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ΤΙΤΛΟΣ

ΑΞΙΟΠΟΙΗΣΗ ΕΝΑΛΛΑΚΤΙΚΩΝ ΚΑΥΣΙΜΩΝ ΣΕ ΛΙΜΕΝΕΣ

ΤΙΤΛΟΣ ΑΓΓΛΙΚΑ

UTILIZATION OF ALTERNATIVE FUELS IN PORTS

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Μεταπτυχιακή Διατριβή που υποβάλλεται στο καθηγητικό σώμα για την μερική εκπλήρωση των υποχρεώσεων απόκτησης του μεταπτυχιακού τίτλου του Διϊδρυματικού Προγράμματος Μεταπτυχιακών Σπουδών «Νέες Τεχνολογίες στη Ναυτιλία και τις Μεταφορές» του Τμήματος Ναυτιλίας και Επιχειρηματικών Υπηρεσιών του Πανεπιστημίου Αιγαίου και του Τμήματος Μηχανικών Βιομηχανικής Σχεδίασης και Παραγωγής του Πανεπιστημίου Δυτικής Αττικής.

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Ο κάτωθι υπογεγραμμένος Μούτσιος Νικόλαος., του Αριστείδη, με αριθμό μητρώου 83/2017. Φοιτητής του. Διιδρυματικού Προγράμματος Μεταπτυχιακών Σπουδών «Νέες Τεχνολογίες στη Ναυτιλία και τις Μεταφορές» του Τμήματος Ναυτιλίας και Επιχειρηματικών Υπηρεσιών του Πανεπιστημίου Αιγαίου και του Τμήματος Μηχανικών Βιομηχανικής Σχεδίασης και Παραγωγής του Πανεπιστημίου Δυτικής Αττικής, δηλώνω ότι: *«Είμαι συγγραφέας αυτής της μεταπτυχιακής διπλωματικής διατριβής και ότι κάθε βοήθεια την οποία είχα για την προετοιμασία της είναι πλήρως αναγνωρισμένη και αναφέρεται στην διατριβή. Επίσης έχω αναφέρει τις όποιες πηγές από τις οποίες έκανα χρήση δεδομένων, ιδεών ή λέξεων, είτε αυτές αναφέρονται ακριβώς είτε παραφρασμένες. Επίσης βεβαιώνω ότι αυτή η διατριβή προετοιμάστηκε από εμένα προσωπικά ειδικά για τη συγκεκριμένη μεταπτυχιακή διπλωματική διατριβή».*

Ο δηλών	Ημερομηνία
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Utilization of Alternative Fuels in Ports

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Abstract

This specific thesis "Utilization of Alternative Fuels in Ports" was undertaken as part of the Postgraduate (MSc) Program of Studies, "New Technologies in Shipping & Transport" of the Department of Shipping trade & Transport and Department of Industrial Design and Production Engineering, University of Aegean and University of West Attica. The upcoming IMO regulations regarding the emissions' reduction derived from vessels in the maritime sector impel ship-owners to adopt alternative sources of energy and new technologies for their vessel's propulsion. The utilization of Liquified Natural Gas (LNG) as an alternative maritime fuel is considered as a credible alternative solution in conformity with the current environmental regulatory framework, as it is a clean energy source at a relatively low price with high safety standards. More specifically, the future estimated LNG demand as a marine fuel for the bunkering procedures of vessels calling at the maritime ports of Cyprus will be analyzed through the use of a specific methodology. This methodology includes the traffic data of each type of vessels calling at the under study ports of Cyprus and based on demand analysis' results, an indicative LNG supply chain will be proposed for covering the estimated future LNG demand at the ports of Cyprus. In the last chapter of this thesis, a cost benefit analysis will be conducted for the retrofit of the main engines of a conventional vessel (that uses Heavy Fuel Oil-HFO as main fuel) calling at the ports of Cyprus, taking into consideration the estimated bunker prices in the shipping market. Additionally, a socio-economic analysis of this vessel's retrofit will be conducted for assessing the benefits that this conversion will create in terms of cost savings for the environment.

Keywords: IMO Regulations, Ship Emissions, LNG, Ports, Alternative Marine Fuels, LNG Supply Chain, LNG Bunkering, Demand Analysis, LNG Price, CBA

Περίληψη

Η παρούσα διπλωματική εργασία με τίτλο «Αξιοποίηση Εναλλακτικών Καυσίμων σε Λιμένες», εκπονήθηκε στα πλαίσια του Μεταπτυχιακού Προγράμματος Σπουδών του Πανεπιστημίου Αιγαίου σε συνεργασία με το Πανεπιστήμιο Δυτικής Αττικής. Οι θεσμοθετημένοι επερχόμενοι κανονισμοί του Διεθνούς Οργανισμού Ναυσιπλοΐας και της Ευρωπαϊκής Επιτροπής για τη μείωση του περιβαλλοντικού αποτυπώματος του κλάδου της ναυτιλίας ωθούν τους πλοιοκτήτες στο να στραφούν σε εναλλακτικές μορφές ενέργειας και νέες τεχνολογίες, Η χρήση του Υγροποιημένου Φυσικού Αερίου (ΥΦΑ) ως ναυτιλιακό καύσιμο αποτελεί μια αξιόπιστη εναλλακτική λύση για τη συμμόρφωση προς τους περιβαλλοντικούς κανονισμούς, καθώς αποτελεί μια καθαρή μορφή ενέργειας σε σχετικά χαμηλή τιμή με ύψιστα επίπεδα ασφάλειας. Ειδικότερα, θα διεξαχθεί ανάλυση της εκτιμώμενης μελλοντικής ετήσιας ζήτησης ΥΦΑ ως ναυτιλιακού καυσίμου για τον ανεφοδιασμό των πλοίων που ελλιμενίζουν σε λιμένες της Κύπρου μέσω της χρήσης μιας συγκεκριμένης μεθοδολογίας που θα εμπεριέχει δεδομένα άφιξης/αναχώρησης όλων των τύπων πλοίων με σταθμό αναχώρησης/άφιξης τα εξεταζόμενα λιμάνια και θα προταθεί επιπρόσθετα η ανάπτυξη της αντίστοιχης βέλτιστης εφοδιαστικής αλυσίδας για την κάλυψη της προκύπτουσας εκτιμώμενης ζήτησης, ως αποτέλεσμα της ανάλυσης του κόστους λειτουργίας της και της διαστασιοποίησης του εξοπλισμού της. Στο τελευταίο μέρος της διπλωματικής εργασίας, θα επιχειρηθεί η τεχνικό-οικονομική ανάλυση ενός πλοίου που επισκέπτεται τα λιμάνια της Κύπρου, και που χρησιμοποιεί ως κύριο καύσιμο βαρύ μαζούτ (HFO) και θα εξεταστεί από οικονομικής σκοπιάς η χρήση ΥΦΑ από τις κύριες μηχανές του πλοίου και όπως και οι επιπτώσεις από περιβαλλοντικής σκοπιάς στη λειτουργία του μέσω μιας μεθοδολογίας που θα περιλαμβάνει και τις εκτιμώμενες τιμές των ναυτιλιακών καυσίμων.

Λέξεις Κλειδιά: Θεσμοθετημένοι Κανονισμοί ΙΜΟ, Αέριοι Ρύποι Πλοίων, Υγροποιημένο Φυσικό Αέριο, Εναλλακτικά Ναυτιλιακά Καύσιμα, Εφοδιαστική Αλυσίδα ΥΦΑ, Ανεφοδιασμός Πλοίων με ΥΦΑ, Ανάλυση Ζήτησης, Τιμή ΥΦΑ, Ανάλυση Κόστους-Οφέλους

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1. Introduction

The aim of this thesis is to present the utilization of Liquified Natural Gas (LNG) as an alternative maritime fuel which is considered as a credible alternative solution in conformity with the current environmental regulatory framework. Therefore, the future estimated LNG demand as a marine fuel for the bunkering procedures of vessels calling at the maritime ports of Cyprus will be analyzed thoroughly and an indicative LNG supply chain will be proposed for covering this estimated demand. In addition to this, the alternative compliance solutions of ship owners with the upcoming regulations are presented and compared to the LNG solution from a financial aspect of view. For examining this practically, a cost benefit analysis will be conducted for the retrofit of the main engines of a conventional vessel (that uses Heavy Fuel Oil-HFO as main fuel) calling at the ports of Cyprus, taking into consideration the estimated bunker prices in the shipping market.

Through the results derived from the financial analysis for the under-study vessel and the demand analysis for the LNG fuel in the examined ports, a generic overview of the alternative solutions for the compliance of ship owners with the regulatory framework for ship emissions' reduction will be illustrated and credible results will be presented.

2. Suggested Compliance Solutions with Regulations for Ship-owners

In the recent years, maritime industry is heavily regulated at national and global level and changes into highly competitive. It is clear that the maritime industry has to comply with a number of regulations concerning the prevention and the emission of harmful substances to the environment. This thesis is based on the general idea of the necessity for environmental friendly solutions for the maritime sector that will be implemented in the under study ports of Cyprus, aligning with European and International Regulations and Rules. More specifically, strict rules now govern the maximum amount of sulphur and nitrogen oxides as well as many other components. As it was aforementioned, a wide number of European and International policies, standards, rules and regulations on climate change and the environment relevant to both shore-side and ship-side already exists and is presented indicatively below:

- European Energy Strategy for Low-Emission Mobility;
- Clean Power for Transport (including Maritime Sector): a European alternative fuels

strategy – Alternative Fuels Directive (Directive EU/2014/94 of the European Parliament and of the Council of 22 October 2014 on the deployment of the alternative fuels infrastructure;

- Sulphur Directive (EU Directive 1999/32/EC of the European Parliament and of the Council of 11 May 2016 relating to a reduction in the sulphur content of certain liquid fuels). As amended by Directive 2012//33/EU and codified by 2016/802/EU;
- MRV Regulation (EU Regulation 2015/757 of the European Parliament and of the Council of 29 April 2015 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, and amending Directive 2009/16/EC);
- ISO Standard 28460:2010 for installation and equipment for LNG ship to shore interface and port operations;
- European Standards EN 13645 and EN 1473 for installation and equipment for liquified natural gas – Design of onshore installations with a storage capacity between 5 and 200 t and above 200 t;
- USCG NVIC No 01-2011-Guidance related to waterfront LNG facilities;
- IACS-LNG Bunkering Guidelines;
- IMO – Prevention of Air Pollution from Ships (MARPOL 73/78 Annex VI – Energy Efficiency and the Reduction of GHG Emissions from Ships / Regulation 12 – Ozone Depleting Substances, Regulation 13 – Nitrogen and Oxides and 14 – Sulphur Oxides);
- IMO – International Code for Construction and Equipment of Ships Carrying Liquified Gases in Bulk (IGC Code);
- Guidelines for systems and installations for supply of LNG as marine fuel to ships (currently under development in the ISO Technical Committee 67 WG);

More specifically, the EU Directive 2016/802 establishes limits on the maximum sulphur content of gas oils, heavy fuel oil (HFO) in land-based applications as well as marine fuels. [Ελευθερίου Αμαλία, Σεπτέμβριος 2017] Furthermore, the Directive includes some additional fuel – specific requirements for vessels calling at EU ports, obligations related to the use of fuels covered by the Directive and the placing on the market of certain fuels such as marine gas oil (MGO).

This specific Directive had been previously amended by Directive 2012/33/EU, now repealed, in order to further adapt the European Union's legislation to developments at international level under MARPOL Annex VI. Since 1 January 2015, stricter sulphur limits for marine fuel in SECAS apply (0.10%) as well as in areas outside SECAS (3.50%). What is more, a 0.1% maximum sulphur requirement for fuels used by vessels at berth in EU ports (including Cyprus' maritime ports) was introduced from 1 January 2010. In addition to this, it should be mentioned that passenger ships operating on regular services to or from any EU port shall not use marine fuels if their sulphur content exceeds 1.50% in sea areas outside the SECAS.

The current lack of widespread LNG bunkering facilities makes it difficult for ships to base on LNG as a marine fuel, especially when they cannot depend on regular seagoing routes. Only relatively few bunker facility sites have been established in Emission Control Areas such as those in Baltic Sea. For promoting sufficiently LNG infrastructure across EU, Directive 2014/94/EU establishes that Member States shall ensure, that an appropriate number of LNG refueling points are put in place at maritime ports by 31/12/2025 and inland port by 31/12/2030,in order to enable seagoing ships and waterway vessels to circulate throughout the TEN-T Core Maritime Network.

For ship-owners' conformity with the upcoming IMO regulations regarding the emissions' reduction derived from vessels, the suggested solutions that will be implemented in the global maritime industry will be presented and analyzed thoroughly below.

2.1 Scrubber Solution

One of the alternative suggested solutions that could be implemented in the global maritime industry constitute the scrubbers. More specifically, scrubbers are air pollution control devices that use liquid to remove particulate matter or gases and these systems in vessels are designed to wash via the use of water the exhaust gases from main, auxiliary engines and boilers to remove sulphur dioxide (SO_2) which is toxic gas that is directly to human health. Scrubber technology in ships is considered as a very efficient air pollution control system that has the potential to remove greater than 95 percent of the SO_2 from the engines and boilers. [Παπασταμάτη Ιωάννα-Μαρία, 2017] The cost of scrubber technology is estimated in a new-build vessel to be around 2.300.000 to 3.300.000 million Euros, where as the cost of retrofitting a scrubber on an existing vessel is estimated to be 4.000.000 up to 4.500.000 million €, based on current market data. [Ιωάννης Γ. Γλύπτης, 2017] Therefore this solution is not so effective based on the fact that any financial instrument could grant their adoption like LNG fuel and their use is considered as cause célèbre and temporary due to the fact that their use does not abundantly comply with the established environmental target for maritime sector after the reference year 2030.

2.2 LSHFO Fuel

An alternative proposed solution for ship owners' conformity with the upcoming IMO regulations constitutes the adoption of Low Sulphur Heavy Fuel Oil (LSHFO) for their fleets of vessels. It should be noted that in the maritime industry, most of the world's maritime traffic consists of vessels with engines powered by Heavy Fuel Oil (HGO) or Marine Gas Oil (MGO). Though both Heavy Fuel Oil and Marine Gas Oil are not cost effective in the current status of the environmental regulations and they contain high levels of asphalt, carbon residues, sulphur and metallic compounds and have viscosity and low volatility properties as well. Due to these characteristics, the burning process of marine diesel engines, can lead these fuels to produce significant amounts of air pollutants such as nitrogen oxides (NO_x), sulphur oxides (SO_x) and carbon dioxide (CO_2). Taking into consideration that the International Convention for the Prevention of Pollution from Ships (MARPOL) sets limits on emissions of Sulphur dioxide and nitrogen oxides, an alternative solution for ship owners in order to comply with the upcoming global regulatory framework constitutes the adoption of the Low Sulphur Heavy Fuel Oil. LSHFO and LSMGO are not cost effective in comparison with LNG fuel and their adoption does not imply any financial contribution by EU financial instruments but their use complies with the reduced sulphur emissions that IMO regulations require. Another critical issue is the lack or adequate supply and storage of LSHFO at the maritime ports. [Παπασταμάτη Ιωάννα-Μαρία, 2017]

2.3 LNG Fuel

The proposed solution of LNG, as an alternative marine fuels for vessels calling at the under study ports of Cyprus will be analyzed in detail. More specifically, in order to meet IMO's and EU Commission's emission requirements, it is necessary to use more refined fuels such as Liquified Natural Gas (LNG). [Ελευθερίου Αμαλία, Σεπτέμβριος 2017] In that context, Liquified Natural Gas (LNG) would be one of the most promising alternative solutions, because in environmental terms, it produces fewer harmful combustion by-products, as it is chemically relatively simple, compared to fuels like Heavy Fuel Oil (HFO) and Marine Gas Oil (MGO).

It is emerged that, until recently; air pollution caused by ships was mostly unregulated. The reason for this is the following: ship pollution constitutes about 3% of the global air pollution. However, concern is growing because ship pollution is concentrated in relatively small areas, with the Baltic Sea being one of the most critical areas. In these areas, diesel marine engines are responsible for an increasingly larger share of air pollution. Furthermore, with the increasing traffic volume and without stringent controls, shipping emissions are likely to become a large environmental problem in the coming years. SO_2 and NO_x ship emissions are expected to overtake land-based system emissions. In particular, the LNG fuel as an alternative marine fuel can significantly reduce he environmental impacts of shipping operations, most likely without increasing costs, therefore switching from conventional heavy fuel oils to LNG can potentially enable a significant reduction in all emissions. LNG, as an alternative marine fuel, can reduce both pollutant and Greenhouse Gas Emissions (GHG emissions). LNG fuel constitutes one of the cleanest burning fuels, producing water vapour and smaller amounts of carbon dioxide and nitrogen oxides when combusted. Because LNG has a higher hydrogen-to-carbon ratio in comparison to conventional fuels, the CO_2 emissions are lower, so it contributes to climate change mitigation as a transition fuel to a low carbon economy. Specifically, it can reduce the emissions of CO_2 by at least 25% and the emissions of NO_X up to 85-90%. As it does not contain sulphur, there are almost no SO_2 emissions and Particulate Matter emissions. Regarding the cost of an LNG vessel's engines' retrofit it is estimated to be 4.000.000 to 6.000.000 million Euros depending on the type of main engines of the vessels and there are predicted financial instruments provided by EU Commission that promote the adoption of LNG fuel in contrast with the other alternative solutions.

3. LNG Bunkering Options

Regarding the existing LNG bunkering options for vessels calling at the maritime ports, it should be noted that there are three widely known solutions that are being implemented at global level. The most usual option is considered the LNG Truck-to-Ship Bunkering (TTS) because of its lower cost and user-friendliness during the procedure of LNG fuel's transportation. Among the factors that affect the choice of LNG bunkering options are the safety level, the flexibility and the distribution flow rate. In Europe, LNG bunkering is being applied in the maritime ports of Antwerp, Amsterdam, Rotterdam, Zeebruge and several ports of Norway.

A) <u>LNG Ship-to-Ship Bunkering (STS)</u>

As it was described previously, the most popular option for the supply of LNG fuel at maritime ports is the LNG Truck-to-Ship Bunkering. Ship-to-Ship (STS) indicates the transfer of LNG fuel, LNG bunkering, from one ship to another. STS operations include both two ocean-going ships underway or harbor operations where moored ship is normally moored or docked at a pier. LNG transfer ship to ship operation occurs with various types of vessels including LNG carrier, FSRU, LNGRV, LNG feeder vessel or LNG bunker barge or vessel. The STS operation may either be a cargo transfer or a fueling operation for a LNG propelled ship. STS operations require strict safety standards and flawless execution considering the factors involved with two ships at sea.

B) LNG Ship-to-Shore Bunkering

Ship-to-shore operations are typically where LNG is transferred from a ship to an onshore storage terminal or depot. Similar systems are applied for Shore-to-Ship where LNG is transferred from the storage terminal or depot to a ship.

The design of these systems can vary based on application-bunkering an LNG propelled ship or loading an LNG carrier. The ship-to-shore operations are generally performed in sensitive environments and require a very high safety concern and all specific circumstances that may have an impact on the operations need to be thoroughly examined.

C) LNG Truck-to-Ship Bunkering (TTS)

Truck-to-ship operations constitute in general an application where ships and ferries are fuelled from tank trucks. This fuelling can either be a direct transfer from a tank truck to the ship of a system where several tank trucks connects to a fuelling skid which can deliver the required quantities of LNG fuel to the ship.

As Truck-to-Ship transfer involves a number of tank trucks moving in and out of position to unload, safety and ease of use are of utmost importance. This method is often used to fuel passenger ships and ferries which presents a serious safety concern. It should be mentioned that typical products need to be implemented to the transfer system for safe and reliable truck-to-ship operations.

4. LNG Fuel Demand Analysis for Cyprus' Ports

The main objective of this chapter is to estimate the demand for LNG as a marine fuel deriving from vessels during the under study years (2020-2030) at the TEN-T Maritime Ports of Cyprus, and particularly the ports of Larnaca and Vasilikos as case studies. First of all a general description of the shipping activity in the abovementioned ports will be provided in order to assess the demand for LNG, and therefore, to proceed with the supply chain analysis for the successful distribution of the fuel. It should be noted that the cases, on which this analysis was based, were designed with the aim to provide reliable results.

4.1 Cyprus' Maritime Sector Overview

For achieving the forecast of the estimated annual LNG demand for vessels calling at Cyprus ports, we need to highlight the main aspects of the maritime industry in the under –study ports of Larnaca and Vasilikos. More specifically, the maritime port of Larnaca constitutes the second largest port in Cyprus and it is located in its southeast part. [https://www.cpa.gov.cy] Larnaca maritime port is situated approximately 2 kilometers from the town center and on the landside is surrounded by residential units. On the north side there are oil product installations and at the south side it borders with Larnaca marina.

It is multiuse port and extending to 445.000 square meters. The port accommodates all types of loads from unpacked (animal food, grain, gypsum) to conventional (lumber, iron, fertilizers, cars) as well as oil products.

For the reference year of 2016, calls from tankers and general cargo vessels in the port of Larnaca and are significantly higher compared to the number of calls that refer to bulk carriers and vehicle carrier vessels, as it can be easily derived by the contents of the following table and graph.

Ship Category	Number of Calls
Tanker Vessels	440

General Cargo Vessels	456
Bulk Carrier Vessels	36
Vehicle Carrier Vessels	20
Total Fleet	**952**

Table 1: Calls by type of vessel at the maritime port of Larnaca.

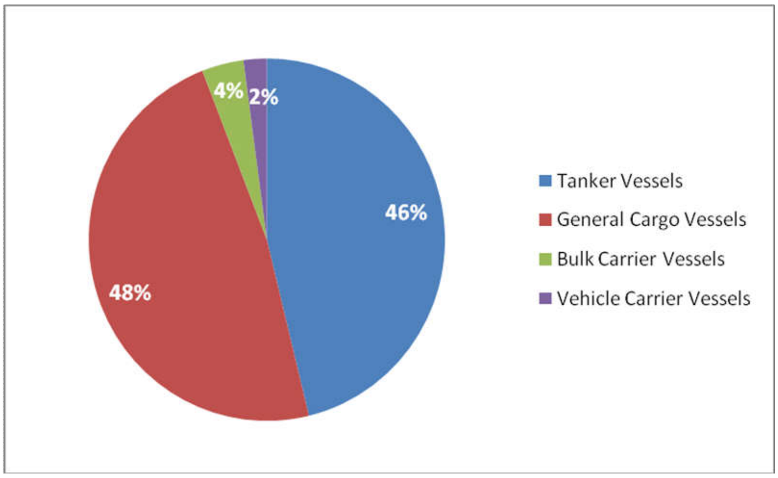


Figure 1: Frequency of calls per type of vessel at the maritime port of Larnaca.

As concerns the maritime port of Vasilikos, it is situated in the southern part of Cyprus between Lemesos and Larnaca and it is especially the industrial terminal for handling unpacked as well as troublesome cargo. The terminal belongs to the Port Authority, which leased it to Vasilikos Cement Works. The lease agreement concerns all kinds of cargo, not only imports but also exports, for the needs of the Cement Works as well as private cargo of other companies, who were granted a license by the Ports Authority.

In particular, the kind of cargoes, which move through Vasilikos Terminal are animal fodder, wheat, coal, perlite, cement, soil, gravel and scrap iron. However, the primary export cargo is cement.

The statistical analysis provided by Statistical Service of Cyprus (CYSTAT) revealed that the maritime port of Vasilikos in the interval between years 2010-2016 had 183 calls from 61 tanker vessels, which was the predominant vessels' type that was reported to have called in this port. Namely, the number of tanker vessels that arrived at Vasilikos Port approached the percentage of 100% of the total ship's types visiting this specific port. [Ocean Finance Ltd, June 2016]

4.2 LNG Demand Analysis' Methodology

For appropriately estimating the LNG demand at the maritime ports of the Larnaca and Vasilikos in Cyprus, two basic elements are needed: the number of refueling that will take place and the fuel quantities to be supplied. For determining the LNG demand, the profile of the maritime industry in Cyprus' under-study ports (Larnaca and Vasilikos) was delineated, by creating a database which includes all the vessels that visited the Ports of Larnaca and Vasilikos in the interval between years 2010-2016 based on facts by Statistical Service of Cyprus (CYSTAT). Then, a detailed description for each ship was conducted by collecting data from Clarksons SIN (Shipping Intelligence Network). The categories of data gathered are presented below:

- Ship Type
- Hull Dimensions
- Capacity (e.g. DWT and Cars)
- Age
- Total Installed Power
- Average Service Speed
- Number of Arrivals in the Maritime Ports

Based on these general and technical and operational characteristics, a series of groupings was conducted in order to categorize the total arrivals on the basis of specific characteristics for each vessel type.

In particular, the initial grouping was based on the type of ship according to the following categorization: tanker vessels, bulk carrier vessels, general cargo vessels and vehicle carrier vessels. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] This grouping assisted in drawing inferences to the routes served by the vessels and thus the geographical areas in which they operate.

Having categorized all vessels according to their type, a further grouping was formed allowing a more comprehensive description of each category calling at the port. More specifically, for tankers, general cargo and bulk carrier vessels, a second grouping was performed according to their age and deadweight capacity (DWT), while for vehicle carrier vessels grouping was performed according to their age and car capacity.

The calculation of the number of LNG refueling procedures, that will take place, was estimated in this specific thesis, mainly based on parameters of capacity (car capacity or DWT) and the age of each vessel. These two features are directly related to the decision-making process for the ship owners to adopt LNG as an alternative marine fuel in a short term perspective. In addition to this, these initiatives will significantly contribute to the institutionalization of LNG fuel in Europe and Mediterranean Sea, that will be achieved with more intensive rates.

On the one hand, the criterion of capacity for each vessel, determines the time she spends in the identified Emission Control Areas (ECAs, SECAs). For instance, general cargo ships with DWT capacity up to 2.000 tons are active in the transit of goods from hub ports to neighboring spoke ports, which leads them to spend a long period of time in these sea areas, unlike ships with ships with a capacity over 7.000 tons that are dedicated mostly to transoceanic voyages (especially serving the commercial routes between Asia Europe) and stay in the ECAs relatively little time.

On the other hand, the age of the vessel contributes significantly to this thesis, due to the fact that is connected directly to the payback period of the investment required. The usual economic life time of the vessels is 25 years. For this reason, using the specific methodology it is assumed that general cargo vessels, bilk carrier vessels, vehicle carrier vessels and tanker vessels up to 15 years will tend to shift to LNG as their main fuel for their propulsion in compatibility with the upcoming regulatory framework. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] Therefore, in order to categorize the number of arrivals by age, age groupings every 5 years until the age of 25 years were formulated (this does not apply for general cargo and vehicle carrier vessels), while older vessels joined in a single category.

In order to calculate the estimated amount of LNG supply that every Class of vessel needs, it is used as an assumption that the distance to be travelled (this does not apply for tanker and vehicle carrier vessels) is approximately 500 nautical miles until the next refuel. More specifically, this distance is considered ideal in relation to the locations of Larnaca and Vasilikos maritime ports from other neighboring commercial and tourist ports.

Regarding the data on typical consumption rates, it is used as model certificate dual fuel engines using 100% gas fuel. For this reason, it is assumed in this thesis a perfect dual fuel engine, which produces at least the average of the total installed power of that Class of vessel. The selection of the engines was made based on data from major manufacturers such as MAN SE and Wärtsilä.

In conclusion, the Classification of vessels facilitates the process of the estimation of the number of refueling ships using LNG as an alternative marine fuel in the forthcoming years (reference years 2020-2025 and 2025-2030) as well as the estimated refueling LNG.

4.3 Cyprus Ports' Tanker Sector Overview

In this section, the calls of the tankers calling at the under study maritime ports of Larnaca and Vasilikos (only tankers calling at this specific port) will be presented in order to assess approximately the estimated LNG fuel demand for these port's maritime users.

4.3.1 Larnaca Maritime Port-Tanker Sector Overview

In 2016, there were 400 calls by 133 tanker vessels at the maritime port of Larnaca. This fact depicts that the liquid fuels is one of the most significant activities of the port. In order to be able to make a better approximation of tanker vessels' profile that visited the port in 2016, a classification of the sample was made, based on their DWT.

The figure below depicts the frequency of the vessels, according to their DWT capacity.

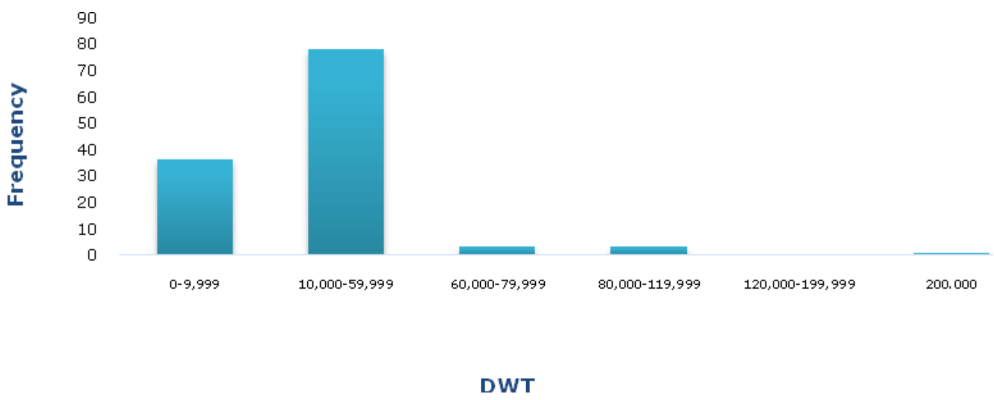


Figure 2: Frequency of tanker vessels at Larnaca port by capacity on DWT.

By selecting as a criterion, the DWT capacity, the sample was divided into two main categories:

- Class A (≤29.999 tons), and
- Class B (≥30.000 tons)

As it can be observed from the figure below, the number of Class B vessels is significantly higher than the population of Class A, namely 75 versus 45. In particular, vessels of the second Class had three times more calls than those of the first, i.e. 332 and 108 calls respectively. The figure below demonstrates the percentage of tankers vessels belonging to each Class of tankers.

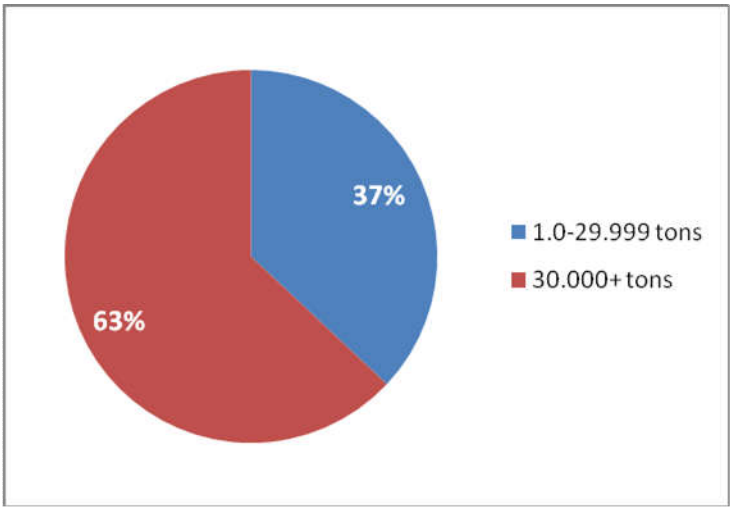


Figure 3: Percentage of Tanker vessels in each category at Larnaca Port for the year 2016.

4.3.1.1 Tankers≤ 29.999 Tons

For the maritime port of Larnaca, the distribution of tanker calls up to 29.999 tons, namely Class A, as a function of age, is depicted in the figure below. The average age was close to 15.58 years.

It should be noted that the age of vessels constitutes an essential factor in classifying vessels for the decision to adopt LNG as a marine fuel, due to the fact that it is directly related to the payback period of the required investment.

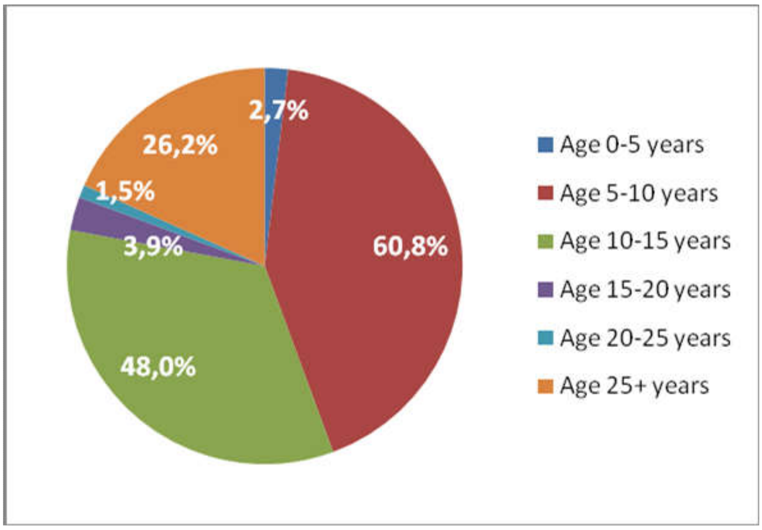


Figure 4: Percentage of calls for tanker vessels up to 29.999 tons by age group.

It is observed from the above figure that the majority of calls. 61% was made by vessels of age between 5-10 years, while vessels over 25 years old exhibit the second highest percentage, 26%. In addition to this, the same number of calls was exhibited by other vessels categories.

More specifically, the ages of the vessels, which are considered ideal to use LNG as a marine fuel is up to 15 years. It is noteworthy to demonstrate that the abovementioned vessels made a total of 227 calls in year 2016 representing 68.4% of the total calls at Larnaca maritime port.

Estimated LNG Supply Volume

Regarding the estimated LNG supply volume, the engines used were mostly 4-stroke. Tankers that call at the maritime port of Larnaca had an average engine power of 3.564 kW and their average service speed was at 9.3 knots.

The typical 4-stroke dual fuel engine that was selected, came from Wärtsilä, in order to assess the special consumption of fuel gas. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] This is the model 9L34DF. This particular engine delivers 4.050 kW at 750 rpm with a consumption of 7.700 kJ/kWh≈142.59 gr/kWh.

The typical distance that is assumed in this thesis for a vessel which needs to move from one port to another and carry out refueling procedures was approximately 750 nautical miles. The required time for a typical vessel of this Class to cover this distance is slightly more than 81 hours.

Therefore, the required fuel supply amount is 41.1 tons≈91.1 m^3 LNG.

4.3.1.2 Tankers≥30.000 Tons

The figure below depicts the distribution of tanker calls above 30.000 tons, namely Class B, as a function of age. The average age was close to 11.47 years.

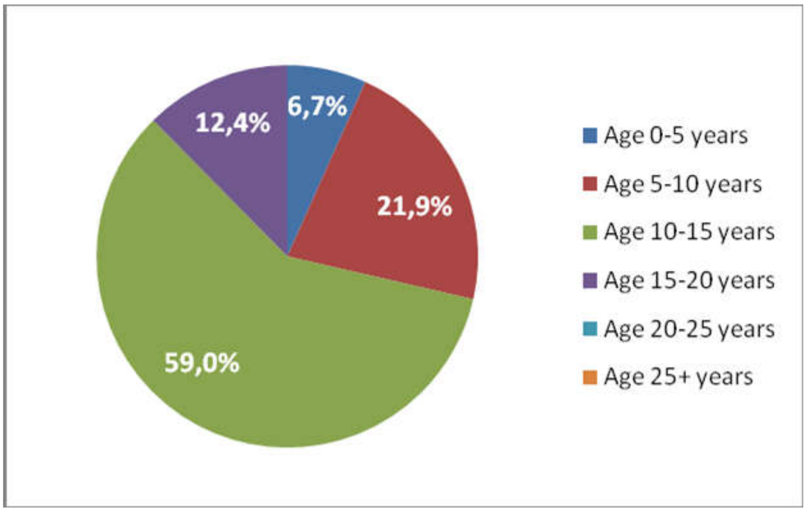


Figure 5: Percentage of calls for tanker vessels ≥ 30.000 tons by age group

It is worth mentioning that all of these vessels made a total of 92 calls in year 2016. It is observed from the above figure that the majority of the calls, 59% was made by vessels aged between 10-15 years, while vessels between 5-10 years exhibit the second highest percentage, 22%. Vessels aged up to 5 years old made a relatively small number of calls, no more than 7%. Finally, vessels between 15-20 years old made approximately 12% of calls.

In particular, the age group for vessels, which are considered ideal to use LNG as fuel is up to 15 years, corresponding to 87.6% of the total calls at Larnaca maritime port.

Estimated LNG Supply Volume

Vessels from this Class that visited the port of Larnaca had an average engine power of 10.136 kW and their average service speed was at 10.8 knots.

A typical 4-stroke dual fuel engine, which was selected, came from Wärtsilä, in order to meet the needs of the engine model. This is the model 12V50DF, which delivers 11.700 kW at 514 rpm, with a specific consumption 134.1 gr/kWh. [Ocean Finance Ltd, June 2016]

The typical distance that is assumed in this thesis for a vessel, which needs to operate from a neighboring port until the next refueling point in the port of Larnaca is approximately 750 nautical miles. The time for a typical vessel of this Class to cover this distance is slightly more than 69 hours.

Therefore, the required fuel supply amount is 94.4 tons≈209.5 m^3 LNG.

4.3.2 Vasilikos Maritime Port-Tanker Sector Overview

During 2010-2016, 41 Tanker vessels were reported to have called in Vasilikos maritime port, each performing a different number of calls. The total number of calls during 2010-2016 was 183. Tanker ships were divided in two categories according to the criterion of capacity in numbers of DWT.

The figure below depicts the segmentation of the sample as a function of capacity in DWT.

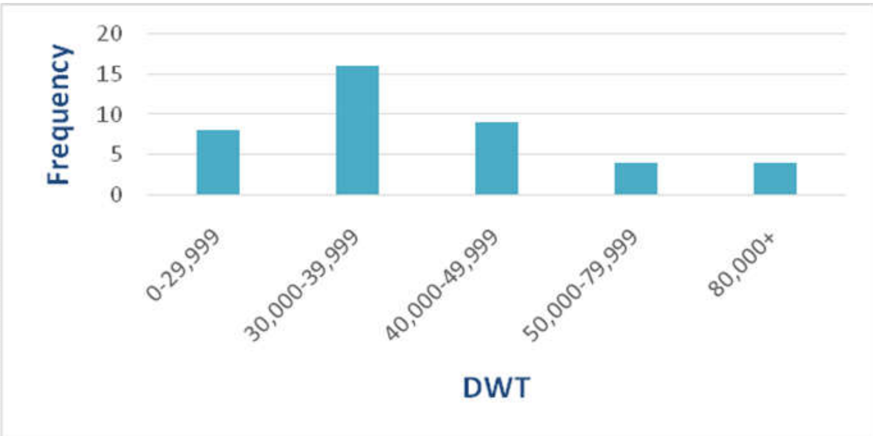


Figure 6: Frequency of tanker ships at Vasilikos Port by capacity on DWT.

By selecting as a criterion, the DWT capacity, the sample was divided into two main categories:

- Class A (≤29.999 tons), and
- Class B (≥30.000 tons)

As it can be observed from the figure below, the number of Class B vessels is significantly higher than the population of Class A, namely 33 versus 8. However the vessels of the first Class had more calls than those of the latter i.e. 125 and 58 calls respectively. The figure below shows the percentage of tanker vessels belonging to each Class.

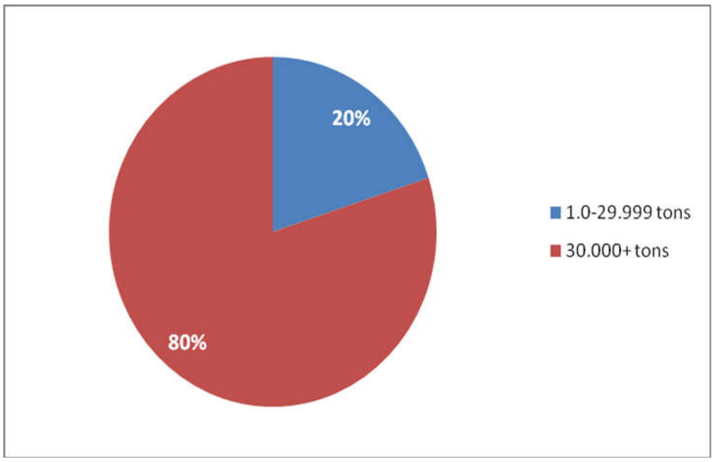


Figure 7: Percentage of Tanker vessels in each category at Vasilikos port for the years 2010-2016.

4.3.2.1 Tankers≤ 29.999 Tons

In particular, the distribution of tanker vessels' calls up to 29.999 tons in the maritime port of Vasilikos, namely Class A, as a function of age, is illustrated in the below figure. The average age was close to 16.88 years.

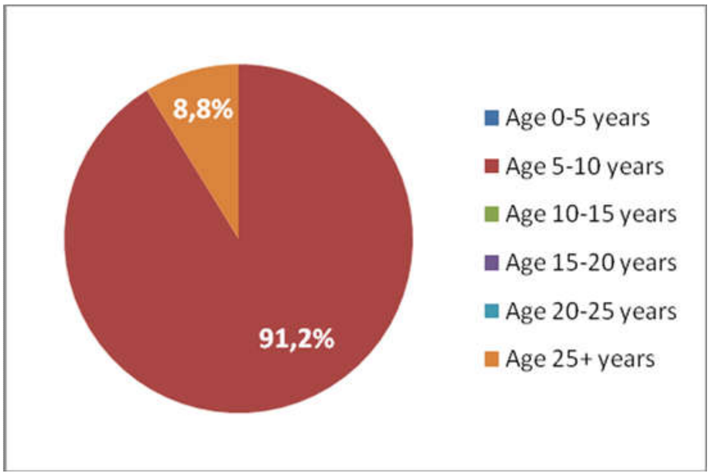


Figure 8: Percentage of arrivals for tanker vessels up to 29.999 tons by age group.

It can be observed from the above figure that from the majority of calls, 91.2% was made by vessels between 5 to 10 years old. Vessels aged over 25 years old represent 8.8% of the calls at the port of Vasilikos.

What is more the age group for vessels, which are considered ideal to use LNG fuel is up to 15 years. It is worth mentioning that all of these tankers made a total of 114 calls during 2010-2016 corresponding to 91.2% of the total arrivals at the port of Vasilikos.

Estimated LNG Supply Volume

Regarding the estimated LNG supply volume, the engines used were 4-stroke. Tankers from Class A that visited Vasilikos maritime port had an average engine power of 1.817 kW and their average service speed was at 9.29 knots.

The typical 4-stroke dual fuel engine which was selected came from Wärtsilä, in order to assess the special consumption of fuel gas. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] This is model 6L34DF. This particular engine delivers 2.700 kW at 750 rpm with specific consumption 7.700 kJ/kWh ≈ 142.6 gr/kWh.

Additionally, the typical distance that is assumed for a vessel, which needs to move from one port to another and carry out refueling procedures was approximately 50o nautical miles. The required time for a typical vessel of this Class to cover this distance is slightly more than 53.8 hours.

Therefore, the required fuel supply amount is 13.9 tons ≈ 31.1 m^3 LNG.

4.3.2.2 Tankers≥30.000 Tons

As it is illustrated in the below figure , the distribution tanker ships arrivals above 30.000 tons in the maritime port of Vasilikos, namely Class B, as a function of age can be depicted graphically.

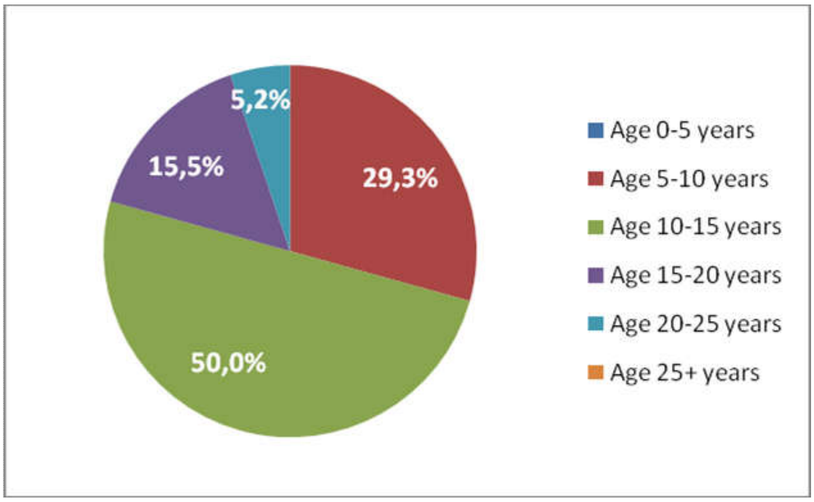


Figure 9: Percentage of arrivals for tanker vessels ≥ 30.000 tons by age group.

It can be easily observed from the above figure that the majority of the calls, 50% was made by vessels between 10 to 15 years old, while vessels between 5 to 10 years old represent the second highest percentage, 29%. Moreover, vessels aged between 20 to 25 years old made a relatively small number of calls, no more than 5%. Finally, vessels between 15 to 20 years old represent about 16% of the total calls.

It should be mentioned that the ideal age for the tankers of Class B to use LNG fuel is up to 15 years old. It is notable that all of these tankers made a total of 46 arrivals in the interval 2010-2016, corresponding to 79.3% of the total arrivals at the port of Vasilikos.

Estimated LNG Supply Volume

As concerns the estimated LNG supply volume, the engines used were mostly 4-stroke. Tanker vessels from Class B that visited Vasilikos maritime port had an average engine power of 14.209 kW and their average service speed was at 11.05 knots.

A typical 4-stroke dual fuel engine 8S50ME-C8.2 GI-TII came from MAN SE, which delivers 13.270 kW at 127 rpm with specific consumption 7.403.4 kJ/kWh≈137.1 gr/kWh.

Furthermore, the typical distance that is assumed for a vessel, which needs to operate from a neighbouring port until the next refuelling in the port of Vasilikos was approximately 500 nautical miles. The required time for a typical vessel of this Class to cover this distance is slightly more than 45.2 hours.

Therefore, the required fuel supply amount is 88.1 tons≈195.7 m^3 LNG.

4.3.3 Larnaca Port's General Cargo Sector Overview

In this subsection, it is depicted that the maritime port of Larnaca had 456 calls from 155 General Cargo vessels in the reference year 2016. In order to be able to make a better approximation of general cargo vessels' profile that visited the port in 2016, a Classification of the sample was made based on their DWT.

The figure below depicts the frequency of the vessels according to the DWT.

Figure 10: Frequency of General cargo vessels at Larnaca port by capacity on DWT.

By selecting as a criterion, the DWT capacity, the sample was divided into two main categories:

- Class A (≤4.999 tons), and

- Class B (≥5.000 tons)

As it can be observed from the figure below, the number of Class A vessels is significantly higher than the population of Class B, namely 95 versus 60. In particular, the vessels of the first Class had almost two times more calls than those of the latter, i.e. 297 and 159 calls respectively. The figure below shows the percentage of general cargo vessels belonging to each Class.

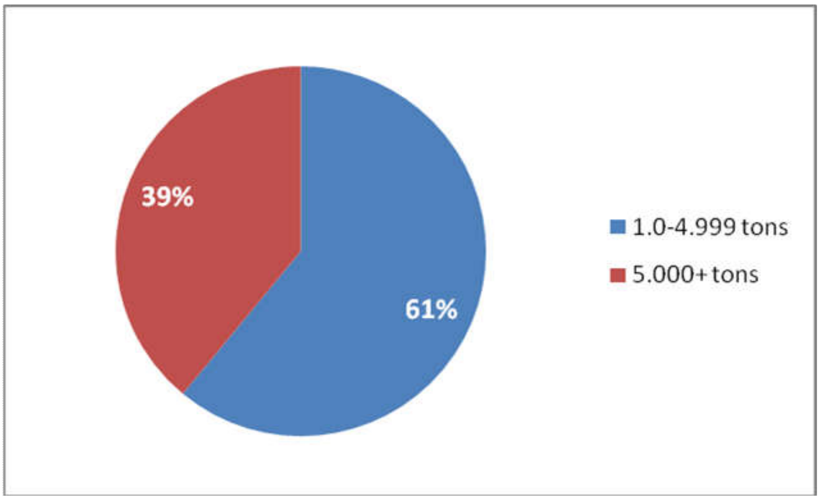


Figure 11: Percentage of General cargo vessels in each category at Larnaca port for the year 2016.

4.3.3.1 General Cargo Vessels ≤ 4.999 tons

The distribution of general cargo vessels' calls up to 4.999 tons, namely Class A, as a function of age, is depicted in the figure below. The average age was close to 25.71 years.

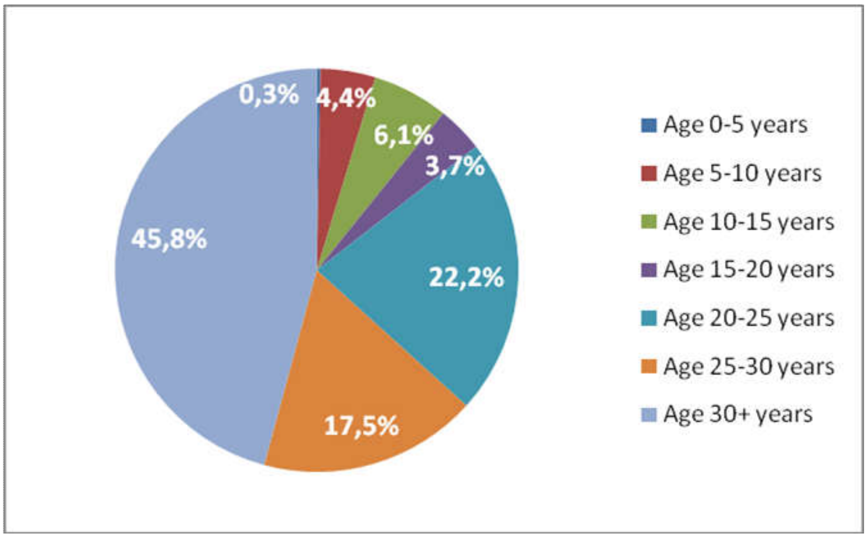


Figure 12: Percentage of calls for general cargo vessels up to 4.999 tons by age group.

It is observed from the above figure that the majority of the calls, 46% was made by vessels over 30 years old, while vessels between the group of 20-25 and 25-30 years exhibit the next highest percentages, 22% and 18% respectively. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] Vessels aged between 5-10, 10-15, 15-20 years age group made a relatively small number of calls.

What is more, the age of vessels, which is ideal for using LNG as a marine fuel in this Class of general cargo vessels is up to 15 years. All of these vessels made a total of 32 calls in year of 2016, corresponding to 10.8% of the total calls at the Larnaca Port.

Estimated LNG Supply Volume

Vessels from this Class that visited the maritime port of Larnaca had an average engine power of 1.737,99 kW and an average service speed at 8.1 knots.

The typical 4-stroke dual fuel engine, which was selected, came from Wärtsilä, in order to assess the specific consumption of fuel gas. This is the model 6L34DF. This particular engine delivers 2.700 kW at 750 rpm with specific consumption 7.629 kJ/kWh≈141.27 gr/kWh.

Moreover, the typical distance that is assumed for a vessel, which needs to move from one port to another and carry out refueling procedures is approximately 500 nautical miles. The required time for a typical ship of this Class to cover this distance is slightly more than 61 hours.

Therefore, the required fuel supply amount is 15.1 tons≈33.5 m^3 LNG.

4.3.3.2 General Cargo Vessels ≥ 5.000 tons

The figure below depicts the distribution of general cargo vessels above 5.000 tons, namely Class B, as a function of age. The average age was close to 19.33 years.

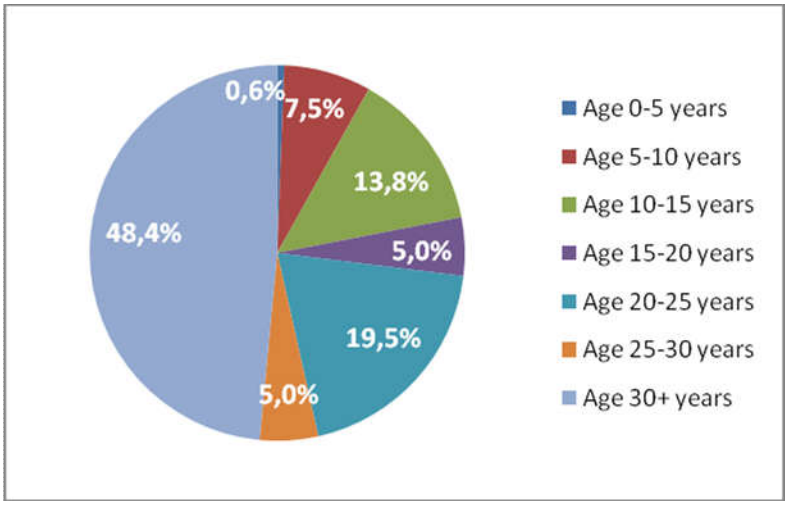


Figure 13: Percentage of calls for general cargo vessels ≥ 5.000 tons by age group.

It is observed from the above figure that the majority of the calls, 48% was made by vessels over 30 years old, while vessels between 20-25 exhibit the second highest percentage, 19%. Vessels aged between 10-15 and 5-10 years old made a relatively small number of calls, no more than 14% and 8% respectively. In addition, approximately the same number of calls was exhibited by the vessels' categories from 25-30 and 15-20 groups. Finally, vessels up to 5 years old represent about 1% of the calls.

The age of vessels, which is ideal for LNG fuel in this Class is up to 15 years. It is notable that all of these vessels made a total of 35 arrivals in year 2016 representing 21.9% of the total calls at the maritime port of Larnaca.

Estimated LNG Supply Volume

Vessels from this Class that visited Larnaca Port had an average engine power of 2.848,22 kW and an average service speed at 8.7 knots.

The typical 4-stroke dual fuel engine, which was selected, came from Wärtsilä, in order to meet the needs of engine model. This is the model 9L34DF. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] This particular engine delivers 4.050 kW at 750 rpm with specific consumption 7.700 kJ/kWh≈142.59 gr/kWh.

The typical distance that a vessel needs to operate from a neighbouring port until the next refuelling point in the maritime port of Larnaca is approximately 500 nautical miles. The required time for a typical vessel of this Class to cover this distance is slightly more than 58 hours.

Therefore, the required fuel supply amount is 23.4 tons≈51.9 m^3 LNG.

4.3.4 Larnaca Port's Bulk Carrier Sector Overview

In this subsection, it is presented that the maritime port of Larnaca had 36 calls from 19 bulk carrier vessels. In order to be able to make a better estimation of the vessels' profile that visited the port in 2016, a segmentation of vessels was made based on their DWT capacity. The figure below, demonstrates the frequency of the vessels according to the DWT.

Figure 14: Frequency of Bulk Carrier Ships at the Larnaca port by capacity on DWT.

By selecting as a criterion, the DWT capacity, the sample was divided into two main categories:

- Class A (≤14.999 tons), and
- Class B (≥15.000 tons)

As it can be observed from the figure below, the number of vessels of Class A is about little more than the vessels of Class B. In particular, the vessels of the first Class had almost three times more calls than those of the latter, i.e. 27 and 9 calls respectively. The figure below depicts the percentage of all vessels belonging to each Class of vessels.

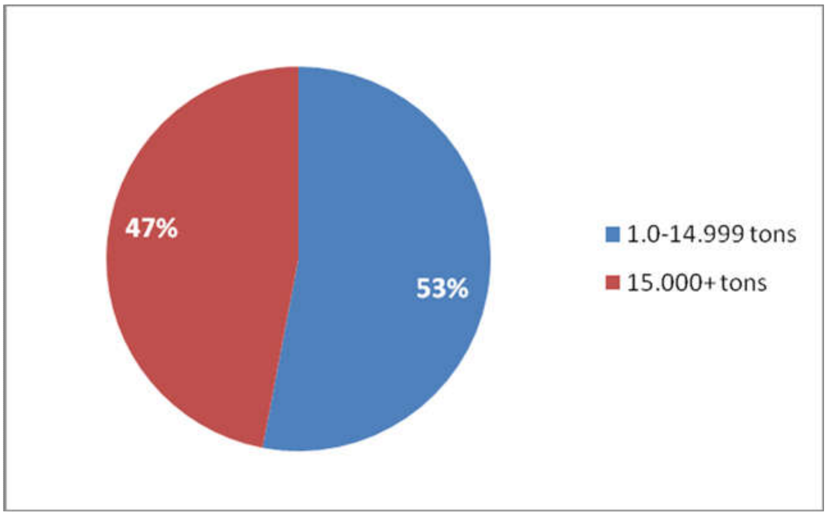


Figure 15: Percentage of Bulk carrier vessels in each category at Larnaca port for the year 2016.

4.3.4.1 Bulk Carriers ≤ 14.999 tons

The figure below shows the distribution of bulk carrier vessels' calls up to 14.999 tons, namely Class A, as a function of age. The average age was close to 12.80 years.

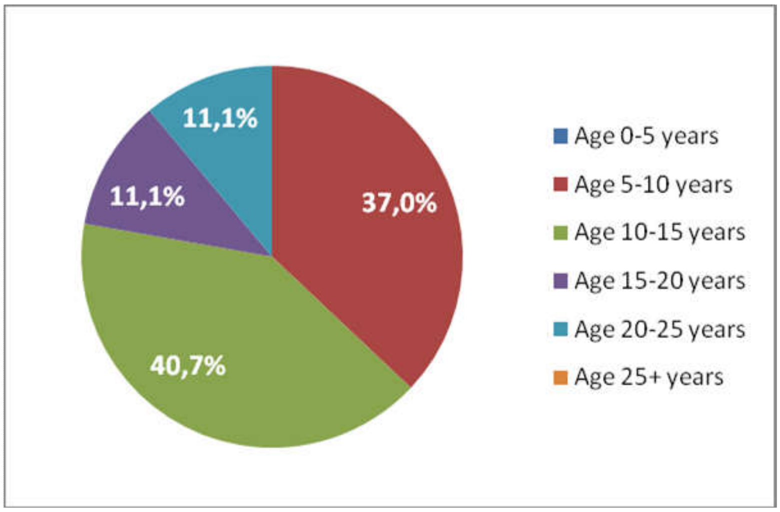


Figure 16: Percentage of Bulk Carrier Vessels up to 14.999 tons by age group.

It is observed from the above figure that the majority of the calls, 41% was made by vessels with age between 10 to 15 years old, while vessels 5 to 10 years old represent the second highest percentage, 37%. What is more, approximately the same number of calls was exhibited by vessels' categories from 15 to 20 and 20 to 25 years old.

Estimated LNG Supply Volume

As for the estimated LNG supply volume, the engines used were mostly 4-stroke. However, in this type we should point out the role of the power generators as they constitute a significant percentage of total installed power capacity. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] Vessels of this Class that visited the maritime port of Larnaca had an average engine power of 2.552 kW and their average service speed was at 9.79 knots.

A typical engine model that was selected, came from Wärtsilä which is 6L34DF. This engine model delivers 2.700 kW at 750 rpm with specific consumption 7.629 kJ/kWh≈141.27 gr/kWh.

The typical distance that was assumed for a vessel, which needs to move from one port to another and carry out refuelling procedures was approximately 500 nautical miles. The time required for a typical vessel of this Class to cover this distance is slightly more than 51 hours.

Therefore, the required fuel supply amount is 18.41 tons≈40.87 m^3 LNG.

4.3.4.2 Bulk Carriers ≥ 15.000 tons

The distribution of bulk carrier vessels' calls above 15.000 tons, namely Class B, as a function of age, is depicted in the figure below. The average age was close to 16 years.

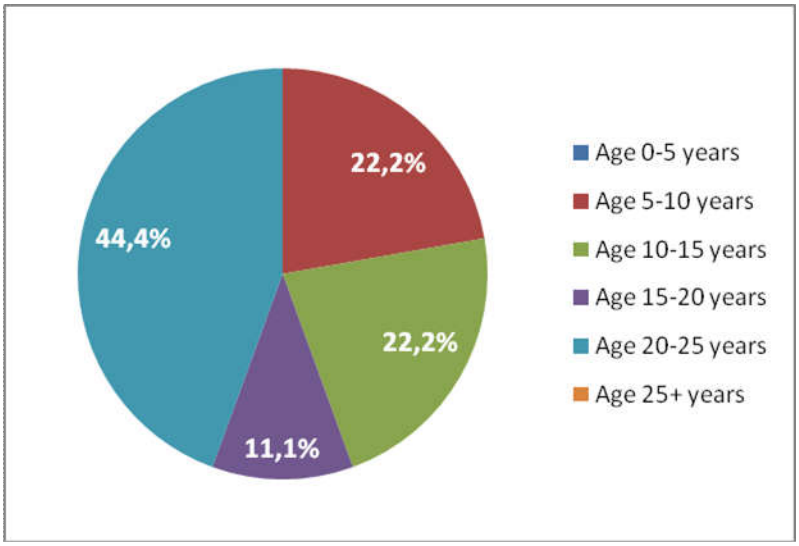


Figure 17: Percentage of arrivals for Bulk Carrier vessels ≥ 15.000 tons by age group.

It is observed from the above figure that the majority of the calls, 45% was made by vessels aged between 20 to 25 years old, while vessels between 5-10 and 10-15 years old exhibit the second highest percentage, 11%. Finally, vessels aged between 15-20 years old represent 1% of the calls.

The age of vessels, which is ideal for using LNG fuel in this type of vessel is up to 15 years. All these vessels made a total of 4 calls in 2016 representing 44.4% of the total calls at the Larnaca port.

Estimated LNG Supply Volume

The engines used were mostly 4-stroke. Vessels of this Class visiting the maritime port of Larnaca had an average engine power of 6.389 kW and their average service speed was at 11.2 knots.

The typical engine model that was selected, came from Wärtsilä, which is 12V50DF. This engine model delivers 11.700 kW at 514 rpm with specific consumption 7.258 kJ/kWh≈134.4 gr/kWh. [Hans Otto Kristensen, September 2012]

In addition to this, the typical distance that was assumed for a vessel, which needs to move from one port another and carry out refuelling procedures, was approximately 500 nautical miles. The time required for a typical vessel of this Class to cover this distance is slightly more than 45 hours.

Therefore, the required fuel supply amount is 38.42 tons≈85.37 m^3 LNG.

4.3.5 Larnaca Port's Vehicle Carrier Sector Overview

In 2016, the maritime port of Larnaca had 2o calls from 17 Vehicle Carrier Vessels. In order to be able to make a better estimation of the vessels' profile that visited the port in the reference year of 2016, the vessels were divided in two categories according to the criterion of their load capacity in numbers of cars. The figure below depicts the frequency of the vessels according to their car capacity.

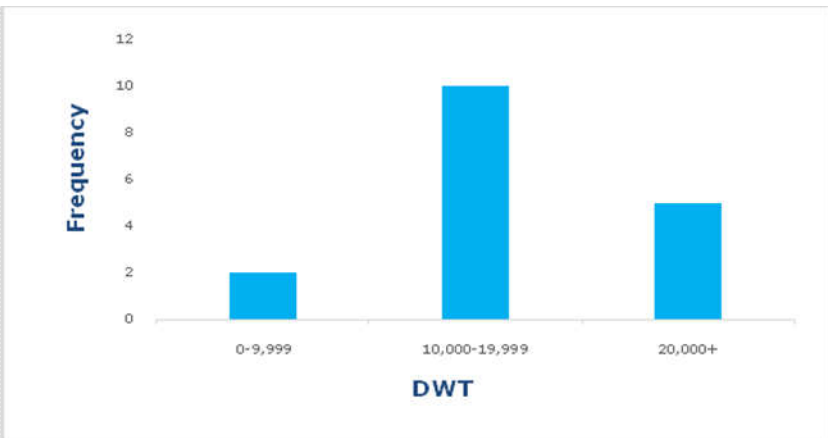


Figure 18: Frequency of Vehicle Carrier vessels at the Larnaca port by car capacity.

By selecting as criterion, the car capacity, the sample was divided into two main categories:

- Class A (≤6.499 cars), and

- Class B (≥6.500 cars)

As it can be observed from the below figure, the number of vessels of Class B is about little more than the vessels of Class A. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] However, both Class A and Class B have approximately the same number of calls, 9 and 11 calls respectively. The figure below shows the percentage of all vessels belonging to each Class.

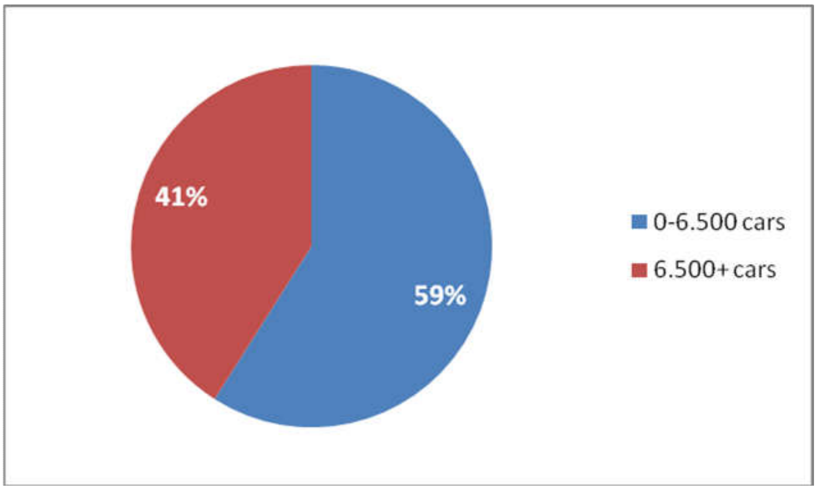


Figure 19: Percentage of Vehicle Carrier vessels in each category at the Larnaca port for the year 2016.

4.3.5.1 Vehicle Carriers ≤ 6.499 cars

The figure below depicts the distribution of vehicle carrier vessels' calls up to 6.499 cars capacity, namely Class A, as a function of age. The average age was close to 16 years.

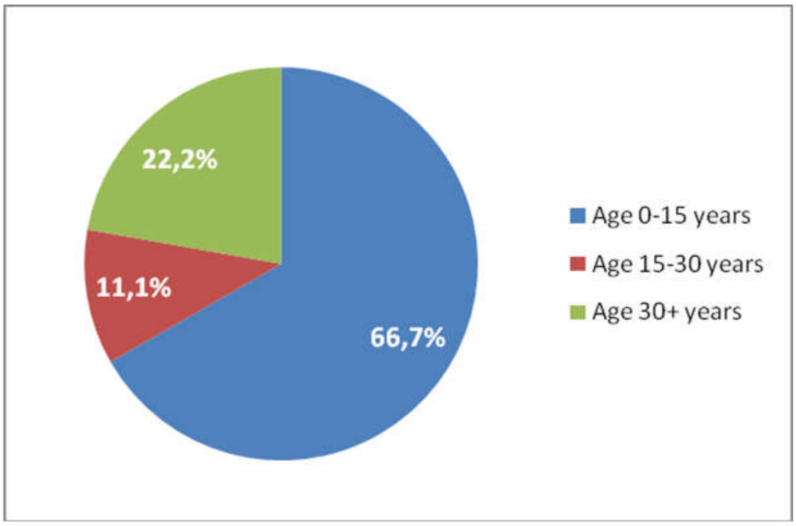


Figure 20: Percentage of arrivals for Vehicle Carrier vessels up to 6.499 cars by age group**.**

It is observed from the above figure that the majority of the calls, 67% was made by vessels up to 15 years old, while vessels over 30 years old exhibit the second highest percentage, 22%. Finally, vessels aged between 15-30 years old represent 11% of the calls.

What is more, the age of ships, which is ideal for using LNG fuel in this Class of Vessel is up to 15 years. It is notable that all these vessels made a total of 6 calls in the reference year of 2016 representing 66.7% of the total calls at the maritime port of Larnaca.

Estimated LNG Supply Volume

Regarding the estimated LNG supply volume, the engines used were mostly 4-stroke. Vehicle carriers of Class A that visited the port of Larnaca had an average engine power of 11.082 kW and their average service speed was at 12.9 knots.

A typical engine model 12V50DF came from Wärtsilä, which delivers 11.700 kW at 514 rpm with specific consumption 7.258 kJ/kWh≈134.4 gr/kWh.

The typical distance that we assumed for a vessel, which needs to move from one port to another and carry out refueling procedures is approximately 500 nautical miles. The time required for a typical ship of this Class to cover this distance is slightly more than 38.7 hours.

Therefore, the required fuel supply amount is 57.6 tons≈127.8 m^3 LNG.

4.3.5.2 Vehicle Carriers ≥ 6.500 cars

The figure below depicts the distribution of vehicle carrier vessels' calls over 6.499 capacity, namely Class B, as a function of age. The average age was close to 6 years.

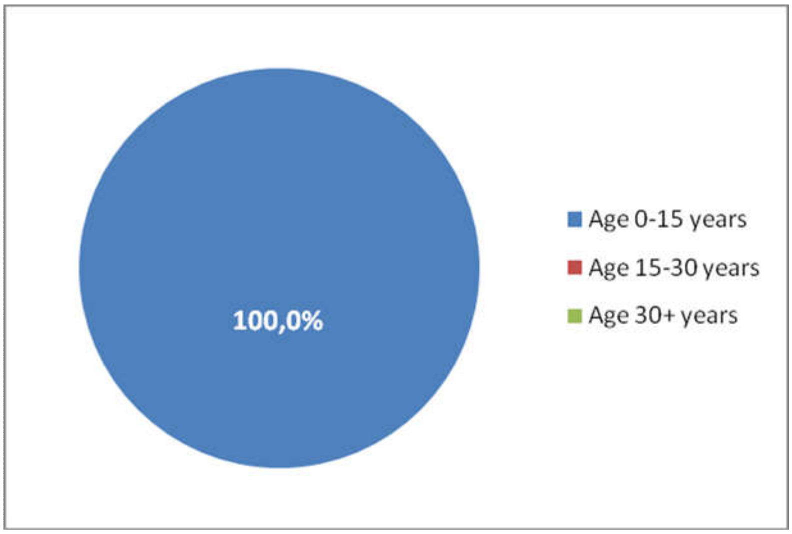


Figure 21: Percentage of arrivals for Vehicle Carrier Vessels ≥ 6.500 cars by age group.

From the above figure, it can be easily observed that all calls at the maritime port of Larnaca were made by vessels up to 15 years old. What is more, the ideal age for the vehicle carriers of Class B to adopt LNG fuel is up to 15 years. It is worth mentioning that all these vessels made a total of 11 arrivals in 2016 representing 100% of the total arrivals at the Larnaca port.

Estimated LNG Supply Volume

As for the estimated LNG supply volume, the engines used were mostly 4-stroke. Vehicle Carriers from Class B that visited Larnaca Port had an average engine power of 14.109 kW and their average service speed was at 15.75 knots.

A typical engine model 8S50ME-C8.2-GI-TII came from MAN SE to meet the needs, which delivers 13.270 kW at 127 rpm with specific consumption 7.403 kJ/kWh≈137.1 gr/kWh.

Moreover, the typical that was assumed for a vessel which needs to travel from a neighboring port until the next refueling point at the maritime port of Larnaca is approximately 1.000 nautical miles. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] The time required for a typical vessel of Class B to cover this distance is slightly more than 63.5 hours.

Therefore, the required fuel supply amount is 122.8≈272.6 m^3 LNG.

4.4 Larnaca and Vasilikos Ports: Estimated LNG volume for refueling

Regarding the estimated LNG demand at the port of Larnaca, it was mentioned that the reported calls reached the number of 952. This total refers to vessels of different types at a percentage of 47.9% corresponding to General Cargo Vessels, 46.2% corresponding to Tanker Vessels, 3.8% corresponding to Bulk Carrier Vessels and 2.1% to Vehicle Carrier Vessels. Based on these statistics, it was assumed that at least the same categories of vessels will in the future occupy the port. For the maritime port of Vasilikos, it should be noted that the reported calls reached the total number of 183 and this total referred to vessels of the same type.

In general, the potential LNG fuel demand is calculated by the combination of the previous assumptions with the technical and operational characteristics of the typical vessels of each category, The occurring LNG demand for each category, as well as the prediction for the total future LNG demand for the years between 2020-2025 and 2025-2030 will be presented in the following table.

More specifically, the expected LNG volume for refueling in the maritime ports of Larnaca and Vasilikos was calculated based on the following assumptions:

- The expected arrivals at the ports of Larnaca and Vasilikos for the under-study periods 2020-2025 and 2025-2030, were approximated for each vessel type and the subclasses of them according to their distinctive criteria of Classification. The number was based on the data provided by Statistical Service of Cyprus (CYSTAT) for the reference year 2016 for Larnaca Port and for the interval 2010-2016 for Vasilikos Port.

- The average fuel delivery volume was based on assumptions, which were set for each Class separately and have been analyzed in the above sections.

- The percentage of ships that will adopt LNG an as alternative marine fuel in order to comply with the environmental regulations set by European Union and IMO, has been selected for each Class separately and was based on assumptions regarding the capacity and age of each vessel.

- The number of ships carrying out refueling procedures at the ports of Larnaca and Vasilikos. In this thesis, it was assumed that the share of the ships carrying out refueling procedures is approximately 25-30% of the share of the total calls with ship age up to 15 years for each type of ship and its subclass for Larnaca port and 50% for Vasilikos Port. Based on the abovementioned parameters, the expected number of LNG bunker operations emerged for the periods 2020-2025 and 2025-2030 respectively and afterwards to the quantities of annual LNG demand in cubic meters for these two periods. Nevertheless, it is almost impossible to know the exact number of recharging ships that will refuel at the port, as they depend on various factors such as market development, fuel prices, competition with neighboring ports and other supply shipping service networks.

The results of this method are intended to lead to a preliminary recommendation for the equipment needed in the port. The following table shows the estimated LNG fuel demand for each ship type and its subclass apart in the Larnaca and Vasilikos maritime ports for the periods 2020-2025 and 2025-2030.

Ship Type	Expected number of Arrivals 2020-2025	Average supply amount (m^3)	Share of fleet that bunker LNG 2020-2025 (%)	Share of fleet that bunker LNG 2025-2030 (%)	Share of total calls with LNG bunker operations (%)	No. of LNG bunker operations 2020-2025	No. of LNG bunker operations 2025-2030	Annual LNG 2020-2025 (m^3)	Annual LNG 2025-2030 (m^3)
Small Tankers	332	91.15	27.35	68	30	27	68	2.482,83	6.207,08
Large Tankers	105	209.51	35.0	87.6	30	11	28	2.313,01	5.782,52
Small General Cargo	297	33.49	4.3	10.8	25	3	8	107,16	267,90
Large General Cargo	159	51.86	8.8	22.0	25	4	9	181,50	453,75
Small Bulk Carrier	27	40.88	31.1	77.8	25	2	5	85,84	214,61
Large Bulk Carrier	9	85.38	17.8	44.4	25	0	1	34,15	85,38
Small Vehicle Carrier	9	127.83	26.7	66.7	25	1	2	76,70	100,0
Large Vehicle Carrier	11	271.65	40.0	100.0	25	1	3	299,91	749,78

Table 2: Estimations for LNG demand as marine fuel in the port of Larnaca in 2020-2025 and 2025-2030.

Ship Type	Expected number of Arrivals 2020-2025	Average supply amount (m^3)	Share of fleet that bunker LNG 2020-2025 (%)	Share of fleet that bunker LNG 2025-2030 (%)	Share of total calls with LNG bunker operations (%)	No. of LNG bunker operations 2020-2025	No. of LNG bunker operations 2025-2030	Annual LNG 2020-2025 (m^3)	Annual LNG 2025-2030 (m^3)
Small Tankers	125	31	36.5	91.2	50	23	57	706.80	5.198,40

Large Tankers	58	196	35.7	79.31	50	10,35	23	2/025,23	1.823,66

Table 3: Estimations for LNG demand as marine fuel in the Vasilikos Port in 2020-2025 and 2025-2030.

The findings of the above table present that the overall bunkering operations by all types of vessels and each subclass of them at the Larnaca port will create an occurring LNG fuel demand of 5.581,10 m^3 during 2020-2025, while for the years during 2025-2030 the overall estimated LNG fuel demand for each ship type and its subclasses will be 13.952,76 m^3. Refueling procedures that will take place at the port of Larnaca will reach 49 during 2020-2025 and 123 during 2025-2030. The above estimations indicate a significant build-up of the annual LNG fuel demand.

It should be noted that small and large tanker vessels, will be the two Classes that will show the largest LNG demand during 2020-2025 reaching 2.482,83 m^3 and 2.313,01 m^3 respectively. In addition, for the years 2025-2030 the demand for the small tanker vessels is estimated to be 6.207,08 m^3, while for the large tanker vessels will be 5.782,52 m^3. These estimations resulted from the assumption that the share of total calls made by tanker vessels of both subclasses with LNG bunker operations is 30% as well as from their expected average LNG supply amount.

On the other hand, the smallest annual LNG demand for the years 2020-2025 will come from large bulk carrier vessels and small vehicle carrier vessels with 34.5m^3 and 76.70 m^3 respectively, while the LNG demand for the years 2025-2030 will reach 85.38m^3 and 100m^3, respectively.

Generally, the tanker vessels are expected to largely determine the demand for LNG fuel at Larnaca maritime port, as they are expected to consume more than 80% of the total annual demand. This is reasonable due to the fact that the tanker vessels had more calls compared any other vessels types' Classes that the port of Larnaca.

As regard the Vasilikos port, the finding of the above table depict that the overall bunkering operations by vessels will create an occurring LNG fuel demand of 2.732,03m^3 during 2020-2025, while for the years 2025-2030 the overall LNG estimated demand will be 7.022,36m^3. Refueling procedures that will take place at Vasilikos maritime port will reach 33 during 2020-2025 and 80 during 2025-2030. The above estimations indicate a significant build-up of the LNG fuel demand in a mid-term perspective.

More specifically, bunkering operations by small and large tanker vessels at Vasilikos port will create an occurring LNG fuel demand of 706.80m^3 and 2.025,23m^3 during the years 2020-2025 respectively, while both the small and large tanker vessels will create an annual demand of 5.198,40m^3 and 1.823,66m^3 of LNG fuel correspondingly during 2025-2030.

5. Supply Chain Analysis for LNG Bunkering at Ports of Cyprus

This section is dedicated to proceed with recommendations for logistics solutions and synchro-modal transportation means required in order to meet the estimated LNG fuel demand, for the under-study years 2020-2030 for both maritime ports of Larnaca and Vasilikos. In particular, this part of the thesis aims at dealing with an optimum solution concerning the important matter of transportation mean's selection and the number needed to cover the forecasted demand for both under study ports.

5.1 Assumptions

In other words, the basic criteria for selecting the appropriate equipment is the estimated volume required to provide LNG, the quantities that can be provided in each refueling process as well as the number of daily refueling procedures. [Λεωνίδας Ε. Χρυσίνας, , Ιούλιος 2013] It should be noted that the estimations for the daily number of refueling was based on the overall number of arrivals for the third quarter of the year, assuming a 30% spike, as it constitutes the worst case-scenario that should be taken into account in the design process in order to meet all the supply needs.

Having factored in the above criteria and having technical and operational characteristics reports of each refueling equipment instrument, we have concluded that four LNG tanker trucks of a capacity 40m^3 each, should be utilized in order to undertake the LNG bunkering process in both ports for the reference years of 2020-2025. Since the LNG demand is expected to grow during the years 2025-2030, three more LNG tanker trucks of a capacity 40m^3 each will be required, in order to handle the bunker volumes of the largest vessels.

The assumption that was taken into consideration was that the LNG tanker trucks will be based in Vasilikos port, where a LNG import facility is planned to be constructed in the following years. [EU CO-FUNDED POSEIDON MED I - COSTA II East] They will be loaded with the required fuel quantity in order to supply the vessels calling not only at Vasilikos port but also at Larnaca maritime port. The LNG tanker trucks will return back to the port where they will remain at stand-by mode for the next trip.

The typical time required by the specially designed LNG Tanker Trucks, to cover this distance from one port to another in order to distribute the LNG fuel, is about fifty minutes with an average speed of 70km/h (47.1 km distance from Larnaca to Vasilikos). As for the technical and operational characteristics of the LNG tanker trucks, their loading capacity/transfer rate is approximately 60m^3 per hour and the required time is 0.83 minutes to load their tank. In particular, the total LNG bunkering timeline for LNG tanker trucks lasts 215 minutes. [PROJECT 2018, BlueHUBS] More specifically, the trucks need 50 minutes to transit to the vessel, 10 before minutes before the process of bunkering, 50 minutes during the bunkering procedure, 5 minutes after the end of bunkering, 50 minutes for the LNG tanker trucks in order to return to the refueling point and 50 minutes for their replenishment. Ultimately, the maximum number of replenishments per day is approximately 13.95 and the average LNG bunker delivery size is about 697.7 m^3 per day.

5.2 Cost of Supply Chain

The aim of this subsection is to provide a preliminary analysis of the proposed investment. The following general assumptions were used in this thesis:

- Economic lifetime of the proposed investment: 30 years
- Economic lifetime of the LNG Tanker Trucks: 10 years
- Weighted Average Cost of Capital: 8%
- The initial does not include taxes.

The initial investment cost for the four LNG tanker trucks was estimated to be 1.300.000 €, based on current market data. It should be noted that cost estimate was made on constant prices of 2019. [Ελευθερίου Αμαλία, Σεπτέμβριος 2017] As we have already mentioned above, these trucks will be introduced in the port of Vasilikos as a starting point in order to cover the estimated annual LNG fuel demand for this period for both maritime ports of Larnaca and Vasilikos. However, three more trucks will be added in the years 2025-2030 for the needs of these two ports and the cost of the additional investment will be 975.000 €. The total investment cost of the LNG tanker trucks for the period 2020-2030 will be 2.275.000 € in accordance with the estimated build-up of the annual LNG fuel demand as time goes by. As concerns the operational costs for the LNG tanker trucks for the period 2020-2025, these were estimated to be 2.215.620 € and with the estimated build-up of the LNG fuel demand in the ports of Larnaca and Vasilikos will reach the amount of 3.535.623 € in the interval 2025-2030.

To be able to proceed with a preliminary economic evaluation of the proposed investment, the cash inflows and outflows should be determined. The criterion of the payback period will be used in order to evaluate the proposed investment. The desired payback periods for which calculations were based 5, 10, 15, 20 and 25 years.

The figure below depicts the evolution of the additional price per ton of LNG for the examined number of depreciation years. It can be observed that in order to amortize the initial investment in the first 10 years, the LNG sale price to the end users should be 498.5 € per ton. Meanwhile, the final delivery price of LNG fuel, HFO and MGO at the maritime ports of Larnaca and Vasilikos were estimated to be approximately 498 €/ton, 341 €/ton and 563 €/ton (approximate bunker prices of November 2019 provided by www.shipandbunker.com).

Cost per ton of LNG for 5 years repayment (€/ ton LNG)	543.8
Corresponding internal rate of return (%)	15%
Cost per ton of LNG for 10 years repayment (€/ ton LNG)	496.4
Corresponding internal rate of return (%)	11%
Cost per ton of LNG for 15 years repayment (€/ ton LNG)	469.5
Corresponding internal rate of return (%)	9%
Cost per ton of LNG for 20 years repayment (€/ ton LNG)	428.2
Corresponding internal rate of return (%)	4%
Cost per ton of LNG for 25 years repayment (€/ ton LNG)	396.4
Corresponding internal rate of return (%)	1%

Table 4: Estimated economic results without taking into account the time value of money.

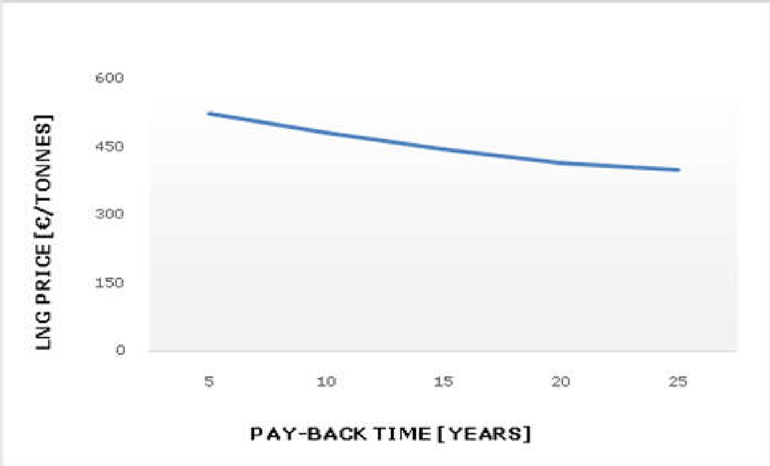
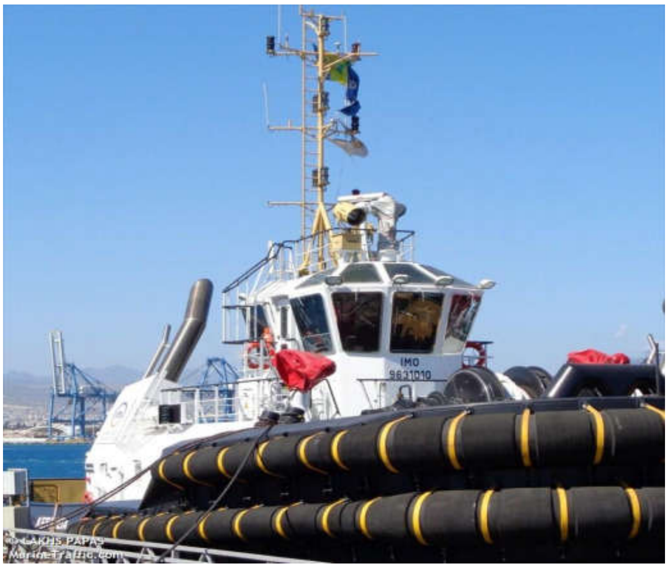


Figure 22: Price per ton of LNG fuel as a function of depreciation years.

6. Financial Analysis for Vessel's LNG Retrofit Evaluation

This section of the specific thesis aims at evaluating the feasibility of a potential investment on the tugboat Keryneia-Ammochostos by retrofitting its two main engines (2x Caterpillar 3516C HD+TA/D engine models with 2.500Kw power for each of them). More specifically, this analysis that will be conducted aims to determine whether LNG as a marine fuel is financial attractive from the point of view of the end user, which is Keryneia Ammochostos tug in the present case. Keryneia/Ammochostos is a utility/escort tug, built in 2014 with hull number 512503 at the Damen Group's Shipyards in South Holland, and owned by V.T.S Vasilikos Tugboat Services. Her loading capacity is 200 tons in number of Gross Tonnage (GRT) and is equipped with Fi-Fi 1 capability. The vessel operates on Cypriot territorial waters from the maritime port of Vasilikos. In particular, in the abovementioned area that the tug sails, she mainly performs escort and stand-by duties to future NG marine fields of Cyprus. She covers approximately a total distance of 80 nautical miles per roundtrip trip, She sails regularly depending on escort demands to a plethora of Cyprus' ports, including the under study maritime port of Larnaca. The duration of the roundtrip lasts 12 hours at the current HFO (Heavy Fuel Oil) situation with an average service speed of 7 knots.



Picture 1: Keryneia Ammochostos escort and utility tugboat **Source:** www.marinetraffic.com

The general technical particulars of the utility/escort tug Keryneia/Ammochostos are shown in the table below:

L.O.A (m)	**32.7**
L.B.P (m)	26.2
Beam (m)	12.82
Depth (m)	5,35
Deadweight/Draft (t)	200/5,36
Main Engine	2x Caterpillar 3516C HD+TA/D @2.500Kw each at 1.800 RPM
Main Generators	2x Caterpillar C6.6 HD+TA, 230/400V @205Kw each
Service Speed (knots)	7.0
Gross Tonnage (tons)	440 tons GRT

Table 5: Technical specifications of the escort tugboat Keryneia/Ammochostos.

According to the date provided by the EU Poseidon Med II project, the tug operates constantly during a year and more specifically 250 days per year, with almost none idle days. The tugboat is powered by 2x Caterpillar 3516C HD+TA/D @2.500Kw each at 1.800 RPM main diesel engines and 2x Caterpillar C6.6 HD+TA, 230/400V @205Kw each generator as auxiliary engines.

As estimations that will be used based on experts' opinion, the estimated specific fuel consumption for HFO, LSHFO and LNG is given in the table below.[PROJECT 2018, BlueHUBS] It should be noted that for the scrubber solution, it was assumed that the specific fuel consumption is 3% higher than the HFO specific fuel consumption.

Specific Fuel Consumption of ME (g/kWh)	
HFO	199,00
LSHFO	201,00
LNG	150,00

Table 6: Estimated Specific Fuel Consumption of Main Engines

6.1 Financial Analysis

The financial analysis that will be conducted in this thesis is based on the Cost-Benefit-Analysis Guide for Investment Projects which was used as the model economic tool appraisal tool for Cohesion policy 2014-2020, published on December 2014 by European Commission-Directorate-General for Regional and Urban Policy. The aim of this financial analysis is to evaluate the financial profitability of abovementioned LNG retrofit investment in order to determine whether LNG as an alternative marine fuel is financially attractive for the utility/escort tugboat Keryneia/Ammochostos. More specifically, the analysis mainly concentrates on the operational profile with regard to fuel consumption and the engine system costs. In addition, it should be noted that no revenues from freights are considered in the analysis but the cash inflows derived from the difference on the operating costs of the under-study vessel.

Firstly, the CBA proceeds by identifying the project investment that should be assessed and its respective costs and benefits, along with its alternatives and their respective costs and benefits. [Guide to Cost-Benefit Analysis of Investment Projects, December 2014] Following that, the project with the larger investment becomes the project against which the comparison is made. It should be noted that in our case we have mutually exclusive project investments, which means that by accepting one the other is immediately rejected. The financial analysis was conducted in line with European Commission's recommendations, used as a general guide to cost benefit assessment of investment projects.

Within the operating period, costs and benefits (project cash flows) for each year were determined and discounted on 2019 constant prices, using the discounted cash flow method. The project's profitability was calculated by using indicators of financial decision making such as the Net Present Value (NPV), the Internal Rate of Return (IRR), the Modified Internal Rate of Return (MIRR), the Payback Period (PP) as well as the Discounted Payback Period (DPP) and finally, the Profitability Index (PI). Below is given a brief introduction to the aforementioned financial indicators.

The Net Present Value (NPV) indicator is the difference between the present value of cash inflows and the present value of cash outflows that occur as a result of undertaking an investment project over a period of time. A positive net present value shows that the projected earnings generated by an investment exceed the anticipated costs and therefore the project is acceptable. On the other hand, if the net present value is negative the project should be rejected. The method can also be used to select between mutually exclusive projects. By using NPV, the project with the highest NPV would be ranked first and that project should be selected against the alternatives with lower NPV indicators.

The Internal Rate of Return (IRR) indicator is the discount rate at which the net present value of an investment becomes zero. More specifically, it is the discount rate which equates the present value of the future cash flows of an investment with the initial investment. It should be noted that if the IRR promised by investment project is greater than or equal to the minimum required rate of return, which in our case is 4% (percentage determined by EU Commission for large project investments), the project is considered acceptable otherwise the project is rejected.

The Modifies Internal Rate of Return (MIRR) indicator assumes that positive cash flows are reinvested at the company's cost of capital, and the initial outlays are financed at the company's financing cost. By contrast, the IRR assumes that the cash flows from a project are reinvested at the IRR. In addition to this, the MIRR is used to rank investments or projects or unequal size.

The Payback Period (PP) indicator measure the length of time it takes a company to recover its initial investment. It can also be explained as the length of time it takes the project to generate cash equal to investment and pay the company back. It should be noted that the shorter the payback period, the sooner the company recovers its cash investment.

The Discounted Payback Period (DPP) indicator is the time needed to pay back the original investment in terms of discounted future cash flows. More specifically, each cash flow is discounted back to the beginning of the investment at a rate that reflects both the time value for money and the uncertainty of future cash flows. If the discounted period is less than the target period, then the project is accepted, otherwise is rejected.

The Profitability Index (PI) or Benefit Cost-Ratio (B/C) is actually a modification of the present value method. It divides the projected capital inflow by the projected capital outflow to determine the profitability of the project. If the PI is greater than one, the project is accepted, otherwise the project is rejected.

For the purpose of the conducted financial analysis, the following key assumptions were adopted: [Guide to Cost-Benefit Analysis of Investment Projects, December 2014]

- The analysis was performed not including VAT and Taxes;
- All cash flows generated by the project during the observed period have been stated in Euros (EUR);
- The analysis was performed for reference period of 25 years;
- The analysis was conducted by using constant (real) prices of 2019 without inflation;
- A financial discount rate of 4.0% was used based on the European Commission's recommendation (EU benchmark);
- Contingencies were excluded from the financial analysis;
- The economic life time of the vessels was set at 30 years.

6.1.1 Capital Expenditures

It should be mentioned that the Keryneia/Ammochostos tugboat currently operates with HFO while under specific circumstances (maneuvering, warm-up, loading-unloading, idling) she also uses HFO. Considering LSHFO as a marine fuel, it was assumed that there is no investment cost for retrofitting Keryneia/Ammochostos tug to operate with LSHFO fuel. However, an investment cost is required for using LNG as a marine fuel or to continue using HFO with scrubber technology. [Ιωάννης Γ. Γλύπτης, 2017] The number of engines that must be retrofitted in order to combust LNG fuel is equal to the number of engines that operate on a daily basis when she is at sea. It is worth mentioning that the cost of crew training and the profit loss due to retrofit were assumed to be parts of the LNG and Scrubber investments and they were not calculated as operating costs. Furthermore, Keryneia/Ammochostos vessel, as an escort/utility tugboat will not lose incomes due to space reduction in the case of retrofitting with LNG fuel, because it has a supporting role and does not carry cargo or passengers in order to have profit loss. The investment cost for each alternative solution is shown in the table below:

CAPEX – Investment Cost	
Retrofit/Re-engine Cost	
Scrubber	4.000.000 €
LSHFO	0 €
LNG	4.400.000 €
Number of ME retrofitted	
Scrubber	2
LSHFO	2
LNG	2
Days Spent on Retrofit	
Scrubber	20
LSHFO	0
LNG	14
Daily Profit Loss Due to Retrofit	
Scrubber	6.000 €
LSHFO	0 €
LNG	4.200 €
Daily Profit Loss Due to Space Reduction	
Scrubber	0 €
LSHFO	0 €

LNG	0 €
Cost of Crew Training	
Scrubber	5.000 €
LSHFO	0 €
LNG	6.500 €

Table 7: Capex Estimations used for the financial analysis of Keryneia/Ammochostos tugboat.

6.1.2 Operating Costs and Revenues

The analysis also considers that the operational costs, also called voyage costs, of each one of the alternative fuels and technologies, based on which the incremental analysis produces the benefits or costs of the comparison of different scenarios, Operational costs constitute the fuel consumption, the fuel system maintenance cost and the daily profit loss due to space reduction, which applies only for the LNG scenario. Regarding the daily profit loss due to space reduction and the tugboat Keryneia/Ammochostos in case of retrofitting with LNG fuel, its space will be reduced in store rooms and void spaces, nevertheless the vessels will not lose incomes, wherefore it has an invasive role and does not carry cargo or passenger in order to have profit loss. On the contrary, the calculation of daily profit loss of Keryneia/Ammochostos tug due to retrofit of its main and auxiliary engines was based on mean charge price of 300 € of an operation for tugboat services (data provided by MESBAS Tariff Port Services).

The net present value of LNG scenario for Keryneia/Ammochostos presents a negative value and shows that the project should be rejected, because the projected earnings generated by LNG investment do not exceed the anticipated costs. [Ocean Finance Ltd., CBA REPORT, February 2016] This negative NPV results mainly from the higher initial retrofit/re-engine cost than Scrubber technology solution, its daily profit loss due to space reduction and retrofit and the costs of crew training. Nevertheless, the LNG scenario still constitutes a cost-effective solution for the Keryneia/Ammochostos escort/utility tug under specified conditions in comparison with other fuels, inasmuch the LNG bunker fuel price in Cyprus is estimated to be quite low (278 € per ton according to quarterly EU energy market reports of 2019) compared to other fuels' prices and the LNG scenario offers high environmental performance for Keryneia/Ammochostos tugboat in combination with long-term benefits that counterbalance the economic cost of the LNG initial investment. Supplementary, it is indicated that the LNG scenario has the least negative NPV in comparison with the solutions of LSHFO fuel and Scrubber Technology, an assumption that in combination with the abovementioned reasons makes the LNG scenario more financial attractive in the longer term compared to LSHFO solution. Based utterly on the criterion of NPV, the LNG scenario seems to be more financial attractive than Scrubber technology solution, when compared to each other.

On the other hand, the scrubber technology does not create any space reduction on vessel's spaces. The waste produced by the operation of scrubber consists one of the most important operating costs that should be managed and disposed of at the port. However, this cost has not been included in the analysis due to lack of data. Likewise, in case of switching the current state of fuel HFO to Low Sulphur Heavy Fuel Oil we don't result to the vessel's space reduction because of this retrofit.

The fuel consumption cost was calculated based on the bunker price in the Port of Piraeus. Namely, the LNG (Liquified Natural Gas) fuel bunker price is calculated to be 12.5% below the price of Heavy Fuel Oil (HFO) at the Piraeus maritime port, according to DNV-GL's study on March 2016. In this bunker price of LNG fuel, we must factor into an extra 10% transport cost for the final price of LNG bunker price, that it was used in this thesis. [American Petroleum Institute (API), 2016] Fuel cost is beyond question the biggest contributor of cost for a ship owner and can represent between 50% and 60% of the total operating costs of any shipping activities. In addition to this, this cost ranges the most from one strategy to the next and plays a crucial role in the decision of the most financial attractive solution from the point of end user. Therefore, the LNG fuel cost depends on the selected supply chain and is thereby also highly influenced by the long-term strategies and market prospects for future demand. On the other hand, the most significant hurdle for the establishment of an LNG bunkering market in the European maritime ports is the level of uncertainty of the actual LNG bunkering price and the relatively price compared to other bunkering fuels.

OPEX-Operating Expenses	
Bunker Price	
HFO	318 €/ ton
LSHFO	496 €/ton

LNG	278 €/ton
Fuel System Maintenance Cost	
HFO	44.000 €
SCRUBBER	46.000 €
LSHFO	25.000 €
LNG	26.000 €
Daily Loss due to Space Reduction	
SCRUBBER	0 €
LSHFO	0 €
LNG	0 €

Table 8: Opex estimations used for the financial analysis of Keryneia/Ammochostos tugboat.

The below table depicts the operating costs of Keryneia/Ammochostos tug using HFO, as well as the operating costs of vessel using the proposed alternative solutions, based on five main situations : sailing, maneuvering, warm-up, loading-unloading and idling.

Operational Costs of Main Engines					
	Sailing	Maneuvering	Warm-up	Loading-Unloading	Idling
HFO	385.624,69 €	15.755,50 €	12.462,00 €	0,00 €	0,00 €
LSHFO	607.522,50 €	15.755,50 €	12.462,00 €	0,00 €	0,00 €
SCRUBBER	512.880,83 €	15.755,50 €	12.462,00 €	0,00 €	0,00 €
LNG	254.109,38 €	15.755,50 €	12.462,00 €	0,00 €	0,00 €

Table 9: Estimated operational costs of main engines of Keryneia/Ammochostos tugboat.

What is more, the use of alternative fuels creates future benefits in cash flows in terms of fuel cost and OPEX. This can be attributed to significant cost savings with bunker fuel playing a leading role. Therefore, the benefits derived from operational costs are considered as cash inflows, while loan repayments are considered as cash outflows for each project in the analysis that was conducted with the aforementioned assumptions. The table below depicts the benefits or costs derived from the proposed alternative solutions. As it can be observed from the following table, the use of LNG instead of conventional fuel (Heavy Fuel Oil or

Marine Gas Oil) results to cost savings of 131.515,31 € per year when the utility /escort tu gis at sea.

Operational Costs of Main Engines					
	Sailing	Maneuvering	Warm-up	Loading-Unloading	Idling
LSHFO	221.897,81 €	0,00 €	0,00 €	0,00 €	0,00 €
SCRUBBER	127.256,15 €	0,00 €	0,00 €	0,00 €	0,00 €
LNG	-131.515,31 €	0,00 €	0,00 €	0,00 €	0,00 €

Table 10: Estimated operational Costs for the three alternative solutions.

6.1.3 Sources of Financing

Concerning the LNG investment on Keryneia/Ammochostos tugboat, the project can be eligible for financing under the Connecting Europe Facility Transport 2014-2020, a financial instrument that provided incentives for the promotion of LNG-fuelled vessels. [EU CO-FUNDED POSEIDON MED I - COSTA II East] More specifically, the investment addresses the objectives of the Priority Innovation and New Technologies and can apply for the maximum co-funding rate, which is 20%. Therefore, the financial profitability was assessed using an assumption the co-financing rate of the relevant priority axis to be 20%.

What is more, it was assumed that in order the project to be financed, the ship-owner will contribute with own funds by 55% of the initial investment cost, while the rest of the investment will be covered by a loan, 25% corresponding to foreign capital. The loan is assumed to be fully repaid after a duration of 10 years with a fixed annual interest rate of 4%. The financing structure of the project is described in the below table:

LNG Investment		
Financing Sources	**m EUR**	**% share**
EU Grant	893.060,00	20%
Private Contribution	2.455.915,00	55%
Private Loan	1.116.325,00	25%
Total Funding	**4.465.300,00**	**100%**

Table 11: Funding Scheme for the implementation of LNG retrofit investment for Keryneia tugboat.

Concerning the investment cost on scrubber technology, i twas assumed that the ship owner will contribute with own funds by 45% of the initial investment, while the rest of the investment will be covered by a loan, 55%. The loan is assumed to be fully paid off after a duration of 10 years with a fixed annual interest rate of 4%. The scrubber technology investment is not eligible for financing under the Connecting Europe Facility Transport 2014-2020. [Ocean Finance Ltd., CBA REPORT, February 2016] Therefore, it is not predicted any Grant by European Commission or state owned entity the installation of scrubber technology to Keryneia/Ammochostos tugboat. The financing structure of the scrubber investment is depicted below:

Scrubber Technology Investment		
Financing Sources	**m EUR**	**% share**
Private Contribution	1.856.250,00	55%
Private Loan	2.268.750,00	25%
Total Funding	**4.125.000,00**	**100%**

Table 12: Funding Scheme for the implementation of Scrubber Technology investment for Keryneia tugboat.

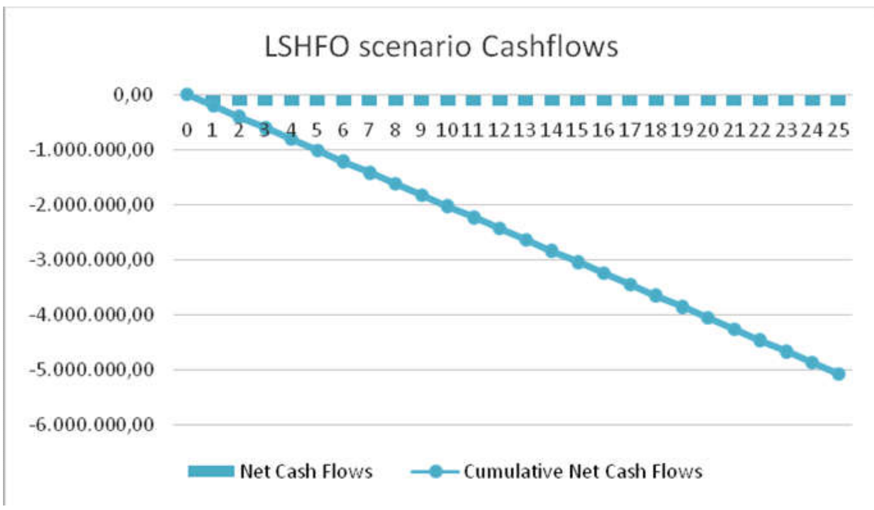
BRIEF RESULTS OF THE FINANCIAL ANALYSIS

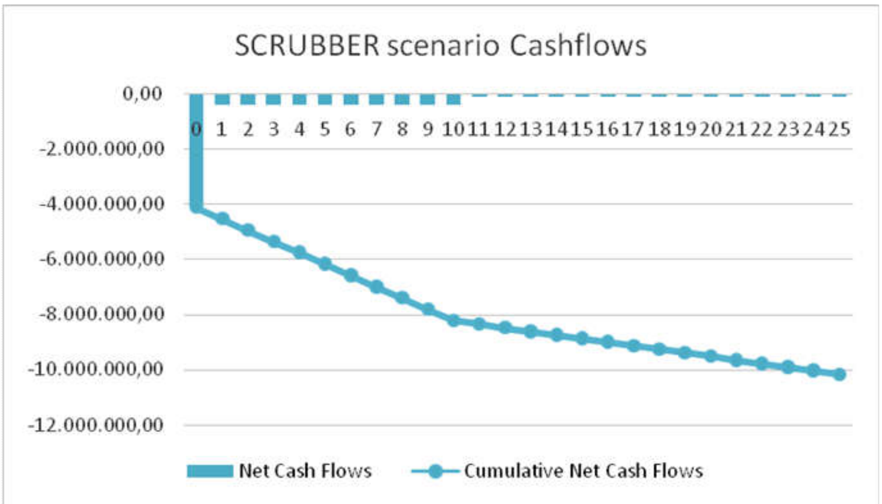
Based on the abovementioned inputs and assumptions, the folowing results derived from the conducted analysis.

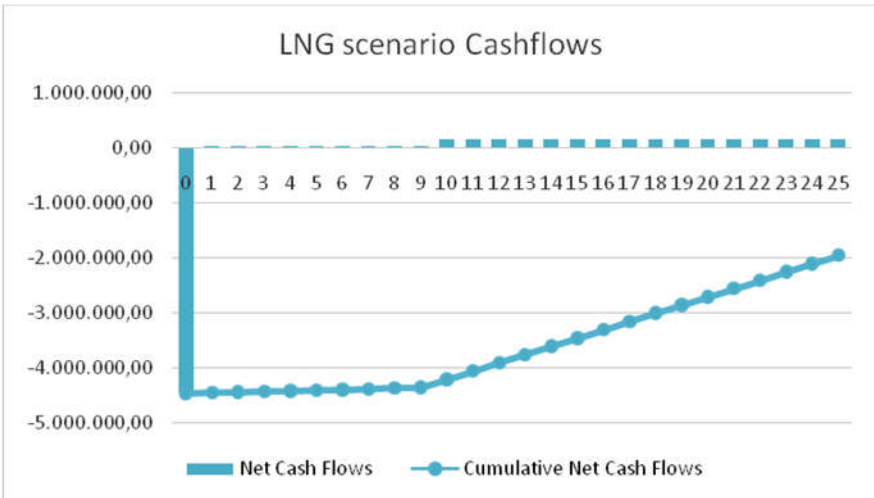
INDICATORS	LSHFO	SCRUBBER	LNG
NPV	-3.169.685,85 €	-8.412.999,87 €	-3.152..905,05 €
IRR	-	-	-3%
MIRR	-100%	-100%	-1%
Payback period	25.00	25.00	25.00
Discounted Payback Period	25.00	25.00	25.00
Profitability Index	**-**	-1.04	0.29
Spread	-178.00	0.00	40.00

Table 12: Consolidated results of the financial analysis for the three alternative solutions for Keryneia tug**.**

The above table illustrates the results derived from the comparison between the current state of fuel (HFO) with the alternative solutions such as Low Sulphur Heavy Fuel Oil, Liquified Natural Gas and Scrubber Technology. As it can be easily observed, cause the LNG solution requires an investment cost 1.1 times more than the scrubber investment cost and it disposes higher daily profit loss due to retrofit and space reduction, the LNG solution for Keryneia/Ammochostos tug presents a neagtive NPV, indicating that the earnings of the project do not exceed the anticipated costs and therefore the investment should be rejected. Moreover, the IRR and MIRR are negative and lower than the financial discount rate (4%) and it has neither payback period nor discounted payback period, indicating that the investment should not be acceptable for this tugboat. Finally, the profitability index is shorter than one, indicating that the use of LNG as a marine fuel pays back 0.29 EUR of 1 EUR invested, due to its investment costs compared with LSHFO solution and displays that the investment should be rejected. Nevertheless, in comparison with other scenarios, the LNG solution produces the least negative NPV and in combination with the fact that the LNG bunker fuel price is estimated to be quite low (278 € per ton due to the penetration of LNG in Cyprus that is an emerging energy market) compared to other fuels' prices and its numerous environmental beneftis that comply with the existing and upcoming IMO regulations for the reduction of ship emissions, it still remains under specified conditions a cost-effective solution. The figures below depict the cash flows of each one of the proposed alternative solutions.





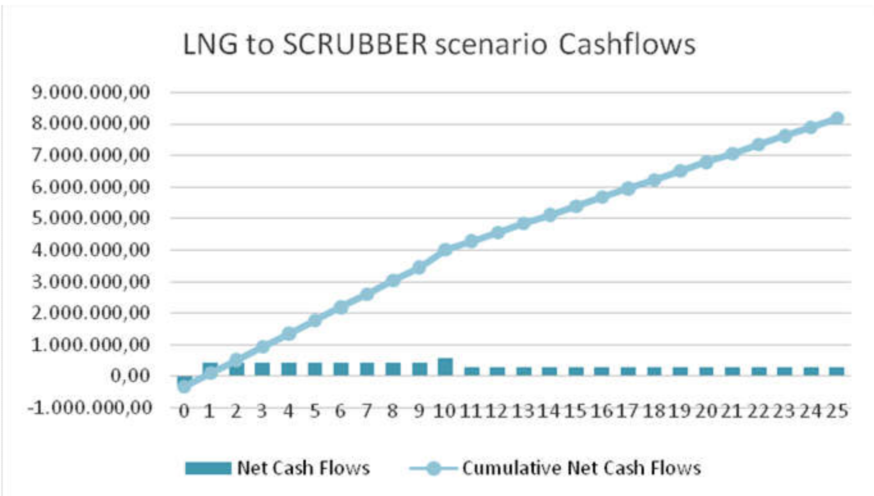


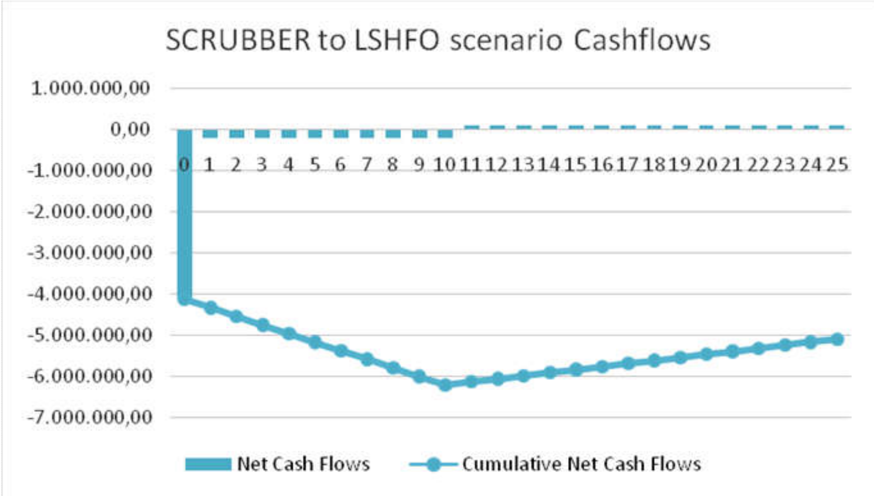
On the other hand, when comparing alternative solutions to each other, the investment on LNG as marine fuel, based utterly on the criterion of net present value, although it is negative, it remains marginally more cost-effective comparing to both scrubber and LSHFO solutions, as a result of the increased operational costs derived from the use of LSHFO and Scrubber Technology, especially due to the high bunker price of LSHFO and HFO fuels. Specifically, the payback period of the investment on LNG comparing to Scrubber Technology is 0.81 years and the discounted payback period is 0.84 years, which is lower than tug's estimated remaining life (26 years remaining life for Keryneia/Ammochostos tugboat), while comparing to LSHFO the payback period and the discounted payback period are 16.19 and 24.87 years respectively, indicating that the company recovers its cash investments after a long period and therefore LNG investment compared to LSHFO scenario is not financial attractive for the tugboat Keryneia Ammochostos. Nonetheless, based on criteria of NPV, estimated bunker fuel prices in Cyprus and environmental benefits, the LNG scenario seems to be a more financial attractive investment and displays economies of scales in longer term compared to LSHFO solution and Scrubber Technology scenario.

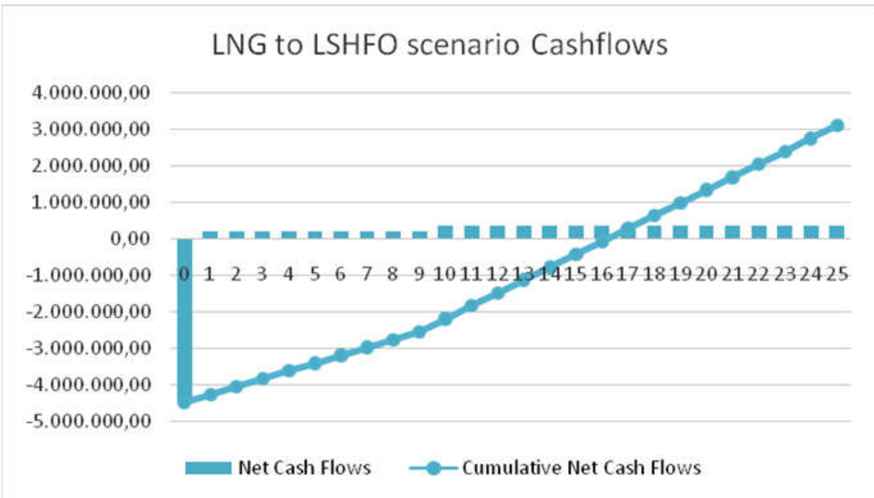
The IRR and MIRR financial indicators of the alternative solutions (LNG, LSHFO and Scrubber Technology) depict also that when comparing LNG to Scrubber, then LNG solution should be preferred since these indicators are above (compared to Scrubber technology) or equal (compared to the LSHFO solution) to the financial discount rate, which is 4%. What is more the profitability index of the investment on LNG compared to Scrubber is 16.46, while the profitability index of the investment on LNG compared to LSHFO is precisely 1.00, an assumption that in combination with the estimated lower fuel consumption cost and the numerous environmental benefits makes the LNG scenario more financial attractive.

INDICATORS	LNG vs SCRUBBER	SCRUBBER vs LSHFO	LNG vs LSHFO
NPV	5.260.094,82 €	-5.243.314,02 €	16.780,80 €
IRR	124%	-10%	4%
MIRR	16%	-5%	4%
Payback period	0.81	25.00	16.19
Discounted Payback Period	0.84	25.00	24.87
Profitability Index	16.46	-0.27	1.00
Spread	40.00	178.00	218.00

Table 13: Results of financial analysis for the three alternative solutions when compared to each other.







6.2 SWOT Analysis of the Proposed Solutions

Comparing the abovementioned alternative solutions for investments on Keryneia/Ammochostos escort and utility tug, a SWOT analysis for each of the three solutions has been conducted except for the finacial analysis. The key element of this SWOT analysis are illustrated in detail in the following figures.

SCRUBBER TECHNOLOGY SOLUTION – SWOT ANALYSIS	
STRENGTHS Environmentally friendly. Suitable Solution for old-aged vessels	**WEAKNESSES** High investment cost Loss of cargo room for vessels Expertised crew training
OPPORTUNITIES Effective Technology Solution for a short-term perspective Solution for maintenance of plethora of conventional vessels	**THREATS** No financial instruments for promoting the use of Scrubber No compatibility with IMO regulations after 2030

LSHFO FUEL SOLUTION – SWOT ANALYSIS	
STRENGTHS Environmentally friendly No retrofit needed for vessel No crew training for its adoption	**WEAKNESSES** High cost of fuel Inadequate number of supply points
OPPORTUNITIES Ideal fuel for vessels aged above 15 years Mixture with other fuels for engines operation	**THREATS** No financial instruments for promoting the use of LSHFO Competition with cleaner and zero-carbon fuels

LNG FUEL SOLUTION – SWOT ANALYSIS	
STRENGTHS Environmentally friendly Competitive LNG price Full compatibility with IMO Regulations and after 2030	**WEAKNESSES** Inadequate LNG infrastructure at the EU maritime ports Loss of cargo room for vessels Retrofit Needed for vessels
OPPORTUNITIES EU Grant for LNG Investments on Infrastructures and vessels Cleaner source of energy and market trends	**THREATS** Underdeveloped LNG infrastructure at ports No adequate financial incentives for investments on vessels Specialized crew for its use

7. Conclusions and General Findings

To sum up, it should be noted that the LNG fuel constitutes a credible alternative fuel under specific circumstances. Considering all the above, it is concluded that with the appropriate financial incentives such as a quite low bunker price of the fuel in conjuction with the radical development of the LNG infrastructure in the majority of the European maritime ports it could result into an effective altertnative solution for the shipowners in order to conform with the IMO and EU Commission' existing and upcoming regulations in the milestone year of 2020 and in a longer term perspective after 2030, when it is predicted that Mediterannean Sea will also be included in the Emission Control Areas (ECAs) or Sulphur Emission Control Areas (SECAs).

According to the results of the section of LNG demand analysis that was conducted, the demand of LNG fuel as marine fuel for the under-study years 2020-2030 at the maritime ports of Larnaca and Vasilikos, is estimated to be 34.771 cubic meters, as total LNG fuel demand for vessels. Specifically, at the maritime port of Larnaca 19.442,11 m^3 of LNG fuel will be needed for bunkering operations in the period of 2020-2030, while at the port of Vasilikos 15.328,90 m^3 of LNG fuel will be needed also for bunkering procedures in the under study years 2020-2030.

Generally, at the maritime port of Larnaca for the period 2020-2025, the number of LNG bunker operations is estimated to be 49 for all types of vessels and for the period 2025-2030 it will be 123. At the maritime port of Vasilikos in the period 2020-2025, the number of LNG bunker operations is estimated to be 33 for the tanker ships that constitute the whole fleet that arrives constantly at the particular port and for the period 2025-2030 it will reach 80 LNG bunkering operations.

Concerning the results of the financial analysis for Keryneia/Ammochostos tugboat, in general it can be concluded that even though the investment cost for LNG technology is at least 1.1 times higher than the initial cost of the Scrubber technology, which is counterbalanced through the contribution of EU Grant that is predicted only for LNG investments by EU Commission, the scenario of LNG constitutes the t most optimal economic option for the Keryneia-Ammmochostos escort and utility tugboat under specified conditions due to the abovementioned environmental benefits and its estimated low fuel bunker price compared to the current statet (HFO) and the alternative solutions of LSHFO and Scrubber Technology. However, a critical parameter that must be examined is that investment decision making is affected by many risk factors such as upgrading of technology, bunker prices' fluctuations, actions of competitors, regulations and legislations at both European and national level of the Member States, as well as the economic environment.

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