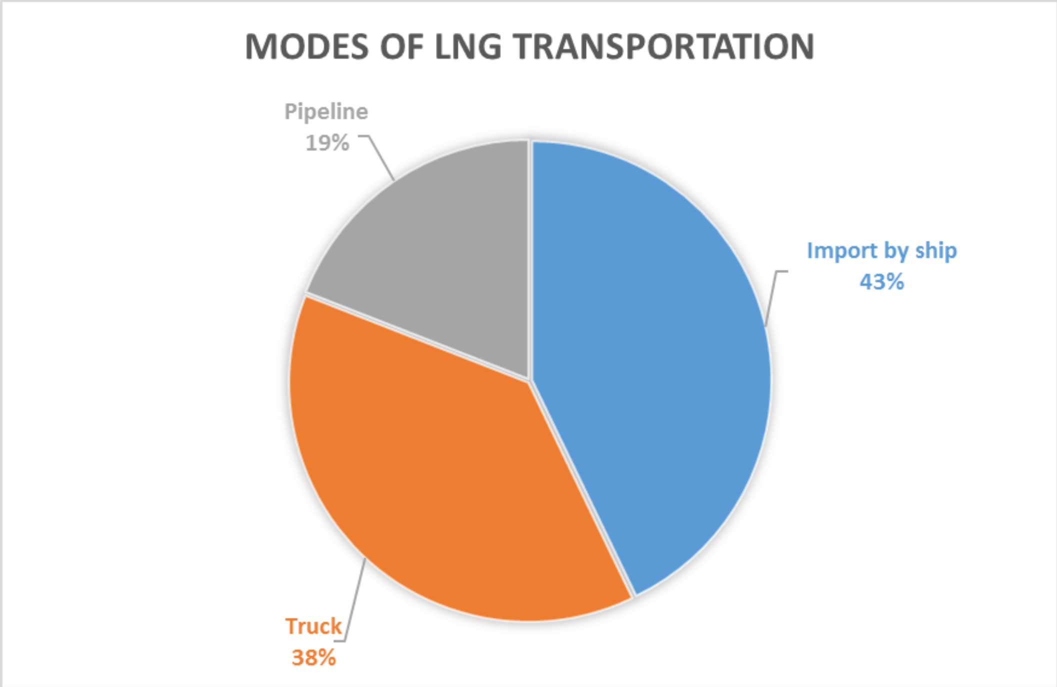


Source: (Author).

3.1.1 Infrastructure technicalities, safety aspects and regulations

Since LNG bunkering is relatively new, its infrastructure is still becoming more available (Calderón et al., 2016). This is directly dependent on the demand for LNG (Kumar et al., 2011). Opinions suggest that lack of infrastructure availability is a barrier to the increase of LNG bunkering service (Wang & Notteboom, 2015). An LNG bunkering infrastructure can be constructed in different ways, depending on the country's demand, and geographical features, as shown in Figure 9.

Figure 9: The most common mode of LNG bunkering according to the replies received.

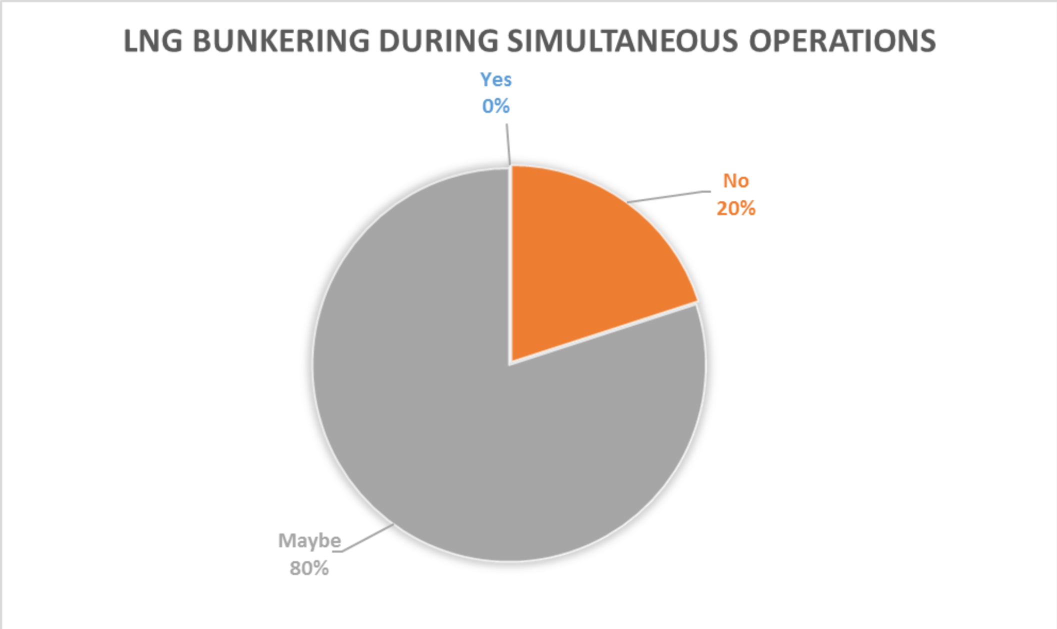


Source: (Author).

When investigating about LNG bunkering service outside port limits, participants described it as a viable solution; however, a dedicated safety risk assessment should be conducted for separate scenarios especially due to weather conditions. Risk assessments vary with each case, and since no relevant data was provided, risk analysis was not possible in this study.

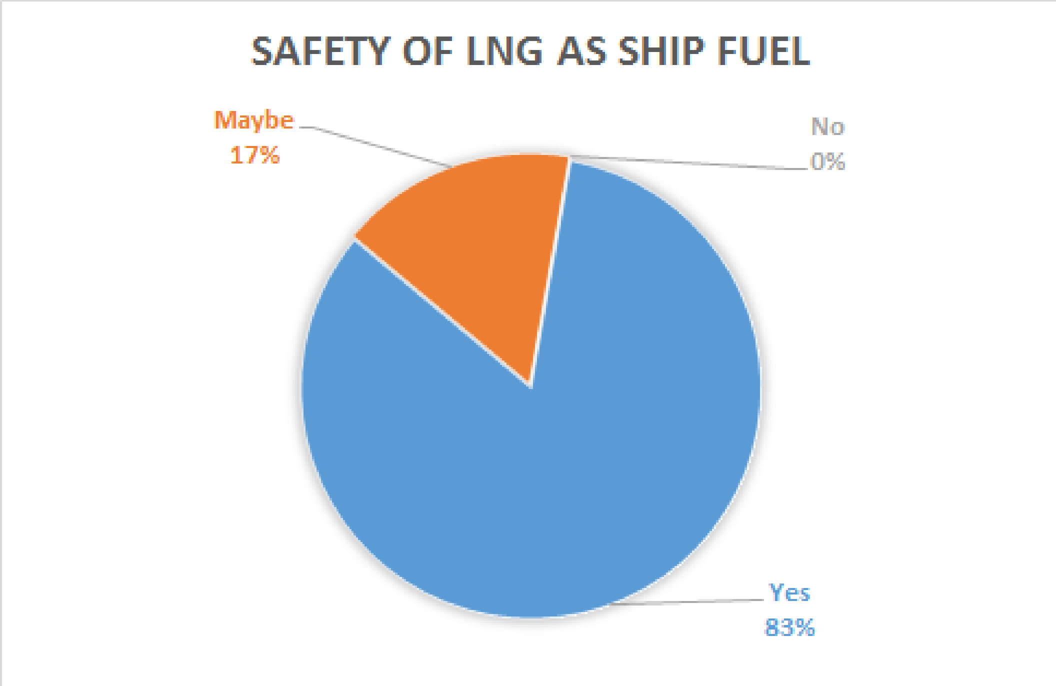
In relation to bunkering services in port, the three modes of bunkering (S-T-S, P-T-S, and T-T-S) were given priority depending on the country. Main issues mentioned here are: what port infrastructure is already available? Can areas be dedicated for such service provision? Ports located within old cities, especially densely populated ones, can be hazardous to residents. SIMOPS is an issue to be analysed per scenario. Some argue that it is safe to allow port operations to continue during LNG bunkering, while others point out the fact of keeping people away from the safety zone and other operations on the port side. HAZID assessment is a must, yet varies with each scenario. For more elaborated assessments where multiple operations occur, assessment might be referred to as risk governance, due to the multiple assessments required (Lindøe & Kringen, 2015). Noting that 80% of the respondents are still not sure about SIMOPS, the general perception on LNG safety indicated a positive trend in considering LNG as safe as indicated in Figure 11.

Figure 10: An opinion from the respondents regarding SIMOPS during bunkering.



Source: (Author).

Figure 11: The view on the safety of LNG as ship fuel.



Source: (Author).

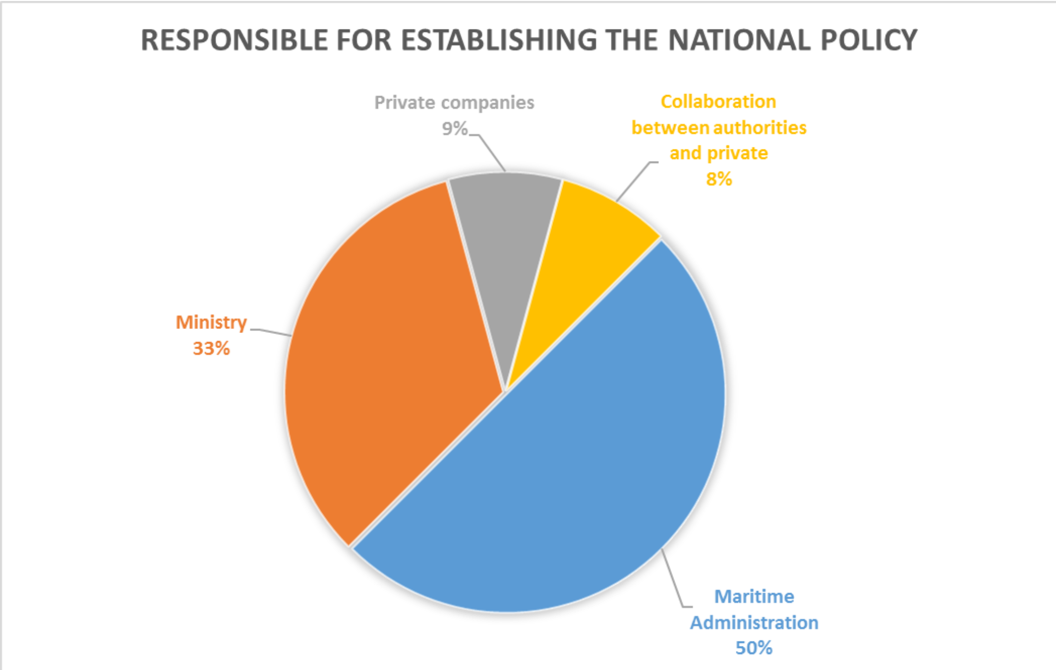
Due to its cryogenic characteristics, LNG requires dedicated storage facilities and equipment. Such equipment requires excellent construction and testing and is therefore costly. This is reflected in the high prices of bunkering vessels, and in the costs of infrastructure within ports. A mark-up cost price of approximately 50% is added to the import price of LNG depending on the size of the infrastructure (DMA, 2012; Schinas & Butler, 2016).

An issue that only minimally emerged in the questionnaire, but is commonly expressed in literature, is the chicken and egg situation ("European commission DG", 2015). While novelty makes it difficult for ship owners to take a decision, especially where potential high-cost repercussions are involved, the drive to bring about change has the opposite effect. This can be achieved by having alternative fuels available while enforcing stricter regulations.

Identified as a motivating aspect, regulations increase countries' interest to invest in LNG. In Chapter 4, an in-depth analysis of international and European regulations identifies targets to be met and documentation to follow in the preparation for LNG procedures. Classification societies and other specialised organisations such as SGMF and IAPH have prepared guidelines as a point of reference. European countries have collaborated regionally to create an infrastructure similar to each other, providing more knowledge into their implementation.

Figure 12 below illustrates that national policy regarding LNG bunkering is mainly the responsibility of the maritime administration. In certain countries, governmental agencies are responsible for LNG bunkering development. Private companies also have their share, as they are in control of private terminals. In replies from Mediterranean countries, where the infrastructure is still in start-up phases, one can note a collaboration between different parties in establishing the infrastructure. From the Maltese regulatory perspective, a regulation gap analysis follows in chapter 5.

Figure 12: The authority responsible from the LNG national policy to their respective countries.



Source: (Author).

As new regulations for reduced emissions from fuel combustion and alternative fuel sources are enforced, the use of LNG would provide a sustainable solution for the shipping industry. Sustainability can be met from different aspects. In terms of fuel consumption, a 5-20% fuel savings can be easily noted in the above scenarios and similarly in literature (Schinas & Butler, 2016). OPEX workload and costs are also effected, with 35% reduction in OPEX costs (Burel, Taccani, & Zuliani, 2013).

3.1.2 Economic effects and related externalities

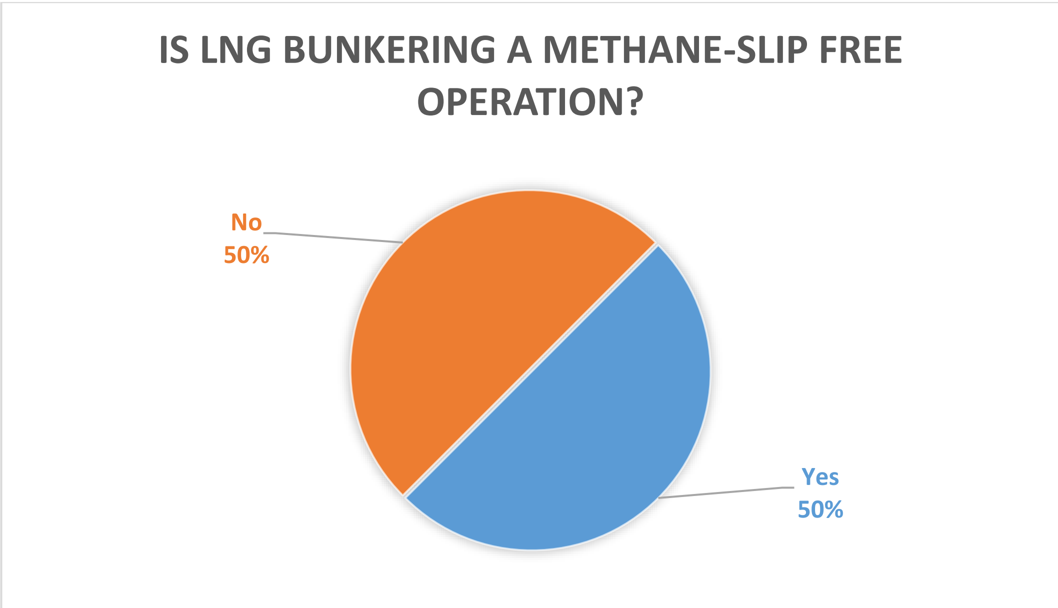
Costings and fuel prices are two main factors which indirectly affect the demand for LNG bunkering. The volatility in prices and the competition from low oil prices is a detriment to investing in LNG systems. Adding to this, the cost to switch the on-board machinery to LNG systems requires a considerable investment, which is not considered viable for retrofitting. Therefore, with such uncertainties which directly affect the investments and profits of the shipping companies, these factors are seen as barriers to LNG bunkering (Nikhalat-Jahromi et al., 2015). Indeed, according to the questionnaire, 25% suggested low oil prices as a main barrier to LNG upbringing, while another 25% of the respondents proposed the costs of technology as the main barrier. This is surely a topic which requires in depth analysis. In chapters 6 and 7, scenarios created on behalf of Malta, will be analysed.

Economic aspects are not only related to technicality and profit making. A socio-economic perspective relates the cost of pollution to societal benefits, resulting in indirect repercussions as health issues, effects on species, and damage to the surroundings. A monetary externality effect can be that of emission taxes (Winnes et al., 2016). Such taxes might be considered a financial burden; however, one should analyse what is the opportunity cost, in this case being the reduction of emissions. The introduction of a new alternative fuel and its bunkering infrastructure would create job opportunities. Such positions could vary from technical people running the plant and assets, to administration personnel and competent persons for training and certification. Equipment retrofitting for gas machinery would also require competent personnel.

3.1.3 Environment

From the environmental aspects of LNG, the industry sees a potential in its use due to its emission advantages. 29% of the respondents listed the fact that LNG's smaller environmental impact is motivating its use around Europe.

Figure 13: The opinion from the respondents regarding the possible methane slip emission from LNG bunkering operations.

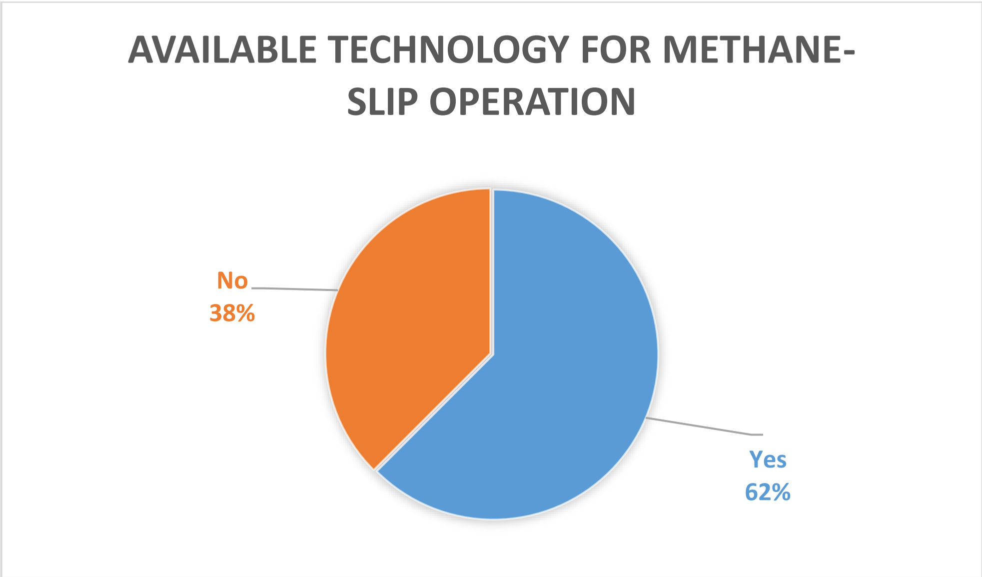


Source: (Author).

The primary environmental concern regarding LNG as ship fuel is the methane slip. On presenting the issue to the public, a 50/50 result was achieved. In fact, the GHG effect of Methane is calculated to be 28 times that of CO_2 when analysed in long term of 100 years (Anderson, Salo, & Fridell, 2015). Although the emission of methane slip from LNG as ship fuel is still subject to long term research, previous research shows that the issue depends on the type of engine technology used on-board. Low loads on gas engines proved to have higher emissions of methane due to the combustion characteristics. This can reach up to 15% methane slip (Brynolf, Fridell, & Andersson, 2014), while 90% of this emission quantity can be controlled by using oxidizing agents. However, this is still subject to testing (Järvi, 2010). So far, there are no restrictions on methane emissions from burning fuels.

During bunkering, methane slip can be a potential source of GHG emission. This mainly occurs during the connection of systems, system venting, or, the worst-case scenario, when an LNG tank experiences over pressure and vents automatically. During a visit to the 'Terminale GNL Italia', it was explained how gas venting from piping and vent mast is captured and redirected to a reliquefaction plant so as not to allow traces of LNG to vent to the atmosphere. Operating procedures for fully functioning LNG bunkering terminals state that before hose disconnection, any remaining liquids are to be purged. Every time an operation takes place, the system requires two hoses, a fuel hose for the LNG and a vapour hose. Hoses should be coded according to their specific use (LNG ship to ship bunkering procedure, 2010). When asked in the questionnaire about the availability of technology for zero methane emission, 62.5% of the respondents replied that it was available, while 37.5% opposed. When asked for a clarification, it was noted that their negative reply was referring to the technology of Methane slip from engine combustion. In chapter 7, the results of an emission analysis case study will be explained.

Figure 14: Respondents' opinion on whether the right technology to avoid methane-slip is available or not.



Source: (Author).

3.1.4 Human element and other factors

With the principle of achieving less emissions and a cleaner environment, it was proposed that companies make use of LNG fuelled ships as a marketing tool. This will combine with it the public perception on LNG. LNG is either seen as a clean fuel or in some cases as a safety threat. This also shows the lack of knowledge of the general public about LNG.

The introduction of a new system triggers the need of employment. LNG requires competent people during construction and operation. It include essential training required to personnel involved on LNG sites even though not working directly with the LNG system itself.

3.2 Maltese perception for LNG Bunkering and related externalities

Opinions of two personnel from different authorities in Malta about the local LNG bunkering situation are on the same wavelength as those from other countries. Abiding with EU directives, the targets set by the EU are a drive for the implementation of LNG in Malta. By 2020, the demand for LNG bunkering in Malta would still be very low (Figure 4, page 16). This demand is expected to rise in the future. Currently, Malta is just in the initial phase of a feasibility study for LNG bunkering. The aim is to investigate what needs to be done to regulate LNG provision and a cost-benefit analysis for the required infrastructure. No further information was available.

In relation to the externality effect of LNG demand increase in Malta, there are potential benefits to consider. Ships in port tend to keep the auxiliary engines running. The ports of Malta are city ports. The Grand Harbour area is home to 199,266 residents, while in 2014, 1,520,828 tourists visited the port area due to its historical sites. 471,554 of these tourists also used the port terminal facilities since they were passengers on cruise ships. ("Project overview and", 2015). In 2010, Malta, as an EU member state committed itself to the National Ceiling Directive. This directive sets limits for the emissions generated, apart from those naturally occurring. With 10% of the emissions being generated from non-road transport, the marine transport sector can contribute towards reducing emissions ("Air pollution fact", 2014).

Another effect which results from air pollution is acid rain. High acidity rain due to dissolved exhaust emissions causes a lot of deterioration to buildings, fields and individual properties such as cars. Natural areas such as fields, rivers and valleys are also affected, with further ecosystem disruption due to the living species in these locations (Chernick & Caverhill, 1990).

The ideal way to analyse the social, economic and environmental impact of LNG as ship fuel in Malta, is through a life cycle analyses (LCA), where the cycle of LNG in Malta is followed from the importation by ship and expected to change by pipeline in the near future. The distribution of LNG for land use should be analysed for the power plant and also as CNG for vehicles, in order to meet national targets as mentioned in section 4.4. LNG for shipping has a different life cycle which includes the liquefaction process. In terms of the economic and environmental aspects, it should be determined what energy consumption and emissions this process would require. Considering an offshore LNG bunkering station, this can prove to be a more feasible bunkering alternative to international ships. The LCA should also include the FOB prices for both the shipping sector as well as for land use, as after all this will also have social impact as a domestic and industrial fuel.

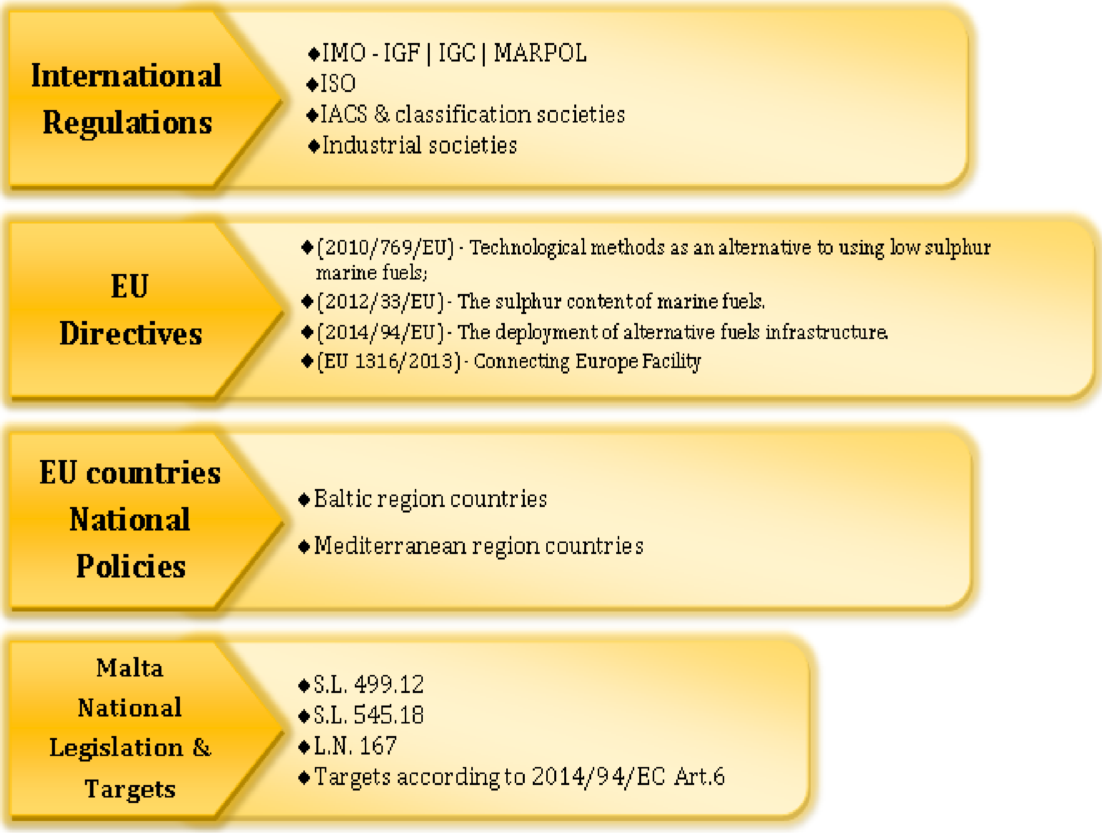
3.3 Conclusion

LNG infrastructure consists of a variety of externalities. Firstly it requires a motivation which is dependent greatly on regulatory input. Other factors will affect competitively, leading to a selection of best profits from fuel use and investment from ship owners. The low oil prices will possibly reduce the motivation of a fuel switch investment to LNG by ship owners. Also due to lack of available infrastructure ship owners will be cautious as they would require bunkering in different locations. However, LNG provides both economic and environmental advantages on the long run. The reduction of emissions are also a benefit to the general public, providing cleaner air, reducing health issues. Thus, LNG can prove effective environmentally, economically and socially.

4 The Legal Framework and Regulations

From international regulations to national legislations, there are several documentations that need to be observed in relation to the use of LNG as marine fuel. This chapter presents a literature analysis as summarised in Figure 15.

Figure 15: The documents with effect of LNG bunkering which are analysed in this chapter.



Source: (Author).

4.1 International Regulations

Through the years, there have been various organizations that published their respective documentation and guidelines for the use of LNG as a marine fuel. The main organizations, with their respective LNG documentations are mentioned below.

4.1.1 International Maritime Organization

In relation to LNG, the IMO has a number of conventions and codes with which LNG bunkering ships will have to comply with:

- International Convention for the Safety of Life at Sea (SOLAS);
- International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978, as amended (MARPOL);
- International convention on Standard of Training, Certification and Watch keeping (STCW);
- Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships MSC.285(86);
- International Code for Construction and Equipment of ships Carrying Liquefied Gases in Bulk (IGC code);
- International Code of Safety for Ships using Gases or Other Low Flashpoint Fuels (IGF Code).

With respect to LNG as a marine fuel, the IGC and IGF codes are the most important. The regulation of emissions from the combustion of fuels on international ships, is addressed in the following convention, and presented on a timeline Figure 16.

MARPOL Annex VI Reg 13: NO_x. Every diesel engine on-board a ship with a power greater than 130kW should comply with this regulation, as tabulated below (see Table 3).

Table 3: NO_x emission limits as set by the IMO.

	Tier I	Tier II	Tier III
Ship construction date	1st Jan 2000 – 1st Jan 2011	On or after 1st Jan 2011	1st Jan 2016 & in NECA area
n<130rpm	17.0g/kWh	14.4g/kWh	3.4g/kWh
130=n<2000rpm	$n^{(-0.2)}$g/kWh	$n^{(-0.23)}$g/kWh	$n^{(-0.2)}$g/kWh
n>2000rpm	9.8g/kWh	7.7g/kWh	2.0g/kWh

Adapted from: (MARPOL, 2013).

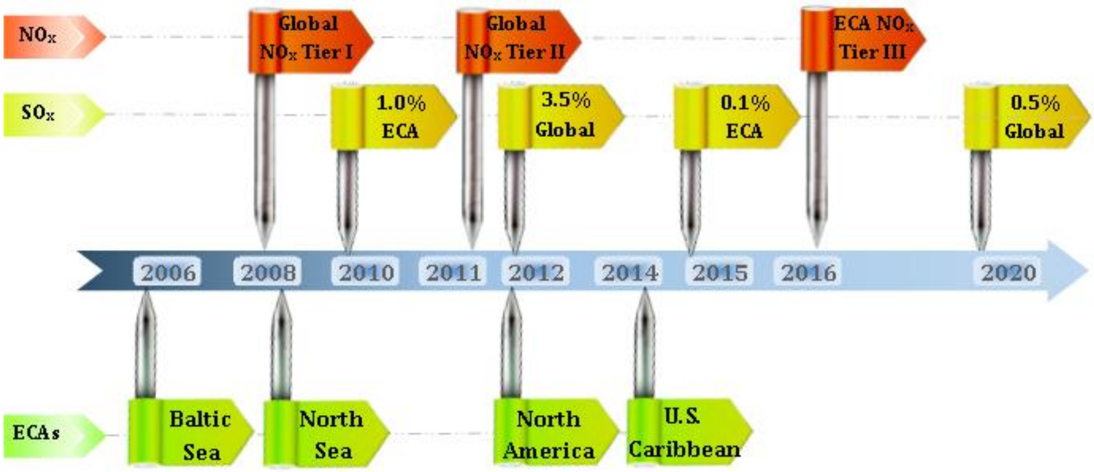
MARPOL Annex VI Reg 14: SO_x and PM. The level of sulphur content is to be complied with by all ships according to the following limits (see Table 4).

Table 4: SO_x emission limits as set by the IMO.

Global		SECA	
Before 1st Jan 2012	4.5% m/m	Before 1st July 2010	1.5% m/m
On and after 1st Jan 2012	3.5% m/m	On and after 1 July 2010	1.0% m/m
After 1st Jan 2020	0.5% m/m	On and after 2015	0.1% m/m

Adapted from*:* (MARPOL, 2013).

Figure 16: Targets as set by IMO.



Adapted from: (MARPOL, 2013).

4.1.2 International Standards Organization (ISO)

The ISO has prepared various standards for the use and operation of LNG related equipment and systems.

- ISO 28460:2010 – Installation and equipment for liquefied natural gas – Ship-to-shore interface and port operations.
- ISO/TS 16901:2015 – Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface.
- ISO/TR 17177:2015 – Guidelines for the marine interfaces of hybrid LNG terminals.
- ISO/TS 18683:2015 – Guidelines for systems and installations for supply of LNG as fuel to ships.
- ISO 20519:2017 – Specification for bunkering of liquefied natural gas fuelled vessels.

The most relevant standard document related to LNG bunkering is the ISO 20519. This document was prepared by the technical committee ISO/TC8 'Ship and Marine Technology'. The need for this international regulation was raised by the IMO and BIMCO. The ISO 20519 was designed with the concept of meeting the industry requirements as seen from the IMO perspective while it supports the IGF and IGC codes. The main content of this document includes:

- Liquid and vapour transferring systems;
- Operational procedures;
- The provision of LNG bunker delivery notes by the service provider;
- Personnel training and certification requirements; and

- LNG facilities requirements to meet the respective regulations.

4.1.3 IACS and major classification societies

IACS is recognised as a principal technical advisor for the IMO. Its aim is to provide the minimum requirements for classification societies in terms of technical standards while ensuring that the appropriate safety and environmental protection within the maritime sector are achieved and maintained. For the LNG sector, IACS has published document 'No. 142 – LNG Bunkering Guidelines'.

Major and well-known classification societies in Europe have also published their independent documentation in relation to LNG bunkering. These regulations are to be applied to LNG ships so that they can be certified safe for seaworthiness. The following are the documents according to their Classification Society.

The rules and guidelines listed in Table 5 are not the only product of classification societies in relation to LNG bunkering. Various project-specific reports have been published.

Table 5: Collection of LNG bunkering related rules and guidelines from classification societies.

Classification Society	Rule Documentation			Publishing Year
ABS		LNG Bunkering: Technical and Operational Advisory		
	Guide	LNG Bunkering		January, 2017
BV	Guide	LNG Bunkering Ship	NR 620 DT R00 E	October, 2015
DNV.GL	Recommended Practice	Development and operation of liquefied natural gas bunkering facilities	DNVGL-RP-G105	October, 2015
LR		Classification of Natural Gas Fuelled Ship		January, 2016
PRS		Bunkering Guidelines for LNG as a Marine Fuel	166/P	March, 2017
		Using LNG or Other Low-Flashpoint Fuels on-board Ships other than Gas	117/P	March, 2017

Adapted from: (Volsem, 2015).

4.1.4 Industrial societies

There are other organizations that publish general guidelines for the gas and shipping industry in order to create awareness and provide standards of operation (Volsem, 2015).

SIGTTO - has published procedures in relation to the ship interfaces and transfer of Cargo LNG;

ISGOTT - in collaboration with IAPH published a handbook with the idea of being a first-hand reference on-board to standardise the procedures of cargo handling between a ship and shore interface; and

SGMF - is an organization which aims to provide the essential information to all sectors related to LNG bunkering so that the increase in use of LNG for ship fuel can occur smoothly, securely and safely. Their guide books explain what is essential, spanning from training and competence, to contracts, technicality, safety and environmental issues (SGMF, 2016).

4.2 EU directives and regulations

The EU, as a region parliament made up of 28 member states, protects the rights of all its members. For this reason, it issues directives as legal documents in order to set targets for its member states. From a technical perspective, the following directives have been issued, to enable LNG bunkering to achieve its desired effect.

- (2010/769/EU) On the establishment of criteria for LNG carriers, of technological methods as an alternative to using low sulphur marine fuels meeting the requirements of article 4b of Council Directive 1999/32/EC.

- (2012/33/EU) The sulphur content of marine fuels.

- (2014/94/EU) The deployment of alternative fuels infrastructure.

- (EU 1316/2013) Connecting Europe Facility

The most important regulations for the implementation of LNG bunkering are:

(2012/33/EU) – In this directive the type of fuel used on board ships is restricted by its sulphur content. It sets new sulphur emission limits of 0.1% from 1st January 2015 for SECA areas. From 1st January 2020, it requires that member states do not allow ships to burn fuel with SO_x content of 0.5% or more within their territorial seas and exclusive economic zones. In ports ships are not allowed to burn fuel with SO_x content of more than 0.1%. It emphasises that member states are responsible for monitoring and controlling these limits.

(2014/94/EU) – This directive presents information on provision of various clean fuels on the market. With respect to LNG, it refers to the need of a region-wide infrastructure to make this type of fuel available in an economically effective method. It mentions the lack of harmonised standards that still create barriers to the industry in terms of LNG use. It mentions projects for the creation of LNG infrastructures such as the TEN-T Core Network. National frameworks are free to make use of the most viable technology according to their needs. Such use of alternative fuels is subject to electricity generation and transport means. Member states are requested to set targets nationally within their policy framework.

(EU 1316/2013) – In view of establishing the infrastructure required to provide cleaner and more efficient transport within the European region, this legal document regulates the provision of funds to its member states for conducting feasibility studies and establishment of the required infrastructure. From the maritime perspective, it considers the setting up of LNG terminals for the supply of fuel and the provision of electrical shore supply. It also specifies that as from 1st January 2020, sulphur content in marine fuels should be less than 0.5% within territorial seas, exclusive economic zones and pollution control zones.

4.3 EU countries' national frameworks and guidelines

In the past few years, following the provision of EU directives mentioned in section 4.2, various studies have been conducted in collaboration with neighbouring countries, with an aim to benefit from the knowledge and experiences of one another in different aspects. This can be seen clearly in northern European countries and the Baltic region. In this region the concept of using LNG bunkering in the maritime industry was developed from scratch because of the stricter regulations of the SECA.

The Rhine inland water region is another example of a collaboration between regions where maritime inland transport is essential. The main outcomes of the LNG Masterplan project in this case were analysis of newly built LNG vessels, infrastructure CBA and regulatory analysis.

In the southern European region, LNG bunkering is still at very early stage. Various studies have been conducted which initiated small pilot infrastructural projects. The Poseidon and the COSTA studies provide the core information available for the Mediterranean region. Valencia and Portugal are also being engaged in similar studies, such as the Core LNGas Hive. The aim is to create an infrastructure connecting the North Atlantic with the western Mediterranean, while the eastern Mediterranean is studied in the Poseidon project.

For these countries to be in a position to develop such LNG bunkering infrastructures, regulatory analysis must be carried out, and a National Policy framework regarding LNG provision as a marine fuel created. The following sub-sections, explore how countries advanced in the LNG sector have prepared for the safe implementation of LNG bunkering in the maritime field.

4.3.1 Baltic region countries framework and guidelines

The Baltic region was selected as a SECA area in 2006, and this increased the interest in alternative fuels, especially LNG. A pioneer in the LNG industry, Norway, is a main producer of natural gas. In 2007, Norway inaugurated its first export terminal. As the country increases its exploration for gas offshore, the preferred transportation method is by ship. Following Norway, other Baltic countries have shown interest in introducing an LNG bunkering infrastructure. Studies were executed and determined a best practice for SECA areas and inland waterways. Various countries have collaborated region-wide and created research groups. The Danish Maritime Authority (DMA) has performed an intensive study on the region-wide infrastructure from the perspective of regulatory and industry standards. This was followed by a full report on the costing and actual LNG fuelled vessels, and different modes of bunkering. The Motorways of the Seas carried out a series of studies, which analysed different exhaust abatement methods and a pilot project related to LNG.

Belgium, Sweden and Germany were the first countries to develop port regulations for their respective commercial ports for the use of LNG. Hamburg, Rotterdam, Belgian ports, Zeebrugge, Gothenburg and Stockholm were the first ports supplying LNG. Other countries like France, Denmark, The Netherlands, Poland and the UK followed with investments in LNG infrastructure.

Every member state had its own process to acquire the required permits for their designated LNG infrastructure, and while some chose to install a few large-scale LNG plants, others opted for small-scale projects. Differences in the permit process vary with each country, ranging from one to four years. A bottleneck leading to longer permit approval is the multiple authorities involved in certifying the project. Familiarity with LNG and its technology also plays an important part in the process of approval (Volsem, 2015). The Baltic Sea region project 'Go LNG' is a region-wide project based on principles of sharing of knowledge, which provides information on different aspects of the LNG industry in different countries. It grew out of the start-up and increase of LNG use in the Baltic and North Sea region (Dalaklis, Ölçer, Madjidian, Ballini, & Kitada, 2017).

4.3.2 Mediterranean countries

Only a few Mediterranean countries have started to analyse deeply on the potential of LNG for bunkering ships. Spain and Portugal are currently investing in the infrastructure, while Italy and Cyprus are conducting feasibility studies. Greece is already operating local ferries on LNG. Some major studies will be described below.

A project conducted under the TEN-T EU Programme, named COSTA (CO_2 & other Ship Transport Emission Abatement by LNG), has provided a better picture to the advantages and size of service that might be ideal for the current market. The project revealed that LNG is an ideal alternative fuel for short-sea shipping in the Mediterranean region. Following the results of COSTA Projects, Italy has included into its national policy framework the use of LNG as a fuel, as it has a number of fixed short routes of this type. Demand values have been identified to help determine what kind of infrastructure is required. The aim of the study was to analyse the potential short term market on the local maritime transportation, with a prospective increase in demand after 2020, as regulations will come into force.

In Italy, the use of fixed LNG bunkering stations and the use of truck bunkering is seen as the ideal infrastructure to reach up to medium sized provision. Analysis of ideal ports that should have the infrastructure is underway. This analysis is based on investments required, space for infrastructure and possible demand increase in the coming years, and it spans various major ports around the Italian Peninsula.

In order to initiate a demand for LNG, ships need to run on LNG. National policy in Italy explains that focusing on the local market in the short term requires the local fleet to switch to LNG operated ships. (“Decreto Legislattivo”, 2017).

Through the Core LNGas Hive project, Spain and Portugal are collaborating to extend the LNG supply chain to the shipping industry. With both the authorities and the industry coordinating the respective studies, the plan is to have the infrastructure up and running by 2020. With 14 studies, they plan to obtain the knowledge and information required to set up the procedures and national policy frameworks, and to secure the required accreditations. 11 studies are targeted to analyse the physical implementation ending the results with pilot infrastructure (“Core LNGas hive”, 2016).

The Poseidon MED project, which was carried out in two stages, gave an initial perspective to the use of LNG as shipping fuel in the eastern Mediterranean region. In Cyprus, partly due to its location close to the Suez Canal entrance, LNG bunkering is a potential service. Cypriot maritime authorities and private investors are developing infrastructure plans with potential promotion in the near future (Demetriades, 2017).

The questionnaire (see Appendix A) revealed that Greece is conducting a study to analyse the potential of LNG bunkering for its territory as part of the Mediterranean. Nothing has been declared more than the ongoing studies from private sectors. Greek authorities are proposing 2025 as an appropriate year for the availability of LNG bunkering infrastructure.

4.4 Malta national legislation and targets

In the Maltese Islands and the waters under their jurisdiction, affairs related to maritime terminals, their facilities, and ship bunkering, are regulated under the S.L.499.12: Dangerous cargo ships, marine terminals and facilities, and bunkering regulations.

The use of fuels in Malta is regulated by the S.L.545.18: Quality of fuels regulations. The legislation stipulates the ISO standards for the processing of fuels to reach the necessary quality. Specifications of emissions from fuels are also indicated. Emission abatement technologies are mentioned, while suppliers and sampling methods are also regulated. LNG as fuel has already been included, since LNG is used as fuel in Malta's main power generation plant.

S.L.423.21: Natural gas market regulations specify details for the storage, distribution, supply and operation of natural gas, as transposed from EU directive 73/2009/EC.

The national targets for the provision of alternative fuels in Malta are in accordance with EU directive 2014/94/EC (CT3017/2017, 2017). Article 6 of this directive specifies:

- the number of available fuelling points;
- available infrastructure to meeting the market demand;
- that LNG bunkering infrastructure should be operational by the end of 2025;
- that LNG distribution system, including loading facilities, should be appropriate; and

- that after 2020, Compressed Natural Gas (CNG) should be made available to the public for use as fuel to motor vehicles.

Chapter 5 will discuss the required amendments to Maltese national legislation in the inclusion of LNG bunkering.

5 Regulation Gap Analysis for LNG in Malta

5.1 Regulatory gap description

With the introduction of a new technology and its evolution, a regulatory framework becomes outdated. Application of new technologies with the aim of having advantages and better service, requires amendments in the regulations to remove loop holes and having a legally accepted system. The scope of a regulatory gap analysis is to figure out the necessary changes in the current legislation and amend in consideration of the new requirements (Wheeler, 2015).

The focus of this chapter is to reveal what documentation is necessary for the implementation of an LNG bunkering infrastructure in Malta. The Maltese legislation is analysed with regards to ship bunkering (S.L. 499.12), and the study points out what needs to be amended in order to facilitate the implementation and use of LNG bunkering practice. The opinions listed are based on other legislations from countries in which LNG bunkering is already available. As a member of the EU, Malta has to comply with the EU directives. This chapter considers the main directives Malta is expected to adhere to, and others that need to be observed in the implementation stages because of environmental issues (see chapter 4).

The second part of the gap analysis examines aspects essential to the implementation of LNG bunkering infrastructure. These are divided in two sections; the essential port operational procedures set-up and the competence and training required.

Figure 17: The different stages how the gap analysis was conducted

Source: (Author).

The following literature has been used, for the gap analysis:

- Dangerous Cargo Ships, Marine Terminals and Facilities and Bunkering Regulations. Subsidiary Legislation 499.12. Malta.
- Quality of Fuels regulations. Subsidiary Legislation 545.18.
- Natural Gas Market Regulations. S.L.423.21.
- Liquefied Natural Gas Bunkering Study, published in 2014 by DNVGL
- D 4.1.2 & D 4.1.4 guidelines for port regulations and best practice LNG bunkering. Published in 2015
- D 2.3.1 LNG bunkering. Regulatory framework and LNG bunker procedures, published in 2015
- Development and operation of liquefied natural gas bunkering facilities (2015).
- D 3.4.10 legal and regulatory road map (2015).
- ISO 20519:2017 Ships and marine technology - Specification for bunkering of liquefied natural gas fuelled vessels.
- Ballini, F. (2013). Air pollution from ships in Danish harbours: Feasibility study of cold-ironing technology in Copenhagen. Italy.

5.2 Gap analysis

Table 6: Gap analysis of the Maltese legislation in relation to ports and bunkering.

Malta National Legislation and Port Regulations

Document	Current	Gap	Amendment Required
S.L. 499.12 Dangerous cargo ships, Marine Terminals & facilities and bunkering regulations	Definition of 'bunker' - "any non-volatile marine grade fuel oil used to fuel a ship or its machinery, and includes lubricating oil"	The definition of bunker at no point includes the gas fuel. It actually specifies that bunkers are non-volatile fuel oils. This means that LNG is not considered as a marine fuel in Malta.	Amendments to the definition are needed for the provision of LNG as ship fuel.
	Definition of 'Jetty pipeline' - "…substance could egress into any port or territorial waters'	LNG release will allow methane as a GHG gas into the atmosphere. Despite having no visible egress, the impact of GHG remains.	Understand the air pollution cause by methane slip, and include this in the definition, in case of LNG pipeline damage.
	Missing definition	Definition to be included	'SGMF', 'IGF code'

	Part III – Bunker supply barges and bunker receiving ships	The information listed at no point specifies the use of LNG bunker vessel. This is all in relation to oil fuels in terms of pollution. It is not subject to LNG bunkering.	The national legislation has to specify the use of LNG bunker vessel.
	Bunkering checklist	The legislation does not include checklists dedicated to LNG bunkering.	All bunkering checklists should include the appropriate checklists for LNG
S.L. 545.18 Quality of Fuels Regulations	Legislation is up-to-date, including emission regulations and LNG carriers making use of Boil off gas.	It does not mention other ships making use of LNG as marine fuel.	Need to include all ship types using LNG as fuel.
LN167 B2133 Natural Gas Market Regulations	No relation to LNG bunkering service providers.	This legislation specifies details for the Natural Gas market in Malta transposed from EU directive 73/2009. It rules the storage, distribution, supply and operation of natural gas.	Reference to LNG bunkering service providers required.

Source: (Author).

Table 7: International and EU regulations, and port guidelines gaps for an LNG infrastructure in Malta.

<table>
<tr><th colspan="4">LNG Bunkering Regulatory Gap in Malta</th></tr>
<tr><th></th><th>Documentation</th><th>Gap</th><th>Amendment Required</th></tr>
<tr><td rowspan="5">International & EU policy</td><td>The sulphur content of marine fuels (2012/33/EU)</td><td>As from 2020, Malta will have to abide to the Sulphur emission level in ports and territorial waters</td><td rowspan="2">By providing an LNG bunkering infrastructure, both in port and for international shipping, Malta will be providing a clean alternative fuel for local and international shipping.</td></tr>
<tr><td>The deployment of alternative fuels infrastructure (2014/94/EU)</td><td>Without the implementation of an LNG bunkering infrastructure, Malta will not be giving its full input to the EU directive in providing alternative marine fuels.</td></tr>
<tr><td>Strategic Environmental Assessment SEA Directive (2001/42/EC)</td><td colspan="2">This directive requires environmental assessment which have to be conducted when setting up a new plan for the implementation of projects on land and sea. The aim is to provide a high environment protection. Therefore, upon setting up an LNG bunkering infrastructure within port, these have to be conducted and abide to accordingly.</td></tr>
<tr><td>IPPC - Industrial Emissions Directive (2010/75/EU)</td><td colspan="2">The aim of this directive is to control pollution levels of industrial plants. For an infrastructure dealing with LNG, the essential tests and certification have to allow commercial operation.</td></tr>
<tr><td>Environmental Impact Assessment EIA Directive (2011/92/EU)</td><td colspan="2">This directive applies to both private and public projects considered to have a possible effect on the environment due to their size and kind of investment. It is up to the national authorities to decide if this directive will be applicable or not. However, it is expected that a project for an LNG bunkering infrastructure would require such an assessment</td></tr>
</table>

	Seveso II Directive (96/82/EC)	In order to control the possibility of major accidents on a project, this directive analyses possible accidents involving hazardous substances. Dealing with LNG, this directive will be essential for the implementation of LNG bunkering infrastructure.	
Port operational guideline and procedures		The mode of bunkering ideal for each port has to be studied specific to port	Introduce the possible modes of bunkering within the ports of service. This will include the study of possible storage of LNG demanding on port size and location. The supply of LNG to the port area will depend on the mode of bunkering chosen.
		No information on the risks and hazard within the Maltese port harbours	All safety scenario analysis such as HAZID, HAZOP, QRA. Guideline on how these analysis should be conducted in relation to LNG can be found in ISO/TS 18683/19, ISO/TS 16901/29 and ISO 20519:2017.
			The study and identification of non-specific bunkering zone with ports. This is also affected by the size of bunker and the mode of bunkering.
			SIMOPS requires a case-by-case analysis depending on which port and what type of ship is requesting bunkering. Multipurpose ports require dedicated assessments for simultaneous operations.

		Procedures for emergency plans for various type of accidents that might occur.
		Accreditation of service providers as per requirements for operators. ISO 18683, ISO 20519 and IAPH accreditation models provide guidelines with the terms under which accreditation is provided
	Control of Bunkering within port	Due to multiple operations within the port area, a control system has to be established to coordinate the port operations and traffic while bunkering
		A best-practice guidelines and procedures within ports should be created, including the procedures for different modes of bunkering
	Possibility of offshore LNG bunkering Station	Setting up the regulations for safety and procedures for conducting an LNG fuel transfer on anchor outside port limits but within territorial waters of Malta.
		Such a case will require more detailed study in terms of the weather conditions, in setting up the safe conditions to allow LNG bunkering to take place.

Competence and training		Training for operators of LNG bunkering to familiarise themselves and understand the knowhow and any possible results of misuse of the LNG system. ISO/TS 18683 and ISO 20519:2017 provides training requirments.
		Familiarisation training for port operators, providing knowledge on how to act in case of emergency.

Source: (Author).

5.3 Regulatory gaps analysis

The in-depth analysis of Maltese subsidiary legislation in relation to ports and bunkering (S.L.499.12) reveals that, so far, LNG has not been considered as ship fuel. The lack of LNG bunkering provision in Malta is also seen in S.L.423.21, where no reference to LNG bunkering is made in the Maltese markets. Missing definitions are a key factor which indicates that there has been no attempt to have LNG provision in Malta.

The fact that Maltese subsidiary legislation only refers to LNG in S.L.545.18, a section on the quality of fuels, indicates that LNG is already available as a fuel in Malta. However, LNG is only available as fuel for the main electrical power plant in Malta. This shows that amendments to this document were only made with LNG supply for the power plant in mind.

This situation shows that the legislation has been amended to accommodate current needs. The fact that LNG was not considered as ship fuel also indicates that this was never part of the legislation. Therefore, one of the first steps that would need to be taken to allow for LNG bunkering in Malta is to amend the legislation legally as suggested in Table 6. Other technical issues related to LNG included in the legislation might require addition of the protection of environment, including GHGs from the atmosphere and safety related details. The National legislation may also be backed-up by dedicated port bunkering procedures which directly specify issues related to particular situations.

Regulatory gaps in the national legislation are affected by international regulations and, in the case of Malta, EU directives as well. Therefore, gaps also exist in meeting the targets set by the directives. With the introduction of LNG provision as a marine fuel, Malta will be meeting the requirements for the EU directives 2012/33/EU and 2014/94/ EU. This will close gaps in reaching sulphur emission targets and providing alternative fuels for marine use. The provision of LNG bunkering service would include in-depth studies, risk assessments, third-parties, and big investments.

The implementation of an LNG bunkering infrastructure has to be in line with multiple EU directives. The creation of a shore based or offshore structure has to be compliant with regulations controlling the impact on the environment and safety. Due to the industrial scale of the LNG bunkering infrastructure, plans are assessed to be in line with EU directives as listed in Table 7. All these directives are essential as they control the effect of the infrastructure on the environment in terms of visual impact, and pollution at building and operational stages. It also assesses the effect on the nearby public, limiting the negative effects of the operation in terms of health and safety matters. The issue with all these directives is that they make the planning and certification process more bureaucratic, as different authorities have to assess the project depending on their control area.

Last but not least, all the regulations need to be provided to the plant operators and area workers for safe and optimum operation. This is done by providing user-friendly guidelines and procedures on how to operate the equipment. Safety procedures and limited access by personnel should be clearly identified. A good understanding of such guidelines requires competent training and drills. Identifying hazardous loop holes in the operation helps in improving the operation in a safe and efficient way.

5.4 Conclusion

Serving fuel nation-wide and to the international shipping context, regulations are a must for the protection of all parties. Therefore, regulations have to be amended to accommodate an efficient and safe system. A gap analysis requires profound analysis of the essential documentation, while comparing to where it is to be reached to identify what needs to be changed. The gaps identified in this chapter, are a must for Malta to be able to allow the provision of LNG bunkering and implementation of its infrastructure according to law.

6 SCENARIOS FOR LNG BUNKERING VIABILITY IN MALTA

6.1 Overview: LNG progress and potential future scenario in Malta

From 2017, Malta has a constant supply of LNG from the FSU dedicated as a fuel to the electrical power generation plant in Delimara. In 2018, Malta is planning to start the implementation phase of the gas pipeline which connect the island to the European grid. This project is expected to take 7 years, expected to be ready by 2024 ("SNAM RETE GAS", 2017).

Figure 18: The LNG terminal close to Delimara power plant and the possible offshore location of the FSU.

Adapted by: (Author).

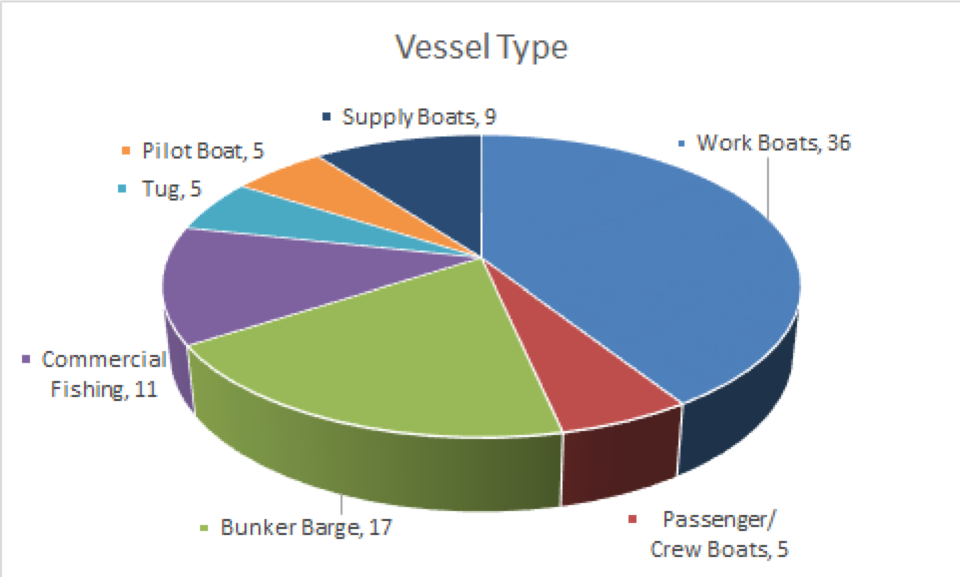
As Malta is into the study phase of the provision of LNG for ship fuel, assumptions according to a study carried out in 2015 for the demand there will be after the regulations come into force in 2020 (CT3017/2017, 2017). A possible demand exponential graph has already been indicated in Figure 4.

With the concept of reducing the emissions from the marine industry in Malta, and in meeting the requirements by the 2020 sulphur cap and alternative fuels, a local scenario will be analysed in this chapter. This scenario has the possibility of starting a potential demand of LNG from the shipping industry until demand increases from the international shipping in the central Mediterranean. Such scenario can be achieved by addressing the local commercial operating vessels[2].

There are approximately 90 commercially operating vessel which are allowed to operate within Maltese ports and the respective territorial waters only. The selection of these ship was obtained from a list of the Maltese registry of shipping. Since the majority of these vessels are less than 500GT, they do not need the full certification of international ships as they fall under the non-convention size vessels, but in terms of emissions regulations, (NO_X, SO_X, etc), they should be compliant with MARPOL since engine power is higher than 130kW. The age of the majority of these vessels allows them to be compliant with the emission regulations. However, with a vision in seeing cleaner vessels operating locally, these should be the first vessels to take action. Information regarding these vessels was provided through the Maltese registry of ships.

[2] These are vessels which operate solely in the Maltese territorial waters and enter into Maltese port often or even daily. Such vessels consists of tug boats, provision and crew boats, bunker barges, fish farming vessels and ferries. Their operation is limited a lot by weather conditions and some also due to seasonal operation. Information on these vessels was provided through Transport Malta.

Figure 19: The selection of the NCV taken into consideration for the scenario.



Adapted from: (Transport Malta).

In view of creating a cleaner shipping in Maltese ports, a scenario will be analysed if these local vessels had to operate on LNG. Although this is a limited demand, and it might not be economically viable to refit an LNG system, the idea of the scenario is to create a possible demand for LNG as ship fuel. If this is seen as a viable demand, the government can also provide incentives or fund through the EU to change these vessels to new LNG fuelled ones.

With the oldest vessel built in 1947 and the latest in 2013, the average age of the commercial fleet in Malta is with a year of build in 1986. This indicated that the local operating vessels are still operating with old machinery which is even more subject to emissions.

This scenario will be analysed on the three principles of sustainability; environment, social, and economic aspects. As policy makers have to be more sustainable in their decision making (Santoyo-Castelazo & Azapagic, 2014), these three principles in this case will provide a better image of how LNG as ship fuel in Malta can provide a more viable way of operating vessels in a more sustainable way.

Through this methodology the effect of LNG as a marine fuel through a comparison between MDO as the current fuel used for the NCV vessels and LNG is determined. Terms of analysis will be:

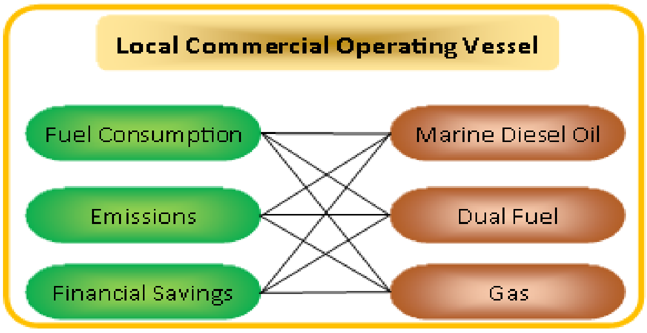
- Fuel consumption;
- Fuel savings;
- Emission values for NO_x, SO_x, CO_2; and
- Ferry case.

The SFC value is determined from literature as proposed by regulations for medium speed diesel fuelled engines (Trozzi & De Lauretis, 2016).

The Ep, is determined from the Maltese registry of ships, courtesy of Merchant Shipping Directorate, Transport Malta.

In order to be in a position to make the appropriate comparison between LNG and MDO the engine type Wärtsilä 20DF characteristics will be used. This engine can be run on gas or diesel fuel. Therefore, for such a small size of engine power, comparison results can be better. The SFC values were taken accordingly. A comparison to an Otto cycle gas engine, running solely on gas, is calculated on the SFC of a Caterpillar G3606LE.

Figure 20: A diagram showing the parameters considered for the scenario analysis.



Source: (Author).

6.2 Assumption

Since these vessels are not used on a daily bases and since they are used per voyage purpose, the following assumption is made.

- The vessels operate for a total of 8 hours per working day. It has to be noted that these vessels do work depending on the voyages required. However, it is being assumed that they work on a daily basis.

- For annual calculations, taking into considerations that these vessels do not operate every day due to workload and also to bad weather, it is estimated that they perform 300 days of work yearly.

- All calculations are done as a total of the 90 vessels, since there is a small number of vessels.

6.3 Calculation

6.3.1 MDO fuel Consumption

$$FC_{MDO} = \frac{SFC * Ep * 8}{10^6}$$

$$FC_{MDO} = \frac{196 * Ep * 8}{10^6}$$

FC = Fuel Consumption (tonnes/day)

SFC = Specific Fuel Consumption (g/kWh) which is 196g/kWh for the Wärtsilä 6L20DF.

Ep = Engine power (kW)

$$Yearly\ FC_{MDO} = \left(\frac{SFC * Ep * 8}{10^6}\right) * 300$$

$$Yearly\ FC_{MDO} = \left(\frac{196 * Ep * 8}{10^6}\right) * 300$$

6.3.2 Dual fuel consumption

Since in the gas mode, dual fuel is used, the fuel consumption for the pilot and gas fuel is calculated separately. In the case of the gas fuel the units need to be changed from kJ/kWh to g/kWh.

$$SFC_{LNG} = \frac{TEC}{Low\ calorofic\ value}$$

SFC = Specific Fuel Consumption (g/kWh)

TEC = Total Energy Consumption (kJ/kWh) which is 8550kJ/kWh for the Wärtsilä 6L20DF.

Low calorific value for LNG = 49,200kJ/kg

$$FC_{DF} = FC_{pilot} + FC_{LNG}$$

$$FC_{DF} = \left(\frac{4.4 * Ep * 8}{10^6}\right) + \left(\frac{173.78 * Ep * 8}{10^6}\right)$$

$$Yearly\ FC_{DF} = \left[\left(\frac{4.4 * Ep * 8}{10^6}\right) + \left(\frac{173.78 * Ep * 8}{10^6}\right)\right] * 300$$

6.3.3 Gas fuel consumption

$$FC_{gas} = \frac{SFC * Ep * 8}{10^6}$$

$$FC_{gas} = \frac{187.1 * Ep * 8}{10^6}$$

$$Yearly\ FC_{gas} = \left(\frac{SFC * Ep * 8}{10^6}\right) * 300$$

$$Yearly\ FC_{gas} = \left(\frac{187.1 * Ep * 8}{10^6}\right) * 300$$

6.3.4 Diesel fuel mode emissions

To calculate the emission quantity from the use of diesel as fuel, the emission factor used was determined from the IMO Greenhouse Gas Study and it was established by the project carried out in the Mediterranean, Costa project. These emission factors do take into consideration the sulphur content of MDO.

Table 8: Emission values for MDO and LNG.

Emission factor (tonnes/tonne fuel)	MDO (tonnes/tonne fuel)	LNG (g/kWh)
CO_2	3.19	455
SO_x	0.01	0
NO_x	0.056	2
PM	0.0011	0

Sourced from: (Furqon Rochyana, Yamin Jinca, & Siahaya, 2014; Perez et al., 2015; Smith, et al., 2015).

The following formulae where used:

$$Total\ CO_2\ emission = FC * CO_2\ emission\ factor$$

$$Total\ SO_x\ emission = FC * SO_x\ emission\ factor$$

$$Total\ NO_x\ emission = FC * NO_x\ emission\ factor$$

$$Total\ PM\ emission = FC * PM\ emission\ factor$$

Total emissions is in (tonnes/day).

6.3.5 DF mode emissions

To calculate the DF mode emissions, the following calculation was used. The content value of each emission was obtained from literature in g/kWh.

$$Total\ Emission_{DF} = Tot\ Emission_{pilot} + Tot.\ Emission_{LNG}$$

$$Total\ CO_2\ Emission_{DF} = \left(Total\ FC_{pilot} * CO_2\ emission\ factor\right)_{pilot} + Total\left(\frac{455 * Ep * 8}{10^6}\right)_{LNG}$$

$$Total\ SO_x\ Emission_{DF} = \left(Total\ FC_{pilot} * SO_x\ emission\ factor\right)_{pilot} + Total\left(\frac{0 * Ep * 8}{10^6}\right)_{LNG}$$

$$Total\ NO_x\ Emission_{DF} = \left(Total\ FC_{pilot} * NO_x\ emission\ factor\right)_{pilot} + Total\left(\frac{2 * Ep * 8}{10^6}\right)_{LNG}$$

$$Total\ PM\ Emission_{DF} = \left(Total\ FC_{pilot} * PM\ emission\ factor\right)_{pilot} + Total\left(\frac{0 * Ep * 8}{10^6}\right)_{LNG}$$

6.3.6 Gas mode emission

$$Total\ CO_2\ Emission_{gas} = Total\left(\frac{455 * Ep * 8}{10^6}\right)_{LNG}$$

$$Total\ SO_x\ Emission_{gas} = Total\left(\frac{0 * Ep * 8}{10^6}\right)_{LNG}$$

$$Total\ NO_x\ Emission_{gas} = Total\left(\frac{2 * Ep * 8}{10^6}\right)_{LNG}$$

$$Total\ PM\ Emission_{gas} = Total\left(\frac{0 * Ep * 8}{10^6}\right)_{LNG}$$

6.3.7 Financial savings

To analyse the financial difference between LNG and MDO the following formulae will be calculated.

$$Yearly\ MDO\ in\ € = yearly\ FC_{MDO} * €667.35$$

$$Yearly\ DF\ mode\ in\ € = (yearly\ FC_{Pilot} * €667.35) + (yearly\ FC_{LNG} * €403.77)$$

$$Yearly\ GAS\ mode\ in\ € = yearly\ FC_{gas} * €403.77$$

For calculation throughout this methodology the following prices will be used.

Table 9: Fuel prices used in calculation.

	Price (€/tonne)
MDO	667.35
LNG	403.77

Sourced from: (Perez et al., 2015).

The Average fuel prices are not consistent through literature. This is effected by various facts:

- Mode of transport of fuel (ship, pipeline etc)
- Location of origin;
- Available supply and demand; and
- Effect from alternative fuels.

LNG prices for comparison within the Mediterranean region are not specified in literature and access to bunkering platforms was not provided. For this reason I opted to use the prices of LNG and MDO according to the Costa study (Perez et al., 2015).

This might not reflect the current situation in the price difference. However, to identify the price difference according to the 2013 average used in the scenarios will still be sufficient, I performed the following analysis.

Table 10: The Costa study prices are the one used for these scenarios. When compared to the current and future fuel prices to determine the price benefit.

	Unit	Costa Study	CME group		
Year		**2013**	**2017**	**2018**	**2019**
MDO	€/tonne	667.35	411.66	408.44	417.99
LNG	€/tonne	403.77	123.81	125.98	120.45
% difference	%	39%	70%	69%	71%

Adapted from: (Perez, Mestre, Saez, & Lara, 2015; CME, 2017).

According to this fuel trading platform, future prices between MDO and LNG are expected to have a higher percentage difference. This means that an investment in LNG fuel system will be much more viable.

6.4 Unit conversion

Reference to literature provides various units for quantities of fuel and currency. The common unit used for this dissertation are €/tonne and €/m^3. The following conversions were used.

Table 11: Unit conversions for LNG

	1-MMBtu	1-Cubic meter LNG	1 tonne LNG
1-MMBtu	1	0.048	0.0192
1-Cubic meter LNG	21.04	1	0.405
1 tonne LNG	52	2.47	1

Adapted from: (Natural gas unit).

Table 12: Currency conversion used during this study.

US$	€
1	0.851

Source: (XE currency converter: USD to EUR, 2017).

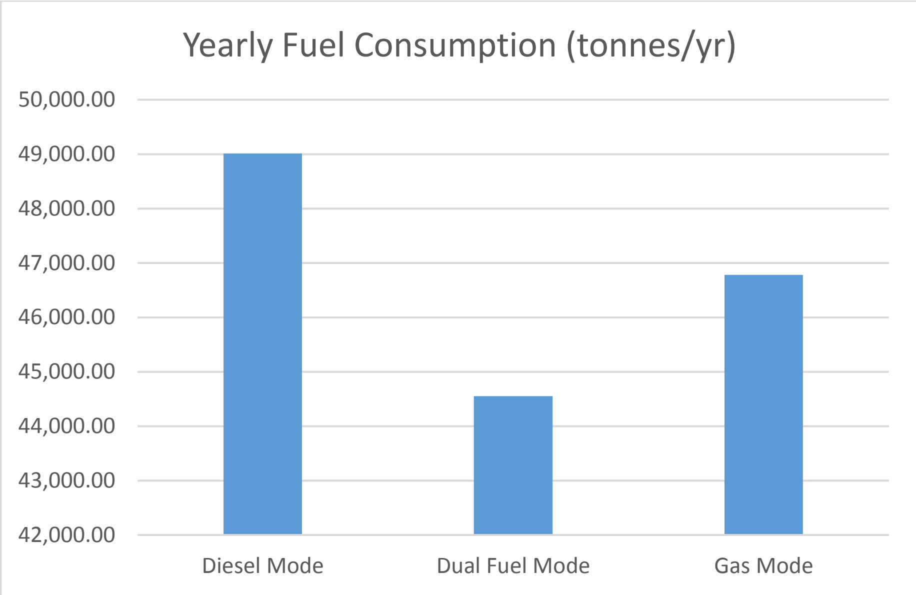
7 Viability of LNG in Malta: Results

7.1 Fuel savings

The calculations gave positive results for the use of LNG. On comparing the diesel mode to the dual fuel mode, a fuel consumption decrease of 9.09% was noted. In financial terms, this would be equivalent to a yearly savings of €14,426,816 in consumption. On comparing diesel to gas mode consumption, a 4.5% fuel reduction can be noted.

There are two main factors in this effect: LNG engines have a SFC of 15% less than other technologies (Smith, et al., 2015). Additionally, the technology used for burning gas has its effect on the amount of fuel burnt. For example, Burning HFO and installing scrubbers tend to increase the fuel consumption (Schinas & Butler, 2016; Elgohary, Seddiek, & Salem, 2015).

Figure 21: For the local commercial vessels operating in Malta, the yearly fuel consumption if they had to operate on different technologies.



Source: (Author).

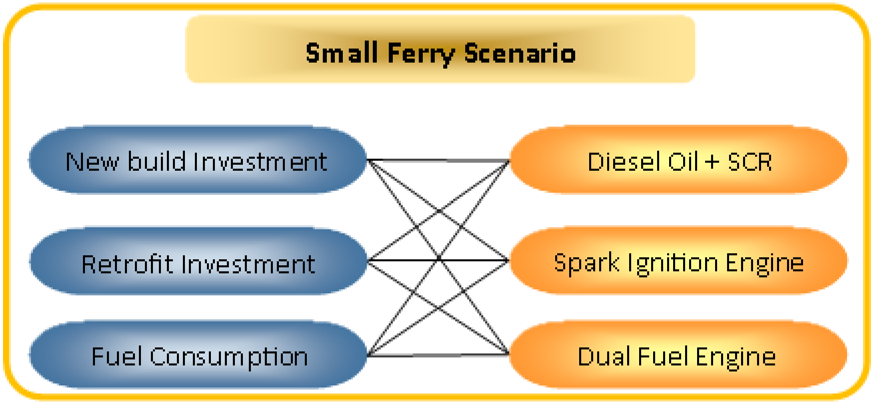
At this stage, one advantage from using of LNG as fuel has been noted. By saving this much from their use of fuel, vessel operators can enjoy the benefit of their investment at an earlier stage. In the following section (7.2), the example of a ferry will illustrate possible investments costs and savings.

7.2 Ferry ship case analysis

In order to be able to see the possible investment required by a small vessel owner to switch to LNG, the following scenario was created as an example. In Malta, there are three ro-pax ferries. Each ferry[3] has a total engine power of 5000kW. Currently running on MDO, these vessels can have good potential if they had to run on LNG.

[3] Gozo Channel (operations) Limited operates three ro-pax ferries between Malta and its sister island Gozo. The ships are 15 years old, each having an electric thruster propulsion system. Every ship has four identical Ulstein generators Model: KRG-O. Every engine has a rated power (MCR) of 1025kW.

Figure 22: The parameters considered for the small ferry scenario.



Source: (Author).

The tables below show, in terms of mechanical operations, the costs required in the case of a new building or retrofitting investment being made. In Table 13, it becomes clear that the LNG machinery system would require a 64% higher initial cost. This is approximately the same for both the dual fuel and the spark ignition gas engine technologies. For a retrofit, according to Table 14 There is a 90% price difference with LNG systems being highly more expensive to retrofit. A price different of 18% identifies between a new build and a retrofit of an LNG system. At such prices, one questions which investment would be the most viable to make.

Table 13: Investment in euros required for a new built ferry machinery system for different technology set-up to meet emission requirements.

Small Ferry New Built Investment cost				
	unit	MDO + SCR	Spark ignition 4 stroke	Dual fuel 4 stroke
Engine size (4*1250)	kW	5,000.00	5,000.00	5,000.00
Fuel pumps, and fuel auxiliaries	€	100,000.00	0.00	0.00
fuel system + tank	€/kW	0.00	245.00	245.00
Engine price	€/kW	180.00	350.00	350.00
SCR	€/kW	45.00	0.00	0.00
Installation cost	€/kW	0.00	100.00	100.00
Initial Investment	€	1,225,000.00	3,475,000.00	3,475,000.00

Source: (DMA, 2012; "Gozo Channel Fleet", n.d.).

Table 14: Investment in euros required for a retrofitting ferry machinery system for different technology set-up to meet emission requirements.

Small ferry retrofitting investment cost				
	Unit	MDO + SCR	Spark ignition 4 stroke	Dual fuel 4 stroke
Engine size (4*1250)	kW	5,000.00	5,000.00	5,000.00
fuel system + tank	€/kW	0.00	245.00	245.00
Engine price	€/kW	0.00	0.00	0.00
SCR	€/kW	45.00	0.00	0.00
Conversion to LNG	€/kW	0.00	175.00	175.00
Installation cost	€/kW	9.00	150.00	150.00
Initial Investment	€	270,000.00	2,850,000.00	2,850,000.00

Adapted from: (DMA, 2012; "Gozo Channel Fleet", n.d.).

Table 15: Potential fuel savings comparing LNG combustion methods and MDO for the ferry scenario.

Ferry fuel cost & consumption				
	Unit	**MDO**	**Spark ignition 4 stroke**	**Dual fuel 4 stroke**
				192.72 7,611.56
Fuel Consumption	tonnes/yr	**8,584.80**	**8,194.98**	**7,804.28**
				128,611.69 3,073,321.20
Fuel Cost	€/yr	**5,729,066.28**	**3,308,887.07**	**3,201,932.89**
Savings LNG on MDO	€/yr		**-2,420,179.21**	**-2,527,133.39**

Adapted from: (DMA, 2012).

Using different technologies for yearly fuel consumption analysis of this ferry, running on LNG can save approximately €2,500,000 on consumption. With this rate, owners could pay back a LNG vessel investment in less than 2 years considering only the machinery. However, fuel savings is always subject to the current fuel market price. Through various literature and the questionnaire conducted, it was noted that fuel price difference between oil and LNG in important to trigger motivation of operators to switch to LNG or invest in other abatement technologies to reduce emissions from fossil fuels. In section 2.4, literature reference showed that the rate of vessels switching to LNG slowed down when the oil prices suddenly dropped. From the questionnaire, the effect of oil prices on LNG was also discussed in section 3.1.2.

This case consisted of only fuel and CAPEX cost. Operational costs should be considered because these are still high. However, LNG is advantageous from the operational perspective as using LNG equipment reduces operational costs by 35% as estimated for a 33,000DWT tanker ship (Burel et al., 2013).

7.3 Emission reduction and taxation

Potential savings were achieved on comparing emission results of using MDO, DF and spark-ignited gas engines.

Table 16: A percentage comparison of the MDO emissions to those of different gas combustion methods.

Emission results (tonnes/year) and potential difference					
	MDO	DF	MDO – DF % difference	Gas mode	MDO-Gas % difference
CO_2	156,337.51	117,279.64	**24.98**	113,770.02	**27.23**
SO_x	490.09	11.0	**97**	0	**100.00**
NO_x	2,744.48	561.70	**79.53**	500.09	**81.78**
PM	53.91	1.21	**97.76**	0	**100.00**

Source: (Author).

Yearly emission values were calculated. The most important is the percentage difference between the MDO emissions and the dual fuel or gas emissions. According to literature, the percentage emission decrease is quite similar (Burel et al., 2013; Xu et al., 2015; Dalaklis, Ölçer, Ballini, & DeWitz, 2016). A decrease of approximately 25% in CO_2 was achieved while obtaining almost 100% from SO_x and PM, and 80% from NO_x (Nicoll et al., 2012; Tzannatos & Nikitakos, 2013). The difference in NO_x and PM percentage is mainly caused from the dual fuel combustion. As diesel fuel is added for igniting the gas, emission levels will increase. In fact, with the use of pilot fuel, the emission limits are not reached for NOx. For this reason, dual fuel engines would still require an EGR or SCR for full compliance (DMA, 2012).

A study using the 'technology warming potential' (TWP) principle identified that comparing NG in dual fuel engines to conventional MDO engines would achieve a climate parity on a 30-year period. Spark ignited gas engines could achieve a 190-year climate parity on the combustion effects from the conventional diesel engines (Thomson et al., 2015).

Following what other European countries have done to incentivise operators making use of cleaner technology, EU subsidies through LNG projects was a main drive to invest. However, in the case of Malta we are seeing a case of small working boats, that investment costs can be a burden considering the high investment cost and the amount of work these vessels conduct. Unless these operators will be incentivised to replace their vessels, they would prefer to pay emission taxes then spending money.

A good incentive for Maltese operators would be having a fund mechanism similar to Norway. Fifteen Norwegian entities have created a non-profit making fund. This fund collects money per kilogram of NO_x emissions produced. The rate for 2017 is 2.30€/kgNO_x ("Duty of emissions of NO_x", 2017). Then the operators who are registered and pay their fee are allowed for financial help on upgrading with cleaner emissions (Winnes et al., 2016).

Table 17: Potential emission fund calculation.

NO_x Taxation - Fund & Savings		
	Diesel Mode	**Dual Fuel Mode**
Emission value of No_x (tonnes/year)	2,744.48	561.70
€/year tax for fund	€ 6,312,310.77	€ 1,291,907.34
By using LNG potential tax savings (€/year)	€ 5,020,403.44	

Source: (Author).

An analysis for a potential fund for Malta based on the tariffs of Norway and the emissions from the commercial vessel scenario operating in Malta was calculated. Considering that today these vessels are all running on MDO, then the fund has a yearly potential of €6,312,310. From the vessel owners' perspective, if all the 90 vessels had to be run on LNG, then each vessel could save €55,782 yearly from the NO_x tax. Other emission tax, or a total emission tax can also be created, as some are already available within the EU (Ballini & Bozzo, 2015). The EU countries already have an imposed CO_2 emission tax for road transport. According to the European Automobile Manufacturers Association, in Malta it is paid through the vehicle registration based on CO_2 emissions, price and vehicle's length. If incentives like these will be implemented to the marine vessels, then a local commercial operator would have to pay depending on their respective vessel emissions.

The advantage is that, like in Norway, local operators will be eligible to use a proportion of the income for the upgrading of their vessels; i.e. machinery retrofitting or new build. Also, due to new LNG equipment after investment, the local operator will have to pay less as his equipment is generating less emissions. The good thing of providing financial assistance can also make the fund more competitive as other local operators would be interested to join, and get financial assistance themselves at a later stage.

Thinking about limitations for Malta to allow a taxation and funding system as mentioned, one has to analyse the outcomes in relation to the current profits and work demand for the vessels into consideration, Age of vessels and current emission levels should be considered. The rate for emission taxation has to be calculated solely for Malta case, Benefits from the funding has to be explained to the vessel owners, as after all the scope is to generate funds for cleaner technology investments.

7.4 Potential LNG scenario in Malta

Currently Malta has an LNG storage facility of 180,000m^3. The only use of this FSU as of today is to supply gas fuel to the power plant in Malta. In June 2017, Malta has signed an agreement with Sicily to embark on building a pipeline which connects the Island to mainland Europe.

Once the pipeline is active Malta could have a small storage on land for LNG as a reserve to fuel the power plant. In the meantime, the pipeline can always supply the power plant. The FSU which at this stage will not be required any more for the power plant, can be moved offshore and anchored on 'Hurds bank' bunkering area. This is used by ships to replenish their bunker supply. Having the FSU located there, this can act as a bunker station to merchant ships. LNG bunkering feeder vessels can also get their supply from the FSU while reaching other ships on anchor.

In the meantime, the jetty in Delimara which was specifically built for the FSU will not be in use. Today on land there is a regasification plant. If this plant is changed over to a reliquefaction plant, gas from the pipeline could be changed to LNG and feed bunker supply to smaller ships which berth to the jetty for bunkering purpose only. As this point, this would be a good location for the small commercial vessels mentioned in the scenario above to be provided with LNG fuel. Also LNG bunkering by truck practice can also be used, however, this would require more safety risk assessments in the respective bunkering areas by the truck.

If the projected LNG bunkering demand curve is considered, we note an exponential increase in the demand. With a start-up of less than 50,000m^3 of LNG yearly in 2021, there is no need to have big infrastructure. The probability is that this demand would be from international shipping as local vessels do not have incentives yet. For this reason, a 4,000m^3 vessel is assumed to be enough to supply the first couple of years. One has to keep in mind that LNG should not be stored for a long time due to roll over.

It is expected that the FSU would be possible to move offshore in 2025 once the pipeline is functioning. In this year it is expected that the LNG demand for ship bunkering will be 70,000m^3. At this stage the LNG bunkering infrastructure would be more appropriate to invest in. A lifetime of 30 years will be considered.

A scenario of what the LNG bunkering infrastructure would include is:

- Offshore FSU;
- 2 bunkering vessels;
- 2 LNG trucks;
- Reliquefaction plant at the jetty.

To picture what investment an LNG bunkering infrastructure would be cost effective in Malta, a NPV of a potential bunkering investment as described above was calculated.

7.4.1 *Assumptions*

- The calculation considers a one investment with no inclusion of third parties;

- For the FSU, an assumed costed is taken for towing and anchoring the ship offshore Malta. No cost of the FSU itself are included (Castro-Santos, Ferreno Gonzalez, Diaz-Casas, Angel, & Formoso, 2013);

- For the reliquefaction plant, minor costs might be required to switch the heat exchanger;

- Only CAPEX costs are considered;

- Price of LNG used is determined from literature. It is the price difference between the import price and the selling price. In the NPV this is the cash flow after tax value. This is sourced as 35.54 €/m^3 (Nijoka, Munro, & Mellen, 2014; Kraal, March 23, 2017);

- A discount rate of 8% is assumed (DMA, 2012);

- The amount on assets, trucks, and vessels is considered a one-time investment in the beginning.

7.4.2 NPV formula

In order to simulate a potential earning from a LNG bunkering infrastructure in Malta, a simple NPV calculation is carried out based on the following formula.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

7.4.3 NPV results

On analysing the NPV Table 19, calculation show that for the assumed demand and CAPEX cost listed, the 15th year of investment will start paying back profits. 15 years not making profits is not considered as a viable infrastructure. The most expensive asset that was listed in the investment was a €40,000,000 bunkering vessel with a cargo capacity of 10,000m^3. In the Malta case where we have to be able to serve international shipping a bunker vessel of this size is required as the international ship fuel tank would require approximately 15,000m^3 (Ge & Wang, 2016). With this capacity, a ship of 30,000kW would be able to sail for approximately 30 days ("Viking Line", 2012; Permala, 2015).

Table 18: Calculation of the CAPEX cost for the NPV of an LNG bunkering infrastructure scenario in Malta.

CAPEX Cost				
	Size of vessel	**Unit Price**	**no. of Units**	**Totals**
Reliquefaction		NA	0	€ 0
FSU		NA	0	€ 0
FSU relocation		€ 700,000	1	€ 700,000
Bunker vessel	1000 m^3	€ 15,000,000.00	1	€ 15,000,000
	10,000 m^3	€ 40,000,000.00	1	€ 40,000,000
Truck	40-80 m^3	€ 500,000.00	2	€ 1,000,000.00
	Total CAPEX			**€ 56,700,000.00**

Adapted from: (DMA, 2012).

Table 19: The NPV calculation for the potential LNG infrastructure scenario in Malta.

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Investment year						0 (investing year)	1	2	3	4	5
Demand/year	15,000	30,000	40,000	50,000	60,000	70,000	85,000	100,000	110,000	120,000	135,000
Cash flow after tax					2,132,400.00	2,487,800.00	3,020,900.00	3,554,000.00	3,909,400.00	4,264,800.00	4,797,900.00
WACC	8%										
PV							2,797,129.63	3,046,982.17	3,103,407.76	3,134,755.32	3,265,370.12
Sum of PV							2,797,129.63	5,844,111.80	8,947,519.56	12,082,274.88	15,347,645.00
Less: initial Cap	(56,700,000.00)										
NPV							(53,902,870.37)	(50,855,888.20)	(47,752,480.44)	(44,617,725.12)	(41,352,355.00)

	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042
	6	7	8	9	10	11	12	13	14	15	16	17
	150,000	175,000	200,000	225,000	250,000	280,000	310,000	355,000	400,000	450,000	500,000	595,000
	5,331,000.00	6,219,500.00	7,108,000.00	7,996,500.00	8,885,000.00	9,951,200.00	11,017,400.00	12,616,700.00	14,216,000.00	15,993,000.00	17,770,000.00	21,146,300.00
	3,359,434.28	3,629,018.51	3,840,231.23	4,000,240.87	4,115,474.14	4,267,899.11	4,375,161.12	4,639,134.41	4,839,994.16	5,041,660.59	5,186,893.61	5,715,188.33
	18,707,079.28	22,336,097.79	26,176,329.02	30,176,569.89	34,292,044.03	38,559,943.14	42,935,104.26	47,574,238.67	52,414,232.83	57,455,893.42	62,642,787.03	68,357,975.36
	(37,992,920.72)	(34,363,902.21)	(30,523,670.98)	(26,523,430.11)	(22,407,955.97)	(18,140,056.86)	(13,764,895.74)	(9,125,761.33)	(4,285,767.17)	755,893.42	5,942,787.03	11,657,975.36

	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054
	18	19	20	21	22	23	24	25	26	27	28	29
	690,000	770,000	850,000	985,000	1,120,000	1,300,000	1,450,000	1,615,000	1,780,000	2,070,000	2,360,000	2,700,000
	24,522,600.00	27,365,800.00	30,209,000.00	35,006,900.00	39,804,800.00	46,202,000.00	51,533,000.00	57,397,100.00	63,261,200.00	73,567,800.00	83,874,400.00	95,958,000.00
	6,136,756.84	6,340,986.00	6,481,286.80	6,954,321.89	7,321,715.09	7,868,906.76	8,126,719.95	8,381,004.29	8,553,025.82	9,209,718.81	9,722,193.77	10,298,934.08
	74,494,732.20	80,835,718.20	87,317,005.00	94,271,326.89	101,593,041.98	109,461,948.75	117,588,668.70	125,969,672.99	134,522,698.81	143,732,417.62	153,454,611.40	163,753,545.48
	17,794,732.20	24,135,718.20	30,617,005.00	37,571,326.89	44,893,041.98	52,761,948.75	60,888,668.70	69,269,672.99	77,822,698.81	87,032,417.62	96,754,611.40	107,053,545.48

Source: (Author).

7.4.4 NPV Analysis

The NPV analysis did not consider the OPEX costs. For the land infrastructure, a lifetime of 40 years is applied. For bunkering vessels, a 20-year lifetime is normally assumed for the bunker vessels. A bunker vessel of 10,000m^3 is calculated to have an OPEX cost of € 3,168,704 yearly.

For such a project, where multiple assets are included, it is common practice that third parties invest the some of the assets. In this case, if the bunker vessel would have been an investment of a third party, the pay-back year would drop to 4 years.

Another possible way to make the LNG infrastructure more viable is to promote and increase the demand. If incentives to local commercial vessels are introduced to help local commercial vessels switch to LNG, then, a demand value would be increased with limited increase in the infrastructure cost. This is because truck supply would be the most needed mode of bunkering for these vessels, due to fuel quantity is small and easily reached from shore. On the other hand, the local vessel owner will also benefit from lower OPEX costs following his new investment and lower fuel prices then MDO.

7.5 Conclusion

Results have shown LNG as marine fuel is beneficial. Potential savings identified for the ferry case, and a potential LNG equipment investment has been calculated with encouraging results, although these are case sensitive. In terms of a national LNG infrastructure, investment is large with a long pay-back period. In-depth feasibility studies would identify and take into consideration broader perspective which might result in improved real case scenarios, thus shorter pay-back time. Speaking on LNG demand, incentives can be a local motivation tool to switch to LNG, leading to long term benefit to both vessel owners and to the country in terms of emission reduction.

8 Recommendations and Conclusions

8.1 Conclusion

The aim of this dissertation was to gain insight into the potential of LNG bunkering in Malta, to define amendments required in the legislation, to determine in a more general context what must be done in preparation for this marine fuel provision service, and to identify the benefits the island could gain.

Malta being an island in the hearth of the Mediterranean, its history is based on maritime affairs. Malta serves as a trading hub for containerised cargo. Offshore, it offers an ideal anchoring location for bunkering S-T-S tankers operations. It is considered as a major location for trade between North African countries and mainland Europe.

The research has shown that regulations are essential for the strategic implementation of an LNG bunkering infrastructure. The introduction of alternative fuels, and the enforcements to use them, is necessary to the industry where high capital investments are required. The use of incentives can have a positive effect on both the government and the respective authorities' perspectives, as emissions targets and cleaner environments are achieved. As ship owners have indicated, especially those of small, local, commercial, operating vessels, upgrading equipment with the latest technology not only helps serve the nation, but also benefits vessel owners through reduced fuel consumption and OPEX costs.

The overall benefit in using LNG bunkering infrastructure and the provision of this fuel has to be analysed in a socio-economic context. The benefits the island would gain from this service include not only a compliance with regulations, but also reduced emissions, and thus a positive effect in terms of the citizens' health. The potential business gains and profits that Malta and local bunkering companies would achieve are also significant. For this reason, the balance between economic gain and social benefits has to be well-assessed.

Since previous studies have identified LNG as an ideal fuel for short sea shipping vessels, Malta has a potential share as trade to mainland Europe takes place by roro-ships. As described in the locally operating commercial vessels, much can be achieved that benefits both the island and its investors.

8.2 Recommendations

As a European Union member state, Malta is required to abide by the EU directive. One of the national targets is to provide an alternative fuel to the shipping industry, which means that Malta is required to provide an adequate infrastructure for the use of LNG as fuel, both on land and at sea.

The issues that have been identified in Chapter 3are similarly applicable to Malta. As soon as a strategy for the development of an LNG infrastructure is formed, local commercial vessel operators and other ship owners in Malta should be provided with first-hand information about the advantages and disadvantages of using LNG as ship fuel.

As the gap analysis in Chapter 5 has identified, LNG has already been included in the regulations on natural gas in Malta. However, bunkering regulations need to be amended accordingly. This should be carried out in a legal manner by the respective authority.

I propose that the incentives given to local vessel operators can benefit both the nation and the investors. As Chapter 7 has shown, Malta would be benefiting from cleaner fuel use, reduced emissions, and higher demand for the new, costly infrastructure of LNG. LNG bunkering on local vessels can also be done with less investment cost, as the most appropriate bunkering mode would be by truck. Meanwhile, vessel owners would receive financial help to invest in new, LNG-fuelled equipment while, in the long term, reduced fuel consumption, cheaper prices, and reduced OPEX costs would enable financial savings.

National investment in LNG bunkering infrastructure in Malta must be well-designed by estimating the potential demand in international shipping. If a gas pipeline were to be installed, especially one connecting directly to the offshore FSU, infrastructure costs on the island could be kept at a minimum and less small bunkering vessels would be required. With infrastructure costs kept low, and by having efficient provision that meets the demand…the delivered cost added to the import cost would be low, enabling Malta to offer competitive prices in the Mediterranean region.

Definitely this is a case for future research. Dedicated and intensive studies are required to assess the potential and limitations of this LNG as fuel provision service. The required space for port bunkering equipment and the required safety zones in Maltese ports questionable, as ports are narrow and surrounded by residents. Therefore the right studies should determine the ideal mode of LNG bunkering. Considering offshore bunkering infrastructure targeting international shipping, this has to be studied for the weather conditions and proper anchoring. Future research is also important to find the latest technology on the emission free equipment. This appropriate equipment for LNG should avoid methane slip. Future research should be also part of the operational guidelines and procedures. While gaining experience improves in procedures will reduce hazards and pollution, while being for efficient.

When dealing with LNG, risk assessment of different scenarios is a must. The cryogenic characteristics and flammability of LNG make it highly hazardous. For this reason, proper HAZID and HAZOP assessments are essential in each scenario. Dedicated safety zones should be determined, while proper use of equipment and procedures should be well-understood and practised. The competence of hands-on operators of such cryogenic systems is also crucial. Personnel running simultaneous operations within the bunkering area should be trained to avoid hazards and to act appropriately in emergency situations.

Due to a lack of information at the technical level, presenting an example of a risk assessment was not possible in this research. Such assessments are case-sensitive, as details and parameters of location and the surrounding environment and equipment are of great effect. It is important to note that such a project, and a full understanding of how to progress with these types of development, would require high levels of technical data.

With respect to the gas supply that is required for the provision of LNG bunkering to ships, it would not be feasible to have the bunkering infrastructure before providing the pipeline supply. Also, as mentioned in Section 2.3 and illustrated by the projected demand curve, the demand for small-scale, operating infrastructure before 2025 is expected to be low. Although sulphur regulations will be enforced in 2020, the rate at which the switch to LNG-fuelled ships will be made is still unclear. For this reason, a gradually-increasing infrastructure capacity would be a point to consider for Malta. One should also note that in Malta, the FSU and the jetty for shore bunkering are already available. Following the pipeline installation, these will no longer be required for the power plant.

In the case of Malta, introducing LNG as ship fuel and installing bunkering infrastructure would improve fuel security. Provision of LNG also enables industrial and marine equipment to run on different fuels, depending on the specifications of the equipment. This can also help achieve lower fuel prices for the consumer due to competition on the fuel market. On more global terms, the connection of the Maltese islands to mainland Europe through a gas pipeline, along with the availability of an offshore FSU within Maltese territorial waters, provides better fuel security as one of our most important resources.

References

2012/33/EU. (2012). Directive 2012/33/EU of the European parliament and of the council of 21 November 2012 amending council directive 1999/32/EC as regards to the sulphur content of marine fuels

2014/94/EU. (2014). Directive 2014/94/EU of the European parliament and of the council of 22 October 2014 on the deployment of alternative fuels infrastructure.

A Brief Histroy of Natural Gas. (2017). Retrieved from American Public Gas Association: http://www.apga.org/apgamainsite/aboutus/facts/history-of-natural-gas

Air pollution fact sheet 2014 - Malta (2014). Denmark: European Environment Agency.

Algell, J., Bakosch, A., & Forsman, B. (2012). Feasibility study on LNG fuelled short sea and coastal shipping in the wider Caribbean region. SSPA.

Almeida, I. (2014). BofA sees global LNG entering multiyear bear market on supplies

Anderson, M., Salo, K., & Fridell, E. (2015). Particle- and gaseous emissions from an LNG powered ship. Environmental Science & Technology, 49(20), 12568. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/26422536

Annual report 2015. (2015). Transport Malta.

Aplin, P. K. (2016). ElectroGas Malta project safety report - non technical summary. London: Aecom.

Ashworth, J. (2012). The genesis of LNG bunkers TRI-ZEN.

Backer, H. (2016). Cleaner exhaust gases from Baltic shipping - the new NECA regulations HELCOM.

Ballini, F. (2013). Air pollution from ships in Danish harbours: Feasibility study of cold-ironing technology in Copenhagen. Italy.

Ballini, F., & Bozzo, R. (2015). Air pollution from ships in ports: The socio-economic benefit of cold-ironing technology. Research in Transportation Business & Management, 17, 92-98. doi:10.1016/j.rtbm.2015.10.007

Baltensperger, T., Füchslin, R. M., Krütli, P., & Lygeros, J. (2015). European Union gas market development. Retrieved from http://arxiv.org/abs/1512.05343

Benito Luis. (2014). Lloyd's register LNG bunkering infrastructure survey 2014. The outlook of ports on provision of LNG bunkering facilities

Blikom, L. P. (2012). Status of LNG as a maritime fuel. Australian Journal of Maritime and Ocean Affairs, 4(3)

Brent crude oil spot price chart. (2017). Retrieved from https://ycharts.com/indicators/brent_crude_oil_spot_price/chart/#/?securities=id:I:BCOSPNK,include:true,,&calcs=&correlations=&zoom=5&startDate=&endDate=&format=real&recessions=true&chartView=&chartType=presentation&splitType=single&scaleType=log&securitylistName=&securitylistSecurityId=&securityGroup=&displayTicker=true&title=&note=&units=true&source=true&liveData=false&quoteLegend=true&legendOnChart=true&partner=basic_650

Brynolf, S., Fridell, E., & Andersson, K. (2014). Environmental assessment of marine fuels: Liquefied natural gas, liquefied biogas, methanol and bio-methanol. Journal of Cleaner Production, 74, 86-95. doi:10.1016/j.jclepro.2014.03.052

Buonfanti, A. (2013). Lo shipping e la portualita' nel Mediterraneo: Opportunita' e sfida per l'italia. Rivista do Economia E Politica Dei Trasporti, (3)

Burel, F., Taccani, R., & Zuliani, N. (2013). Improving sustainability of maritime transport through utilization of liquefied natural gas (LNG) for propulsion. Energy, 57, 412-420.

Calderón, M., Illing, D., & Veiga, J. (2016). Facilities for bunkering of liquefied natural gas in ports. Transportation Research Procedia, 14, 2431-2440. doi:10.1016/j.trpro.2016.05.288

Castro-Santos, L., Ferreno Gonzalez, S., Diaz-Casas, V., Angel, J., & Formoso, F. (2013). Position keeping costs of floating offshore platforms for marine renewable energies

CAT G3606LE Gas Petroleum Engine. (2010).

Cazzola, P., Cuenot, F., Kojima, K., Onoda, T., Staub, J., & Taylor, M. (2009). Transport energy and CO_2: Moving towards sustainability. Paris: International Energy Agency. doi:10.1787/9789264073173-en

Chernick, P. L., & Caverhill, E. J. (1990). The valuation of environmental externalities in energy conservation planning. In Anon (Ed.), ACEEE 1990 summer study on energy efficiency in buildings: (pp. 286)

CME. (2017). European 3.5% fuel oil barges FOB rdam (platts) futures quotes. Retrieved from http://www.cmegroup.com/trading/energy/refined-products/35pct-fuel-oil-swap-rotterdam-platts.html

Core LNGas Hive (2016).

Cozzi, L. (2016). World energy outlook special report 2016: Energy and air pollution.International Energy Agency.

Crook, L., Vidas, E. H., Coffey, C., & Amarin, N. (2017). Perspectives on the development of LNG market hubs in the Asia Pacific region. Washington DC: U.S. Energy Information Administration.

CT3017/2017. (2017). Provision of services for a technical study and cost-benefit analysis for the development of LNG as a marine fuel in Malta

Dalaklis, D., Ölçer, A., Ballini, F., & DeWitz, J.Protecting the arctic environment: Challenges
and opportunities for liquefied natural gas.

Dalaklis, D., Ölçer, A. I., Madjidian, J. A., Ballini, F., & Kitada, M. (March 20, 2017). Bridging the LNG knowledge gap in the Baltic Sea region: The go LNG initiative and the establishment of a competence centre. Inted2017,

Decreto Legislattivo n.257. (2017). Disciplina di attuazione della direttiva 2014/94/UE del parlamento europeo e del consiglio, del 22 ottobre 2014, sulla realizzazione di una infrastruttura per i combustibili alternativi. [Decreto Legislativo 16 Dicembre, n. 257]

Demetriades, M. (2017). Address by minister of transport, mr M. Demetriades, at the annual ‘‘Frederick maritime day’’

de Ven, M. v. (2015a). D 2.3.1 LNG bunkering regulatory framework and LNG bunker procedures LNG Masterplan Consortium.

de Ven, M. v. (2015b). D 4.1.2 & 4.1.4 guidelines for port regulations and best practice LNG bunkering LNG Masterplan Consortium (Rhine Port Group).

Development and operation of liquefied natural gas bunkering facilities (2015). DNV-GL.

DMA. (2012). North European LNG infrastructure project. Copenhagen: Danish Maritime Authority.

Duty of emissions of NOx 2017 (2017).

Elgohary, M. M., Seddiek, I. S., & Salem, A. M. (2015). Overview of alternative fuels with emphasis on the potential of liquefied natural gas as future marine fuel. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment, 229(4), 365-375. doi:10.1177/1475090214522778

European commission DG MOVE Lot 2. (2015). LOT2 "Creating Awareness on LNG Risks and Opportunities". Study on the completion of an EU framework on LNG-fuelled ships and its relevant fuel provision infrastructure. Brussels: European Union.

European Union natural gas import price chart. (2017). Retrieved from https://ycharts.com/indicators/europe_natural_gas_price/chart/#/?securities=id:I:EUNGIP,include:true,,&calcs=&correlations=&zoom=5&startDate=&endDate=&format=real&recessions=true&chartView=&chartType=presentation&splitType=single&scaleType=log&securitylistName=&securitylistSecurityId=&securityGroup=&displayTicker=true&title=&note=&units=true&source=true&liveData=false&quoteLegend=true&legendOnChart=true&partner=basic_650

Fischer, C. T. (2009). Bracketing in qualitative research: Conceptual and practical matters. Psychotherapy Research, 19(4-5), 583-590. doi:10.1080/10503300902798375

Furqon Rochyana, M., Yamin Jinca, M., & Siahaya, J. (2014). MDO and LNG as fuels (duel fuel) to support sustainable maritime transport (A case study in KM. ciremai). International Referred Journal of Engineering and Science, 3(7), 32-38.

Gap analysis, S. A. (2016). Control of major accident hazards assessment report Gap analysis S.A.

Ge, J., & Wang, X. (2016). Techno-economic study of LNG diesel power (dual fuel) ship. WMU Journal of Maritime Affairs, 16(2), 233-245. doi:10.1007/s13437-016-0120-x

Gerrish, R. J., & Listowska, I. (2017). In Jordan J., Hicken P.(Eds.), Tackling 2020: The impact of the IMO and how ship owners can deal with tighter sulfur limits.

Global LNG bunkering infrastructure (2014). DNV-GL.

Global Sulphur Cap 2020. (2016, October). DNV GL AS.

Gozo Channel Fleet. Retrieved from www.gozochannel.com/en/fleet.htm

Gruber, N., & Galloway, J. N. (2008). An earth-system perspective of the global nitrogen cycle: With humans having an increasing impact on the planet, the interactions between the nitrogen cycle, the carbon cycle and climate are expected to become an increasingly important determinant of the earth system. Nature, (7176), 293.

GTE. (2016). The environment for gas network investment in Europe. Gas Infrustructure Europe, GTE. London: Frontier Economics Ltd.

Guide for Implementation of Sulphur Oxide Exhaust Gas Cleaning Systems. (2016). London: Oil Companies International Forum.

He, J. (2015). Objectives and strategies for energy revolution in the context of tackling climate change. Advances in Climate Change Research, 6, 101-107. doi:10.1016/j.accre.2015.08.005

Holden, D. (2014). Liquefied natural gas (LNG) bunkering study. DNV-GL.

How Flexible are LNG Markets in Practice? (2016). Global Gas Security Review. International Energy Agency.

International code for construction and equipment of ships carrying liquefied gases in bulk (2016). International Maritime Organization.

International code of safety for ships using gases or other low-flashpoint fuels (2016). International Maritime Organization.

ISO/TC 67. (2015, January 13). ISO/TS 18683:2015 Guidelines for systems and installations for supply of LNG as fuel to ships. International Standards Organisation.

ISO/TC 8. (2017, February). ISO 20519:2017 Ships and marine technology - Specification for bunkering of liquified natural gas fuelled vessels. ISO.

ISO/TC67. (2011, June). ISO 22460:2010 Installation and equipment for liquefied natural gas – Ship-to-shore interface and port operations. ISO.

ISO/TR17177. (2015, April 30). ISO/TR 17177:2015 Guidlines for the marine interface of hybrid LNG terminals. ISO.

ISO/TS. (2015, March 31). ISO16901:2015 Guidance on performing risk assessment in the design of onshore LNG installations including the ship/shore interface. ISO.

Janoska, P. (2017). Tracking clean energy progress 2017. International Energy Agency.

Järvi, A. (2010). Methane slip reduction in Wärtsilä lean burn gas engines. 26th CIMAC World Congress on Combustion Engines.

Kennedy, D., Bellamy, O., Gault, A., Golborne, N., Hall, T., Haynes, J., Wilson, J. (2011). Review on UK shipping emissions. London: Committee on Climate Change.

Key Natural Gas Trends. (2016). Natural Gas information. International Energy Agency.

Kidney, A. J., & Parrish, W. R. (2006). Fundamentals of Natural Gas Processing. CRC Press.

Klenke, K. (2016). Qualitative research in the study of leadership Emerald Group Publishing Limited. Retrieved from http://lib.myilibrary.com?ID=889672

Kraal, D. Integrated gas-to-liquefied natural gas projects: government revenues in Australia and industry concerns.

Kumar, S., Kwon, H., Choi, K., Hyun Cho, J., Lim, W., & Moon, I. (2011). Current status and future projections of LNG demand and supplies: A global prospective. Energy Policy, 39(7), 4097-4104. doi:10.1016/j.enpol.2011.03.067

Kyoto Protocol. (1998). Kyoto Protocol. United Nations.

Larkin, A. B., Anderson, K., Gilbert, P., Mander, S., Walsh, C., & Traut, M. (2014). High seas, high stakes - high seas project final report.Tyndall Center for Climate Change Research.

Li, A. H. F. (2016). Hopes of limiting global warming: China and the Paris agreement on climate change. China Perspectives, (1), 49.

Lindøe, P. H., & Kringen, J. (2015). Risk governance of hazardous industrial ports and areas: A case study of industrial areas and harbors in Norway. Journal of Risk Research, 18(7), 931-946. doi:10.1080/13669877.2015.1017829

LNG bunkering in the Mediterranean (n.d.)

LNG ship to ship bunkering procedure (2010). . Uddevalla, Sweden: Swedish Marine Technology Forum.

LNGi status update (2017). DNV-GL.

Maione, M., Fowler, D., Monks, P. S., Reis, S., Rudich, Y., Williams, M. L., & Fuzzi, S. (2016). Air quality and climate change: Designing new win-win policies for

Europe. Environmental Science and Policy, 65(-), 48-57. doi:10.1016/j.envsci.2016.03.011

Mallia, B., Hane, S., Pisani, I., Scerri, J., Schellekens, J., & di Martino, A. (2015). Connection of Malta to European gas network - technical and financial feasibility study for connecting Malta to European gas network.

Maritime and Port Authority of Singapore. (2016, October 6). Network of Ports and Maritime administrations Formed to Develop World's First Harmonised LNG Bunkering Standards. Singapore: Maritime and Port Authirity of Singapore. Retrieved from www.mpa.gov.sg

MARPOL consolidated edition 2011: Articles, protocols, annexes and unified interpretations of the international convention for the prevention of pollution from ships, 1973, as modified by the 1978 and 1997 protocols (2011). (5th ed.). London: IMO.

MARPOL. (2013). MARPOL: Annex VI and NTC 2008 with guidlines for implementation. London: International Maritime Organisation.

Martinez, L. H. (2005). Post industrial revolution human activity and climate change: Why the United States must implement mandatory limits on industrial greenhouse gas emissions The Florida State University College of Law.

Meech, R. (2005). Designation of the Mediterranean Sea as a SOx emission control area under MARPOL annex VI.

Miles, M. B., & Huberman, M. A. (1994). Qualitative data analysis (2. ed.). London: SAGE Publ.

Mokhatab, S., Mak, J. Y., Valappil, J. V., & Wood, D. A. (2014). Handbook of Liquified Natural Gas. Oxford: Elsevier.

MSC.285(86) interim guidelines on safety for natural gas-fuelled engine installations in ships; (2009). International Maritime Organization.

Natural gas unit. Retrieved from http://www.lngplants.com/conversiontables.html

Nicoll, S., Aagesen, J., & Ajala, L. (2012). LNG-fuelled deep sea shipping - the outlook for LNG bunker and LNG-fuelled new build demand up to 2025 Lloyd's Register.

Nijoka, D., Munro, B., & Mellen, F. (2014). Competing for LNG demand: The price structure debate Ernest & Young.

Nikhalat-Jahromi, H., Angeloudis, P., Bell, M. G. H., & Cochrane, R. A. (2015). Global LNG trade: A comprehensive up to date analysis. Maritime Economics & Logistics, 19(1), 160-181. doi:10.1057/mel.2015.26

North European LNG infrastructure project. (2012). Copenhagen: Danish Maritime Authority.

Nugraha, F. (2009). Effective implementation of emission control area towards cleaner shipping operations: Focusing on sulphur oxides (SOx) emission reducation World Maritime University.

Perez, E., Mestre, A., Saez, L., & Lara, J. (2015). Feasibility of LNG as a fuel for the Mediterranean SSS fleet: Profitability, facts and figures. Fundacion Valenciaport.

Permala, A. (2015). LNG RoPax ferry Viking Grace. Best Fact, Best Practice, Case Quick Info, 2(130) Retrieved from http://www.bestfact.net/wp-content/uploads/2015/08/2-130_BESTFACT_CL2_Quickinfo_VikingGrace.pdf

Project overview and results final report. (2015, July). Port-PVEV. Transport Malta.

Rajal, B., & Tuttinger, M. (2015). D.3.4.10 legal & regulatory road map LNG Masterplan Consortium.

Resolution MEPC.280(70). (2016). Resolution MEPC.280(70) - effective date of implementation of the fuel oil standard in regulation 14.1.3 of MARPOL annex VI.

Santoyo-Castelazo, E., & Azapagic, A. (2014). Sustainability assessment of energy systems: Integrating environmental, economic and social aspects. Journal of Cleaner Production, 80, 119-138. doi:10.1016/j.jclepro.2014.05.061

Schinas, O., & Butler, M. (2016). Feasibility and commercial considerations of LNG-fueled ships. Ocean Engineering, 122, 84-96. doi:10.1016/j.oceaneng.2016.04.031

SGMF. (2016). Gas as a marine fuel an introductory guide (2nd ed.) Society of Gas as a Marine Fuel.

Shipping 2020. (2012).DNV.

Shipping movements in Malta. (2017). Retrieved from https://www.shortsea.org.mt/statistics

S.L.499.12. (2015). Dangerous Cargo Ships, Marine Terminals and Facilities and Bunkering Regulations. Subsidiary Legislation 499.12. Malta.

Smith, T., Jalkanen, J., Anderson, B., Corbett, J., Faber, J., Hanayama, S., Pandey, A. (2015, April). Third IMO Greenhouse Gas Study 2014. London, UK: International Maritime Organization.

SNAM RETE GAS. (2017). Demand assessment report for incremental capacity between Italy and Malta.

SOLAS: Consolidated edition 2014 : Consolidated text of the international convention for the safety of life at sea, 1974, and its protocol of 1988 : Articles, annexes and certificates (2014). (Sixth edition ed.). London: International Maritime Organization.

STCW including 2010 manila amendments: STCW convention and STCW code (2011). (2011 ed., 3rd consolidated ed.). London: International Maritime Organization.

Stern, J. (2014). International gas pricing in Europe and Asia: A crisis of fundamentals. Energy Policy, 64, 43-48. doi:10.1016/j.enpol.2013.05.127

Studies on the feasibility and use of LNG as a fuel for shipping. (2016). In IMO (Ed.), Air pollution and energy efficiency study series

Taking the LNG lead. (2016), Singapore Market Report 2016, 25-27.

The EU emissions trading system (2016). European Union.

The Future of Shipping. (2014). Hovik, Norway: DNV GL.

Thomson, H., Corbett, J. J., & Winebrake, J. J. (2015). Natural gas as a marine fuel. Energy Policy, 87, 153-167. doi:10.1016/j.enpol.2015.08.027

Trozzi, C., & De Lauretis, R. (2016). EMEP/EEA air pollutant emission inventory guidebook. - 1.A.3.d navigation (shipping) 2016. Luxembourg: Publication Office of the European Union.

Tzannatos, E., & Nikitakos, N. (2013). Natural gas as a fuel alternative for sustainable domestic passenger shipping in Greece. International Journal of Sustainable Energy, 32(6), 724-734. doi:10.1080/14786451.2013.811414

UNFCCC. (1992). United Nations Framework Convention on Climate Change. United Nations.

Viking Line. (2012). MS Viking Grace

Volsem, S. V. (2015, June 10). LOT 1: Analysis and evaluation of identified gaps and of the remaining aspects for completing an EU-wide framework for maritime LNG distribution, bunkering and use. DNV GL.

Wang, S., & Notteboom, T. (2015). The role of port authorities in the development of LNG bunkering facilities in north European ports. WMU Journal of Maritime Affairs, 14(1), 61-92. doi:10.1007/s13437-014-0074-9

Wärtsilä 20DF Product Guide. (2016, September).

Wheeler, T. A. (2015). Regulatory gap analysis. U.S.: Sandia Corporation.

Winnes, H., Fridell, E., Yaramenka, K., Nelissen, D., Faber, J., & Ahdour, S. (2016). NOx controls for shipping in EU seas.

Winter Graugaard, C. (2013, October 22). LNG for Shipping - Current status. DNV.

Wuersig, G., & Chiotopoulos, A. (2015, May). LNG today and tomorrow. In Focus - LNG as Ship Fuel, 6.

XE currency converter: USD to EUR. (2017). Retrieved from http://www.xe.com/currencyconverter/convert/?Amount=1&From=USD&To=EUR

Xu, J., Testa, D., & Mukherjee, P. K. (2015). The use of LNG as a marine fuel: The international regulatory framework. Ocean Development & International Law, 46(3), 225-240. doi:10.1080/00908320.2015.1054744

Appendix A: Questionnaire

LNG Bunkering Research

The aim of this data compilation is to assist myself, Mr. Mark Philip Cassar, student at the World Maritime University MSc in Maritime Affairs - Maritime Energy Management, in this research on LNG bunkering focusing on the Mediterranean area. As part of my studies, I am analysing what is being implemented in the LNG bunkering sector from the regulatory and infrastructure point of view. The study will focus more on the regulatory aspects of safety and operational point of view of the ship-to-ship bunkering mode. Also a general overview of the potential market in the Mediterranean will be identified.

This questionnaire consists of eight sections. The majority of the questions are multiple choice and check boxes. Only few questions require brief description. There should not be any questions which might effect the anonymity of the responding question. Only the company and general LNG related experience for the responding person is required. Should you find questions which you think no information can be provided due to their technical level, feel free to skip, however, the more you manage to answer will be highly appreciated. Section 1 and 2 (General) is important to be answered. Should you consider withdrawal from responding this questionnaire you can do so by just closing the link without saving.

The information collected from this questionnaire will be presented in the form of charts and graphs from google forms. In this way I will assure that the information from any individual questionnaire must remain confidential, and the anonymity of respondents be preserved. Any publication or divulging of information from which individual identity may be deduced is permissible only with the written consent of the individuals concerned immediately prior to publication.

I thank you in advance for the time and knowledge put into this questionnaire. Your effort can help me achieve better results in my research, for which I truly appreciate.

Thank you.

Kind Regards,
Mark Philip Cassar

1. **Email address** *

____

Consent & Company Background

2. **"I consent to my information provided here under, as outlined in the questionnaire description above, for use of this research purpose. I understand that the information and data will be held and processed in the strictest confidence and deleted after graduation."**
   Please tick the checkbox below as approval of your consent.
   Check all that apply.

   ☐ Consent Approved

3. **1.1 Which company your represent while responding to this questionnaire?**

   ____

4. **1.2 Which country is your company located in?**

   ____

5. 1.3 Which maritime sector your company operates in?

Mark only one oval.

- ◯ Shipping company
- ◯ Bunkering service provider
- ◯ Education
- ◯ Energy Efficiency
- ◯ Maritime Administration
- ◯ Port Authority
- ◯ Other: ____________

6. 1.4 In relation to LNG, which stage of implementation is your company?

Mark only one oval.

- ◯ undergoing studies
- ◯ implementation planning
- ◯ infrastructure building
- ◯ running commercially

7. 1.5 A brief description of LNG related experience within your company will be helpful.

____

____

____

____

____

8. 1.6 Will your company be in a position to provide the student the opportunity to observe the real operation of LNG bunkering? If yes, please choose which mode of service can be experienced.

Check all that apply.

- ☐ Yes, Port-to-ship
- ☐ Yes, Ship-to-ship
- ☐ Not possible

2. General

9. 2.1 Which set of international regulation related to LNG bunkering does your company make use of?

Check all that apply.

- [ ] IGC Code
- [ ] IGF Code
- [ ] National policy
- [ ] EU Directives
- [ ] ISO 20519: Ships and marine technology - Specification for bunkering of liquefied natural gas fueled vessels.
- [ ] S-T-S Transfer guide for Petroleum, Chemicals and Liquified Gases
- [ ] SMGB - the socieyt for gas as a marine fuel.
- [ ] Other: ____________________

10. 2.2 Does your company has its own LNG procedures?

Mark only one oval.

- ( ) Yes
- ( ) No

11. 2.3 How many years do you think that are required to be able to provide LNG fuel to ships on an international level?

Consider the building of appropriate infrastructure and having LNG systems on board.

Mark only one oval.

- ( ) by 2020
- ( ) by 2025
- ( ) by 2030
- ( ) After 2030

12. 2.4 In your opinion what is the most motivating issue to switch to LNG fuel?

____

13. 2.5 In your opinion what is a barrier to switch to LNG fuel?

____

14. 2.6 Do you consider LNG as ship fuel safe?

Mark only one oval.

- ( ) Yes
- ( ) No
- ( ) Maybe

15. **2.7 Please provide a short reason for your answer in 2.6.**

16. **2.8 Do you have any information related to LNG bunkering projects which can be provided to the student?**

    Any information regarding ongoing projects, procedures, guidelines, shipping traffic and bunkering statistics in the Mediterranean will be highly appreciated. If information is not possible to provide through the questionnaire, please send the information on: s17061@wmu.se or by google drive on the same email address.

3. National Policy

17. **3.1 If possible, please provide a link to a related national policy/ guidelines in your country related to LNG bunkering.**

    If a file is available, please send the file on: s17061@wmu.se

18. **3.2 Which are the most important instruments followed for the amendments of policy related to LNG bunkering in your country?**

    List any international regulations, directives, standards or other documents which were used for implementation of the national policy.

19. **3.3 Which national bodies are involved in establishing/amending the national policy for LNG bunkering?**

Mark only one oval.

- ( ) Maritime Administration
- ( ) Port Authority
- ( ) Ministry
- ( ) Dedicated Governmental Agency
- ( ) Private companies
- ( ) Other: ______________________

20. **3.4 Which organisation is responsible to monitor the commercial procedures of LNG bunkering from different stake holders?**

____

____

____

____

____

4. Training & Education

21. **4.1 Do you think there is sufficient LNG related training available?**

Mark only one oval.

- ( ) Yes
- ( ) No

22. **4.2 If No, explain why?**

____

____

____

____

____

23. **4.3 Does your country's authority / competent bodies ask for specific training to conduct LNG operations?**

Mark only one oval.

- ( ) Yes
- ( ) No

24. **4.4 If yes, which organisation provides this training in your country?**

____

25. **4.5 Which competent authority verifies and endorse the training in your country?**

____

5. Infrastructure and Safety

26. 5.1 If any, which of the following LNG transportation methods are available in your country?

Check all that apply.

- [ ] Pipeline
- [ ] Truck
- [ ] Import by ship
- [ ] Export by ship
- [ ] LNG processing facilities
- [ ] Other: ____________________

27. 5.2 Are the above methods being used for:

Mark only one oval.

- ◯ Transportation purposes only
- ◯ Providing fuel to ships commercially
- ◯ Providing fuel to ships of tests and implementation stage.

28. 5.3 In your company, who is in charge of performing a feasibility study to analyse the risks and safety in relation to the operation of LNG bunkering?

Mark only one oval.

- ◯ Internally by the company
- ◯ Sub-contracted private entity

29. 5.4 Which areas did the feasibility study include?

Check all that apply.

- [ ] Safety & risk Assesments
- [ ] Location possibility
- [ ] Weather conditions
- [ ] Technology systems
- [ ] Mode of service provided

30. 5.5 Can you mention any other case scenarios which have been analysed during the feasibility study?

____

____

____

____

____

31. **5.6 What is your opinion, about having LNG bunkering service outside port limited but within territorial waters of a country?**

32. **5.7 Describe in few words the ideal location for a port/truck to ship LNG bunkering?**
Answer from the safety and feasible procedure of the operation depending on your operations terminal layout.

33. **5.8 Describe in few words the ideal location for a Ship-to-ship LNG bunkering.**
Answer from the safety and feasible procedure of the operation depending on the regulations and sea conditions in your country.

34. **5.9 Mention any important points that you think are essential for ship-to-ship LNG bunkering both in port and outside port limits.**

35. **5.10 Do you consider LNG bunker a hazard to other operations conducted simultaneously (SIMOPS) in close areas?**
Mark only one oval.

- Yes
- No
- Maybe

36. **5.11 If yes, which SIMOPS do you consider as hazardous?**

37. **5.12 Can you provide information related to LNG bunkering infrastructure to the student?**
Any information regarding LNG bunkering infrastructure (technical documents, safety documents studies, cost-benefit analysis, etc) will be highly appreciated. If information is not possible to provide through the questionnaire, please send the information on: s17061@wmu.se or by google drive on the same email address.

6. Operation & Technicalities

38. **6.1 Which weather / ambient / atmospheric conditions would you consider as a hazard to LNG bunkering operation?**
Mark according to severity of weather condition.
Mark only one oval per row.

	Low severity	Medium Severity	High Severity
Wind	◯	◯	◯
Rain	◯	◯	◯
Thunderstorm	◯	◯	◯
Air Temperature	◯	◯	◯
Direct Sunlight	◯	◯	◯
High Currents	◯	◯	◯
Waves	◯	◯	◯
Ice	◯	◯	◯

39. **6.2 Do you think that other port activities can restrict the operation of LNG bunkering?**
Mark only one oval.

◯ Yes
◯ No
◯ Maybe

40. **6.3 Please indicate very briefly what port activities can restrict bunkering.**

41. 6.4 Can you think of any particular process along the procedure of LNG bunkering which can be crucial if something goes wrong?

42. 6.5 Do you consider LNG barges using push-tug propulsion still safe to use outside port areas?
Mark only one oval.

- Yes
- No
- Maybe

43. 6.6 Please provide a short comment about your previous answer.

7. Environment

44. 7.1 In your opinion, LNG bunkering can be considered as Methane-slip free operation?
Mark only one oval.

- Yes
- No

45. 7.2 Do you consider small amount of natural gas release to the atmosphere, such as pipeline venting, a safety hazard, environmental hazard or both?
Check all that apply.

- [ ] Safety hazard
- [ ] Environmental hazard
- [ ] Both

46. 7.3 Do you think technology is available to avoid assured zero methane emission during LNG bunkering operation?
Mark only one oval.

- Yes
- No

8. Case scenario: Having a LNG bunkering operation underway between a merchant vessel and an LNG bunker vessel, 8nm outside port limits in water depths of 60m on anchor.

47. 8.1 What do you consider as potential hazard, if any?

48. 8.2 During bunkering operation, a force 4 wind picks up with direction abreast to the bunkering vessel. In fact the ship rolling motion is easily felt by the crew. To what hazardous scale do you suggest that the hazard level of such a case can be?
Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
low hazard	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	⬭	High Hazard

Appendix B: Scenario Calculations

	Fuel Consumption (tonnes/day)			
Engine Power	Diesel Mode	Dual Fuel Mode		Gas (Otto) Mode
(kW)	MDO	$Pilot_{MDO}$	LNG	LNG
160.00	0.25	0.01	0.22	0.24
169.00	0.26	0.01	0.23	0.25
175.00	0.27	0.01	0.24	0.26
224.00	0.35	0.01	0.31	0.34
240.00	0.38	0.01	0.33	0.36
240.00	0.38	0.01	0.33	0.36
257.00	0.40	0.01	0.36	0.38
265.00	0.42	0.01	0.37	0.40
268.00	0.42	0.01	0.37	0.40
292.00	0.46	0.01	0.41	0.44
293.00	0.46	0.01	0.41	0.44
300.00	0.47	0.01	0.42	0.45
310.00	0.49	0.01	0.43	0.46
316.00	0.50	0.01	0.44	0.47
321.00	0.50	0.01	0.45	0.48
324.00	0.51	0.01	0.45	0.48
336.00	0.53	0.01	0.47	0.50
350.00	0.55	0.01	0.49	0.52
350.00	0.55	0.01	0.49	0.52
372.00	0.58	0.01	0.52	0.56
382.00	0.60	0.01	0.53	0.57
397.00	0.62	0.01	0.55	0.59
418.00	0.66	0.01	0.58	0.63
424.00	0.66	0.01	0.59	0.63
448.00	0.70	0.02	0.62	0.67
448.00	0.70	0.02	0.62	0.67
456.00	0.72	0.02	0.63	0.68
458.00	0.72	0.02	0.64	0.69
477.00	0.75	0.02	0.66	0.71
488.00	0.77	0.02	0.68	0.73
488.00	0.77	0.02	0.68	0.73
514.00	0.81	0.02	0.71	0.77

515.00	0.81	0.02	0.72	0.77
515.00	0.81	0.02	0.72	0.77
516.00	0.81	0.02	0.72	0.77
520.00	0.82	0.02	0.72	0.78
522.00	0.82	0.02	0.73	0.78
530.00	0.83	0.02	0.74	0.79
574.00	0.90	0.02	0.80	0.86
588.00	0.92	0.02	0.82	0.88
588.00	0.92	0.02	0.82	0.88
596.00	0.93	0.02	0.83	0.89
615.00	0.96	0.02	0.85	0.92
620.00	0.97	0.02	0.86	0.93
650.00	1.02	0.02	0.90	0.97
662.00	1.04	0.02	0.92	0.99
671.00	1.05	0.02	0.93	1.00
690.00	1.08	0.02	0.96	1.03
701.00	1.10	0.02	0.97	1.05
749.00	1.17	0.03	1.04	1.12
810.00	1.27	0.03	1.13	1.21
814.00	1.28	0.03	1.13	1.22
821.00	1.29	0.03	1.14	1.23
858.00	1.35	0.03	1.19	1.28
884.00	1.39	0.03	1.23	1.32
914.00	1.43	0.03	1.27	1.37
925.00	1.45	0.03	1.29	1.38
960.00	1.51	0.03	1.33	1.44
961.00	1.51	0.03	1.34	1.44
984.00	1.54	0.03	1.37	1.47
1,044.00	1.64	0.04	1.45	1.56
1,090.00	1.71	0.04	1.52	1.63
1,119.00	1.75	0.04	1.56	1.67
1,480.00	2.32	0.05	2.06	2.22
1,598.00	2.51	0.06	2.22	2.39
1,800.00	2.82	0.06	2.50	2.69
1,834.00	2.88	0.06	2.55	2.75
1,834.00	2.88	0.06	2.55	2.75
1,865.00	2.92	0.07	2.59	2.79

	1,940.00	3.04	0.07	2.70	2.90
	1,968.00	3.09	0.07	2.74	2.95
	2,000.00	3.14	0.07	2.78	2.99
	2,072.00	3.25	0.07	2.88	3.10
	2,200.00	3.45	0.08	3.06	3.29
	2,220.00	3.48	0.08	3.09	3.32
	2,220.00	3.48	0.08	3.09	3.32
	2,354.00	3.69	0.08	3.27	3.52
	2,480.00	3.89	0.09	3.45	3.71
	2,958.00	4.64	0.10	4.11	4.43
	3,089.00	4.84	0.11	4.29	4.62
	3,300.00	5.17	0.12	4.59	4.94
	3,360.00	5.27	0.12	4.67	5.03
	3,372.00	5.29	0.12	4.69	5.05
	3,400.00	5.33	0.12	4.73	5.09
	3,400.00	5.33	0.12	4.73	5.09
	4,180.00	6.55	0.15	5.81	6.26
	4,200.00	6.59	0.15	5.84	6.29
	9,095.00	14.26	0.32	12.64	13.61
Totals	***104,185.00***	***163.36***	***3.67***	***144.84***	***155.94***
Ep Avg.	***1,183.92***	**DF Total FC=**	***148.51***		

Engine Power	Emissions for gas only			
(kW)	CO2 (455g/kWh)	Sox (0g/kWh)	Nox (2g/kWh)	PM
160.00	0.58	0.00	0.00	0.00
169.00	0.62	0.00	0.00	0.00
175.00	0.64	0.00	0.00	0.00
224.00	0.82	0.00	0.00	0.00
240.00	0.87	0.00	0.00	0.00
240.00	0.87	0.00	0.00	0.00
257.00	0.94	0.00	0.00	0.00
265.00	0.96	0.00	0.00	0.00
268.00	0.98	0.00	0.00	0.00
292.00	1.06	0.00	0.00	0.00
293.00	1.07	0.00	0.00	0.00
300.00	1.09	0.00	0.00	0.00
310.00	1.13	0.00	0.00	0.00
316.00	1.15	0.00	0.01	0.00
321.00	1.17	0.00	0.01	0.00
324.00	1.18	0.00	0.01	0.00
336.00	1.22	0.00	0.01	0.00
350.00	1.27	0.00	0.01	0.00
350.00	1.27	0.00	0.01	0.00
372.00	1.35	0.00	0.01	0.00
382.00	1.39	0.00	0.01	0.00
397.00	1.45	0.00	0.01	0.00
418.00	1.52	0.00	0.01	0.00
424.00	1.54	0.00	0.01	0.00
448.00	1.63	0.00	0.01	0.00
448.00	1.63	0.00	0.01	0.00
456.00	1.66	0.00	0.01	0.00
458.00	1.67	0.00	0.01	0.00
477.00	1.74	0.00	0.01	0.00
488.00	1.78	0.00	0.01	0.00
488.00	1.78	0.00	0.01	0.00
514.00	1.87	0.00	0.01	0.00
515.00	1.87	0.00	0.01	0.00
515.00	1.87	0.00	0.01	0.00
516.00	1.88	0.00	0.01	0.00
520.00	1.89	0.00	0.01	0.00

522.00	1.90	0.00	0.01	0.00
530.00	1.93	0.00	0.01	0.00
574.00	2.09	0.00	0.01	0.00
588.00	2.14	0.00	0.01	0.00
588.00	2.14	0.00	0.01	0.00
596.00	2.17	0.00	0.01	0.00
615.00	2.24	0.00	0.01	0.00
620.00	2.26	0.00	0.01	0.00
650.00	2.37	0.00	0.01	0.00
662.00	2.41	0.00	0.01	0.00
671.00	2.44	0.00	0.01	0.00
690.00	2.51	0.00	0.01	0.00
701.00	2.55	0.00	0.01	0.00
749.00	2.73	0.00	0.01	0.00
810.00	2.95	0.00	0.01	0.00
814.00	2.96	0.00	0.01	0.00
821.00	2.99	0.00	0.01	0.00
858.00	3.12	0.00	0.01	0.00
884.00	3.22	0.00	0.01	0.00
914.00	3.33	0.00	0.01	0.00
925.00	3.37	0.00	0.01	0.00
960.00	3.49	0.00	0.02	0.00
961.00	3.50	0.00	0.02	0.00
984.00	3.58	0.00	0.02	0.00
1,044.00	3.80	0.00	0.02	0.00
1,090.00	3.97	0.00	0.02	0.00
1,119.00	4.07	0.00	0.02	0.00
1,480.00	5.39	0.00	0.02	0.00
1,598.00	5.82	0.00	0.03	0.00
1,800.00	6.55	0.00	0.03	0.00
1,834.00	6.68	0.00	0.03	0.00
1,834.00	6.68	0.00	0.03	0.00
1,865.00	6.79	0.00	0.03	0.00
1,940.00	7.06	0.00	0.03	0.00
1,968.00	7.16	0.00	0.03	0.00
2,000.00	7.28	0.00	0.03	0.00
2,072.00	7.54	0.00	0.03	0.00
2,200.00	8.01	0.00	0.04	0.00

2,220.00	8.08	0.00	0.04	0.00
2,220.00	8.08	0.00	0.04	0.00
2,354.00	8.57	0.00	0.04	0.00
2,480.00	9.03	0.00	0.04	0.00
2,958.00	10.77	0.00	0.05	0.00
3,089.00	11.24	0.00	0.05	0.00
3,300.00	12.01	0.00	0.05	0.00
3,360.00	12.23	0.00	0.05	0.00
3,372.00	12.27	0.00	0.05	0.00
3,400.00	12.38	0.00	0.05	0.00
3,400.00	12.38	0.00	0.05	0.00
4,180.00	15.22	0.00	0.07	0.00
4,200.00	15.29	0.00	0.07	0.00
9,095.00	33.11	0.00	0.15	0.00
Totals (tonnes/day)	379.23	**0.00**	**1.67**	0.00

Yearly Fuel Consumption (tonnes/year)

	Diesel Mode	Dual Fuel Mode		Gas Mode
	MDO	PilotMDO	LNG	LNG
		1,100.19	43,452.65	
Total FC (tonnes/yr)	**49,008.62**	**44,552.84**		**46,783.23**

Costs of fuel (€/year)

Unit	Diesel Mode	Dual Fuel Mode		Gas Mode
	MDO	PilotMDO	Gas	LNG
		734,214.20	17,544,875.00	
€/year	**32,705,905.23**	**18,279,089.20**		**18,889,665.75**

Emission values - tonnes/yr

	Diesel Mode	Dual Fuel Mode			Gas Mode
Emissions	MDO	PilotMDO	LNG	Total dual Fuel	LNG
CO2	**156,337.51**	3,509.62	113,770.02	**117,279.64**	**113,770.02**
SOX	**490.09**	11.00	0.00	**11.00**	**0.00**
Nox	**2,744.48**	61.61	500.09	**561.70**	**500.09**
PM	**53.91**	1.21	0.00	**1.21**	**0.00**