

Economic Assessment of LNG Bunkering in the Portuguese Coast and Atlantic Islands

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ABSTRACT: A transition to alternative fuels is one of the measures to prevent the evolution of climate change and the degradation of air quality. Since maritime transport is one of the most difficult modes of transport to be decarbonised and one of the largest responsible for emissions of pollutants highly harmful to the environment and to ecosystems, and Liquefied Natural Gas (LNG) used as a marine may improve this situation, ships are being designed and built to run on LNG. However, since it is a recent source of energy, when used as a ship fuel, there are many concerns about the economic feasibility of providing an LNG bunkering service. The main aim of this paper is to obtain conclusions about the economic feasibility of a LNG bunkering service to ships in the Portuguese coast and Atlantic islands, using a bunkering vessel based in the port of Sines. To achieve that goal this study focused on three crucial points: LNG demand forecast in the Portuguese coast and Atlantic islands, simulation of LNG bunkering operations to ships and an investment analysis. The main conclusion is that the demand forecasted for Portuguese ports is likely to be very low over the next years. In order to have a feasible LNG bunkering service, assuming the use of newly built dedicated bunkering tankers, it is concluded that port authorities and the national government need to grant economic support, at least at the early stages of this service.

Key Words: Sustainability, Maritime Transportation, Emissions, Bunkering, LNG, Cost.

1. INTRODUCTION

Mitigation measures should focus on all sectors, but mostly on those that contribute more for the degradation of the environment. In 2010 the transport sector contributed around 14% to Greenhouse Gases (GHG) emissions (IPCC, 2014). This sector continues to be one of the major sources of GHG emissions today.

Maritime transport is one of the modes of transport more difficult to be decarbonised (IEA, 2017). By 2050 it is estimated that maritime transport could be responsible for around 17% of total Carbon Dioxide (CO₂) emissions if new policies are not implemented (EEA, 2017).

Regarding the emission of other gases, transport sector is the one that most minimizes air quality, severely harming people's health and the environment. According to data collected from 28 countries from European Union Maritime transportation is the biggest responsible for Sulphur Oxide (SO_x) emissions, accounting for 17% of total emissions, and a major contributor to Nitrogen Oxide (NO_x) emissions, accounting for 19% of total emissions (EEA, 2017). It is estimated that of the fuel consumed by ships, engaged in international voyages, Sulphur Dioxide (SO₂) emissions reach around 90% of total emissions derived from transport sector (IEA, 2016).

It can be verified that, considering GHG emissions and gases that minimizes air quality, maritime transportation is one of the major contributors to environmental pollution and, therefore, where severe and effective measures must be applied, some of which already currently in force.

1.1. Regulations Applied to Maritime Transportation

The International Maritime Organization (IMO) is an international body mainly responsible for implementing measures on safety and environmental performance in maritime transport and shipping. IMO established

Emission Control Areas (ECAs) for SO_x and NO_x emissions. These areas are: Baltic Sea area, North Sea area, North American area (covering designated coastal areas off the United States and Canada) and United States Caribbean Sea area (around Puerto Rico and the United States Virgin Islands). The sulphur content in marine fuels is the one that has received increasing attention from IMO. Figure 1 shows SO_x regulations in marine fuels over the years.

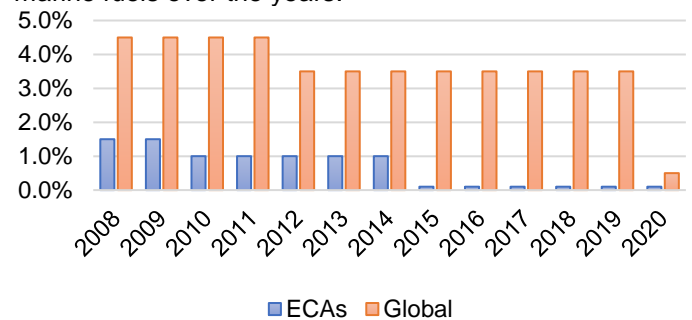


Figure 1 - SO_x regulations in marine fuels over the years (Resolution MEPC.176 [58]).

Currently sulphur content cannot exceed 0.1% and 3.5% inside ECAs and outside these ones, respectively. From 2020 the sulphur content will reduce to 0.5% globally.

Regarding NO_x emissions there are three Tiers (defined according to ship build data) intended to regulate ships that have installed marine diesel engines with output power greater than 130 kW. Tier III is the most severe, standing out of the rest. It should be noted that Tier III is only applied to vessels sailing inside ECAs while Tier I and Tier II are applied globally.

1.2. European Union Measures

European Union (EU) has been making efforts to comply with IMO regulations and to ensure improvements in air

quality. To this end EU has implemented different directives. Directive EU 2016/802 is relating to a reduction in the sulphur content of certain liquid fuels. Directive 2001/81/EC is related with national emission ceilings for certain atmospheric pollutants. Directive 2014/94/EU, and probably the one that encourages the most the entry of LNG into the maritime sector, is related with the deployment of alternative fuels infrastructure. It requires ports in the European Union to have in place refuelling points for LNG by 2025 and inland ports to have in place refuelling points for LNG by 2030.

1.3. LNG as a Ship Fuel

Natural Gas (NG) is an energy source essentially composed of hydrocarbon gas mixture, resulting from the decomposition and accumulation of organic matter. For use in maritime transport NG is first cooled and converted into Liquefied Natural Gas (LNG) through liquefaction plants. After the conversion process LNG is stored at approximately atmospheric pressure and at a negative temperature of around 160°C (EMSA, 2018).

There are several options to comply with the regulations applied to maritime navigation: use of marine fuels with reduced sulphur content, use of alternative fuels and use of methods to reduce emissions. LNG is an alternative fuel with highest potential to comply with maritime regulations, mainly due to more severe measures of SO_x emissions from 2020 and for ships under IMO Tier III (IMO, 2016). Table 1 aims to demonstrate a comparison between the different options to comply with current regulations.

Table 1 – Main advantages and disadvantages of LNG, reduced sulphur fuels and HFO + *Scrubber*, adapted from (IMO, 2016).

| Option | Advantages | Disadvantages |
|-----------------------|--|---------------------------------------|
| LNG | - LNG price - SO _x , NO _x , PM, CO ₂ | - Capital cost - Fuelling points |
| Low sulphur fuel | - Capital cost - SO _x , NO _x | - Fuel price - Tier III; SCR, EGR |
| HFO + <i>Scrubber</i> | - HFO price - Availability | - Maintenance - Tier III; SCR, EGR |

LNG is the option that produces lower emissions and is available at attractive prices. Figure 2 show the average emission reductions when compared to Heavy Fuel Oil (HFO).

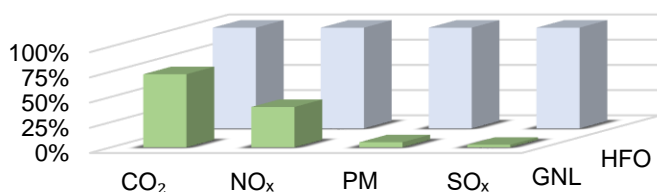


Figure 2 - LNG emissions reduction when compared with HFO (EMSA, 2018).

However LNG implies high capital costs and currently there are few refuelling points. Low sulphur fuels allow reductions in SO_x and NO_x emissions and the investment

does not suffer much difference when compared with conventional ships. However the fuel price is high and for ships under IMO Tier III it is necessary to adopt Selective Catalytic Reduction (SCR) or Exhaust Gas Recirculation (EGR). HFO+*Scrubber* is a widely used option since HFO price is low and there are no fuel availability issues. However it implies periodic maintenance actions and, as well as low sulphur fuels, it implies SCR or EGR when the ship is under IMO Tier III.

LNG can be burned permanently or be changed/mixed with another marine of fuel. The most common option is to change between other marine fuel, with vessels adopting dual-fuel engines. The main reason is the flexibility it presents, bypassing issues such as the absence of an adequate number of LNG filling stations and fuel price volatility. Currently 64% of the ships in operation use dual-fuel engine technology (DNV, 2018).

1.4. LNG Bunkering Methods

LNG bunkering process can happen through three different methods: Truck-to-Ship (TTS), Ship-to-Ship (STS) and Port-to-Ship (PTS). Figure 3 shows the three different LNG bunkering methods.

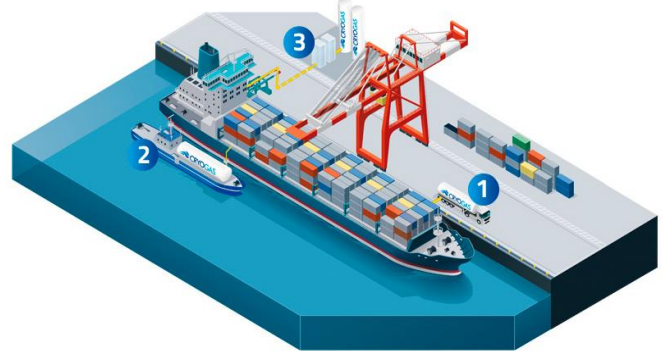


Figure 3 - LNG bunkering methods.

Numbers 1, 2 and 3 refer to the TTT, STS and PTS bunkering methods, respectively. The most appropriate LNG bunkering method depends on the characteristics and particularities of the LNG fuelled ships. Currently, TTS method is the most common due to the reduced investment in tanker trucks. However through this method the bunkering volume is low, typically around 50 and 100 m³ (EMSA, 2018). PTS method is the one that allows larger volumes of LNG to be supplied at a considerable velocity. However, it presents operational limitations when LNG is transported over long distances inside the port. In this method the bunkering volume is high, typically between 500 and 20,000 m³ (EMSA, 2018). STS method is the one that allows greater flexibility in the bunkering operation since LNG can be supplied to ships in different places. STS is characterized by a bunkering volume considerable, typically between 100 and 6,500 m³ (EMSA, 2018).

2. LNG DEMAND FORECAST

NG is a well-developed energy source. However, it is assumed to be a recent technology when used as ship fuel. For that reason the future demand of LNG is an uncertain. Although there are processes capable of

allowing predictions with satisfactory levels of accuracy, for a variety of subjects, when it comes to a new concept new doubts emerge and accurate results are difficult to be obtained.

2.1. LNG Demand Forecast in the Portuguese Coast

Since the data available for the Portuguese case is poor the best option is to elaborate different scenarios with the objective of identifying and quantifying different hypotheses that may become a reality. For the demand prediction in the Portuguese ports under study (Sines, Lisbon, Leixões, Funchal and Ponta Delgada) the following equation was created and implemented:

$$DLNG_{ijk} = Pen_{jk} \times F_k \times N_{ijk} \times P_{jk} \times T_k \times Q_k \quad (1)$$

Where,

$DLNG_{ijk}$ – LNG demand [m^3]

Pen_{jk} – Penetration of LNG in world fleet [%]

F_k – Correction for penetration of LNG in Portugal [%]

N_{ijk} – Number of ships calls in Portuguese ports

P_{jk} – Probability of bunkering [%]

T_k – Average tank size as function of ship type [m^3]

Q_k – Quantity of tank filled [%]

i – Port; j – Year; k – Ship type

It was decided to establish the year of 2030 as the reach of the forecast for 2 main reasons. The first one is because certain data must be assumed and the longer the scope the greater the likelihood of an accumulation of uncertainty. For that reason may not be possible to obtain reliable predictions after 2030. The second reason is because COSTA project (CID, 2014) only establishes the demand prediction for Portuguese ports until 2030. It is with the data given by this study that it is possible to establish a comparison with the results obtained through equation 1 and validate them.

- **Penetration of LNG in world fleet**

According to data given by different entities it is possible to state that in general the world demand in 2030 will be between 20 and 30 Million tonnes of LNG (Oxford Institute for Energy Studies, 2018). Table 2 shows the estimated newbuilds required to meet 2030 forecasts of LNG consumption in the marine sector, given by those entities.

Table 2 - Annual number of newbuildings required to meet estimated demand in the maritime sector, adapted from (Oxford Institute for Energy Studies, 2018).

| LNG demand in 2030 [Million tonnes] | 20 | 30 |
|--|------------|------------|
| Number of newbuilds per annum since 2020 | 170 400 | 255 600 |

It is noted that newbuilds are only considered to appear in 2020, the current number of LNG fuelled vessels in operation is enough to meet demand until the end of 2019. Knowing that currently there are 125 ships in operation (DNV, 2018), at the end of 2030 it is estimated to exist between 1,995 and 2,930 ships, according to a world demand of 20 Million tonnes, whereas in the same year it is estimated to exist between 4,525 and 6,725 ships, according to a world demand of 30 Million tonnes.

In order to verify if the number of LNG ships is within reasonable limits, it was decided to analyse other existing LNG fleet size forecasts. After comparison it is concluded that values given by Table 2 shows satisfactory levels of precision and are within reasonable limits.

Once the number of ships in operation is established for each year it is necessary to identify the number of newbuilds per ship type. For this it is assumed that new constructions follow the existing percentage of ships in operation and ordered. This information can be easily obtained in DNV (2018). Finally, the world fleet size was searched. The reference year is 2016 in which there was a world fleet size of 89,804 ships (EMSA, 2006-2016). It is assumed that between 2016 and 2030 the number of ships stays the same.

- **Correction for penetration of LNG in Portugal**

It is assumed that LNG penetration in Portugal follows the same trend of world penetration for the different types of ships. Although the maritime area of Portugal is not inside an ECA it is believed that Portugal will benefit from its optimum geographical location.

- **Number of ships calls in Portuguese ports**

The number of ships calls in the ports under study is easily obtained in documents published by their respective port authorities. It is possible to know the different types of ships that calls to the port and their number. Here two hypotheses will be considered until 2030. One in which the average number of ships remains constant until 2030 and another where there is a gradual increase of 3% each year.

- **Probability of bunkering**

According to data collected from Galp, this company is nowadays responsible for supplying around 2,000 ships nationwide, reaching approximately 800,000 tonnes of marine fuel sold each year (Revista Cargo, 2018). It is known that in 2017 there were sold around of 966,453 tonnes of marine fuel in Portuguese maritime bunkers (DGEG, 2017). Galp has the biggest share in the market of marine bunkers and, therefore, it is assumed that the total number of ships to be supplied each year is around 2,000. It is known that in 2015 the number of calls in mainland and in the islands was around 15,872 ships. In this way it is estimated that there is a probability of bunkering of about 12.6% in Portuguese ports. In the absence of additional information it is assumed that this probability is equal in all ports and for all types of ships. Over the years, two hypotheses are taken into consideration. One where the probability of bunkering remains the same and another where there is a gradual increase of approximately 1% each year. This is the equivalent of stating that in 2030 the probability of bunkering in Portuguese ports is around 25%.

- **Average tank size**

The tank size can be different in each type of ship. The tank size for each type of ship comes from an average value obtained from data collected from different existing ships. The purpose is to find LNG tanks with different volumes in order to increase the confidence of the average value, capable of defining the overall capacity of the existing and future LNG tanks.

- **Quantity of tank filled**

To quantify the volume of LNG to be provided it is considered a bunkering of 75% of the average tank size. It is believed to be a value that reflects the reality of bunkering operations and, given the lack of information about this matter, this is the value to be considered.

2.2. LNG Demand Results

It should be noted that the LNG forecast is expressed in tonnes. For conversion it is known that the specific mass of LNG is 448 kg/m³ at a pressure of 1 bar and a negative temperature of approximately 160°C (EMSA, 2018). Figure 4 shows the LNG demand prediction for the ports under study, obtained by the different scenarios.

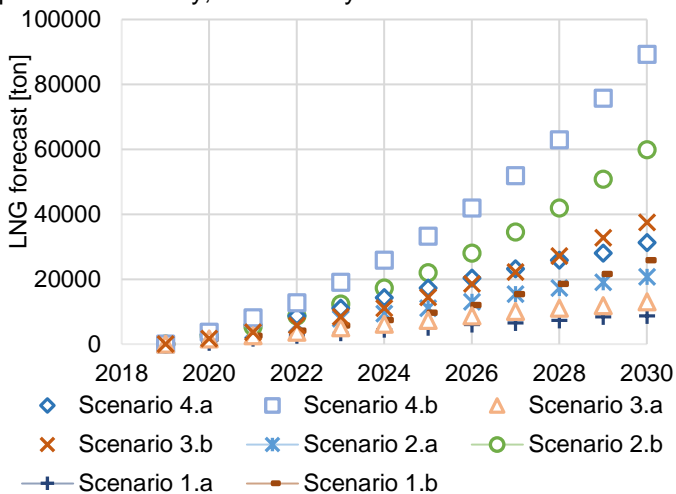


Figure 4 - LNG demand forecast in the Portuguese ports.

Scenarios from 1 to 2 are function of a world demand of 20 Million tonnes of LNG and scenarios from 3 to 4 are function of a world demand of 30 Million tonnes of LNG. Scenarios characterized by “a” are the ones where it is not considered a gradual increase of ship calls and a gradual increase of the probability of bunkering. The values given in figure above reflect the total sum of all of ships and ports. Figure 5 shows the comparison between the values given by COSTA project and the values obtained in this study, function of a world demand of 30 Million tonnes.

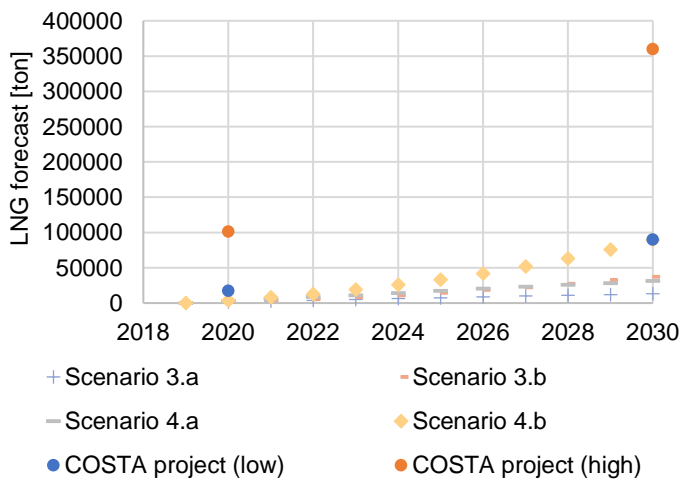


Figure 5 – LNG forecast comparison with data collected from COSTA project (Cid, 2014)

According to COSTA project (Cid, 2014) in 2030 it is estimated a demand of LNG between 90,000 and 360,000 tonnes in Portuguese ports. Comparing the values obtained with those given by that project it is verified that there is a considerable difference, all scenarios are characterized by a demand of less than 90,000 tonnes. However it is known that the demand values for the Portuguese ports given by COSTA project are function of a world demand very optimistic and unlikely to happen, according to this project the world demand in 2030 will be between 37 and 136 Million tonnes. Even more, the forecast given in that project is for all Portuguese ports while the forecast given by Figure 5 is just for the ports under study, already mentioned. Knowing that the scenarios are obtained through a world demand lower than that predicted by the mentioned project and only for the ports of Sines, Leixões, Lisbon, Funchal and Ponta Delgada, it is believed that the estimated LNG demand assumes reasonable values.

It should be noted that, according to all scenarios given by Figure 4, there is no LNG to be supplied in 2019. It is known that there are no LNG barges/bunker vessels operating in Portuguese ports and that in port of Sines it is only possible to receive LNG, not to export it (Revista Cargo, 2018). Currently the only available bunkering method is TTS, applied with low frequency in port of Funchal. This bunkering method only allows small volumes of LNG to be supplied. For all these reasons it is believed that LNG demand results obtained through equation 1 are reasonable and that reflect what may become a reality for Portugal.

3. SIMULATION OF LNG BUNKERING SERVICE

The simulation of LNG bunkering service is based on a discrete event simulation using ARENA simulation software. In this way it is possible to evaluate the LNG bunkering operations according to different demand scenarios and to the randomness of some events and processes. Proceeding to multiple simulations of the same system, decision making and optimization of the voyage model are possible. With the data obtained through simulation it is possible to carry out an economic feasibility analysis in order to conclude the possibility of having an attractive LNG bunkering service in Portugal.

3.1. Voyage Model

The voyage model is defined by all processes necessary for bunkering operations using a bunkering vessel based in the port of Sines. This vessel is intended to provide fuel to LNG fuelled ships inside the ports of Sines, Lisbon, Leixões, Funchal and Ponta Delgada. As mentioned, the bunker vessel is based in the port of Sines. This is the only port where there is an import terminal where the bunker vessel refuels its LNG tanks. After refuelling the bunkering vessel can answer to LNG requests.

The simulation process begins with the bunker vessel with full tanks and waiting for a mission at the port of

Sines. In the absence of requests the vessel remains inactive and waiting for a request. If a certain request appear the bunker vessel starts its voyage to the port where the request is made. When arrived the LNG bunker vessel carry out the bunkering operation. When the bunkering operation is concluded the same question of the initial time of the simulation occurs. If there are no requests the vessel waits for a mission in port, the last one in which the last operation has been made, if there is some request pending the vessel starts again its voyage to the port where the new order is requested. When the remaining capacity of the LNG tanks is insufficient to meet the next request there is the need to return to the port of Sines and refuel the tanks. After that a new cycle can began and a new request answered. Attached to this report it is possible to find the flowchart of the voyage model (Annex A). It represents all the processes implemented in ARENA software to simulate the LNG bunkering service. In order to fully define the voyage model the following points are presented for better understanding:

- **Periodic maintenance**

Periodic maintenance is required once a year and it is scheduled to take place in the middle of the year. To this end the bunker vessel suspends its activity, considering an off-hire period of 15 days. If the vessel is waiting for a mission the maintenance will take place immediately. If the vessel is in some simulation process the maintenance occurs at the end of it.

- **Criteria adopted for decision making**

When the bunker vessel is waiting for a mission and there are no pending requests it was decided to set a remaining LNG quantity as a limit. If the remaining LNG quantity of the bunker vessel tanks is less than this value then the vessel is ordered to travel to the port of Sines and to refuel its tanks. Otherwise the vessel keeps waiting for the next request in the port where the previous bunkering process occurred. The criteria quantity defined are: the equivalent of the total capacity of the vessel, two thirds of the capacity of the vessel and one third of the capacity of the vessel.

- **Maximum LNG request pending time**

In order to simulate a more realistic model it was decided to adopt a condition regarding the waiting time of LNG requests. Customers who request for LNG may choose to give up the order and refuel at another country if the waiting time is longer than expected. For this reason it is considered that the requests are made with 72 hours in advance. If the waiting time exceeds this value the request is dropped. Otherwise the supply vessel is within the service schedule time and the request remains pending. It is highlighted that the fulfilment of requests is based on FIFO rule (First In-First Out).

- **Bunker vessel main characteristics**

It is considered 2 different bunker vessels, one with an LNG capacity of 1,530 m³ and another with an LNG capacity of 3,000 m³. It is intended to assess which one has the greatest potential for bunkering operations in the Portuguese coast. Table 3 identifies the main characteristics of each one.

Table 3 - Bunkering vessels main characteristics.

| LNG bunker vessel | 1,530 m ³ | 3,000 m ³ |
|-----------------------------|----------------------|----------------------|
| L _{OA} [m] | 73 | 84.7 |
| L _{BP} [m] | 67.4 | 82.6 |
| B [m] | 12.8 | 15.2 |
| D [m] | 6.5 | 8 |
| T [m] | 3.5 | 4.25 |
| GT | 2,300 | 3,900 |
| P _{ME} [kW] | 2x1,100 | 2x1,200 |
| P _{AE} [kW] | 2x640 | 2x1,065 |
| Q̇ pump [m ³ /h] | 4x200 | 4x200 |
| v [kn] | 14 | 12 |

Both vessels travel with a velocity of 12 kn outside of ports and 6 kn inside the ports. Each vessel has 2 separate LNG tanks with 2 pumps for each one with a capacity of 200 m³/h. One pump is there only to prevent possible interruption of the main pump. It is considered that LNG is never supplied from both tanks at the same time, in this way flowrate never exceeds 200 m³/h. It is known that there is an existing passenger ship with an LNG capacity of 445 m³ is characterized by a maximum supply flowrate of precisely 200 m³/h (EMSA, 2018). In this way it is believed that this is a reasonable value to be used. All the main characteristics given by Table 3, as well as those not mentioned, are based on information obtained in T.A. Santos, C. Guedes Soares (2015) for the LNG bunker vessel of 1,530 m³ and in a Wärtsilä design datasheet for the LNG bunker vessel of 3,000 m³.

- **Voyage time**

Some events such as bad weather, engine malfunctions and port congestion can increase the expected voyage time. In order to simulate a more realistic model a triangular distribution is used to consider unforeseen circumstances. Minimum and average values are equal and given by the distances and velocities considered. Maximum value is defined by an increase of 25% in voyage time. In this way voyage time distribution is defined as T~TRIA (1, 1, 1.25).

- **LNG bunkering time**

Here it is also considered possible pump faults and adverse weather conditions that could increase bunkering time duration. As the previously point a triangular distribution is applied in order to consider unforeseen circumstances. Minimum and average values are equal and given by the total of LNG handled and the flowrate of the process. Maximum value is defined by an increase of 10% to this value. In this way processes time distribution is defined by T~TRIA (1, 1, 1.10).

- **LNG request distribution**

To introduce the number of requests in the system and its distribution it is necessary to determine how often they arise. In each scenario the annual number of orders requested is known for each port and for each type of ship. However there is no data about the time distribution of it. In this case Poisson distribution is the most credible option to estimate the distribution of the number of requests over time (Asperen et al., 2004). By using this

distribution the time between consecutive arrivals is given by a negative exponential distribution. In this way time between consecutive requests, for each type of ship and in each port, is defined by $T\text{-EXPO}(\bar{X})$, where (\bar{X}) represents the mean time between consecutive arrivals.

3.2. Voyage Model Simulation using ARENA Software

Simulation time scope is 12 years, starts at the beginning of 2019 and ends at the final of 2030. The simulation is performed for all scenarios, bunker vessels and criterion defined. In total there are 48 possible systems to simulate. It is highlighted that each simulation of each system is replicated 100 times. This means that for the same simulation it is possible to analyse the behaviour of the same system when there are variations of applied distributions. Regarding LNG requests, in a given replication the number of ships requiring LNG may be higher than estimated and in another one may be lower. Simulating the same system 100 times it is verified that the average request value tends to equal the estimated value, with a very small difference.

3.3. Voyage Simulation Results

Since it is impossible to show all the results from all simulations this section only is intended to focus on the results regarding the first replication of the system defined by the bunker vessel of 1,530 m³, demand scenario 4.b and criteria quantity of 1,020 m³. The idea is to have a general idea from the obtained results. Table 4 shows processes duration and handled LNG quantities.

Table 4 - Processes duration and handled LNG quantities.

| Year | Voyage (h) | Bunkering (h) | Waiting (h) | LNG acquired (m ³) | LNG supplied (m ³) |
|------|------------|---------------|-------------|--------------------------------|--------------------------------|
| 2019 | 0 | 0 | 8,400 | 1,530 | 0 |
| 2020 | 595 | 0 | 7,726 | 6,965 | 7,310 |
| 2021 | 1,188 | 79.7 | 6,983 | 20,862 | 20,516 |
| 2022 | 1,723 | 228.7 | 6,345 | 29,627 | 29,627 |
| 2023 | 3,371 | 331.6 | 4,537 | 43,156 | 43,857 |
| 2024 | 2,706 | 479.7 | 5,102 | 55,634 | 54,933 |
| 2025 | 4,345 | 605.0 | 3,243 | 71,467 | 71,812 |
| 2026 | 4,461 | 787.5 | 3,127 | 75,374 | 75,029 |
| 2027 | 5,568 | 814.1 | 2,050 | 73,003 | 73,003 |
| 2028 | 5,837 | 802.5 | 1,581 | 89,356 | 90,403 |
| 2029 | 5,963 | 976.1 | 1,433 | 93,436 | 93,157 |
| 2030 | 7,125 | 1009,3 | 249 | 94,548 | 95,184 |

In 2019 the annual maintenance is the only process triggered, a process whose duration is 360 hours. After 2019 there is a gradual increase in voyage and bunkering times. Naturally there is also a gradual increase in LNG acquired and sold quantities. In the opposite direction waiting time reduces over the years as function of an increase of LNG requests. It is noted that in Table 4 bunkering time consists of the sum of all bunkering processes, refuelling of the bunker vessel itself included. In order to have a better understanding of the time spent in each process, it was decided to focus on their duration

in the middle and at the end of the simulation. Figure 6 shows the weight of each process duration at the end of 2024 and 2030.

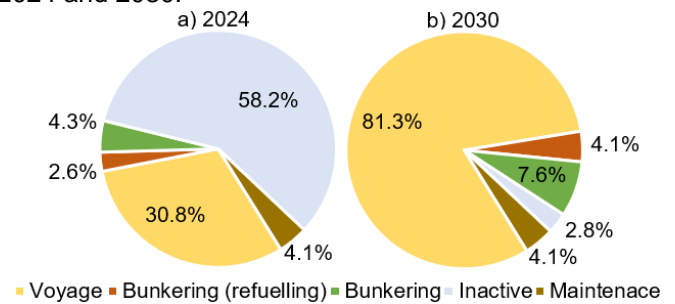


Figure 6 - Weight of each process duration at the end of 2024 and 2030.

It is observed that at the end of 2024 the period of inactivity of the bunker vessel is very high, reaching around 58.2% of the total time of that year, even knowing that scenario 4.b is the one where higher LNG demand is predicted. At the end of 2030 it is verified that voyage time is very high, function of a substantial number of LNG requests, reaching around 81.3% of the total time of that year.

Lastly, and before proceeding to the next section, it is necessary to analyse the moment at which LNG requests are made. Figure 7 shows the exact moment to which every LNG request attended were made.

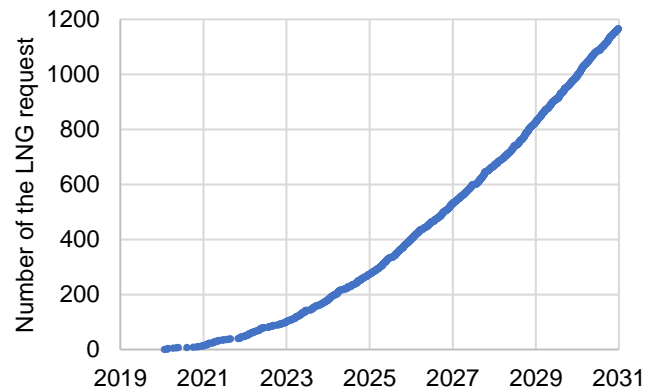


Figure 7 - Moment where LNG request are made.

It should be noted that the requests that dropped out of the waiting list, those whose waiting time exceeded 72 hours, are not taken into consideration. It can be observed that the curve given by Figure 7 follows the desired trend by presenting a continuous growth. This leads one to verify that the Poisson distribution is correctly applied and because of that it is concluded that the results obtained through simulation are not compromised.

3.4. Economic Feasibility Assessment

Cash flow is a financial tool that allows to conclude about the economic feasibility of a given business. There are several measures of merit that can be obtained through this economical tool in order to verify the attractiveness of the LNG bunkering service. The chosen one is Required Freight rate (RFR). This RFR, expressed in euros per tonne, reflects the fuel surcharge to be supported by the customer. From the sum of this value to the LNG market

cost the cost that the customer effectively must pay is obtained. Cash flow takes into consideration all ship costs, revenues, taxes and an applicable discount rate. Table 5 shows the assumptions made for the economical parameters applied.

Table 5 – Parameters applied for economic analysis (T.A. Santos, C. Guedes Soares, 2015).

| | |
|---|------|
| Bank loan [%] | 50 |
| Bank loan payment time [Years] | 8 |
| Loan interest [%] | 6/8 |
| Bunker vessel depreciation after 12 years [%] | 52.8 |
| Internal rate of return [%] | 8/10 |
| Corporate taxes [%] | 21 |

The values given by the table above are the ones used in this study. It is believed that they reflect the existing conditions in projects of this nature. It is noted that for cash flow construction the operating costs of the vessel are obtained according to D’Almeida empirical formulae. These costs are: manning, current maintenance, stores and consumables, insurance/P&I and administration. Other ship costs than these ones are easily calculated from data collected from different studies and from the results obtained from voyage simulation. Lastly, there are the cargo handling costs tariff charged by the LNG terminal in Sines. It is known that the tariff estimated to be charged at European import terminals is around 17.9 euros/tonne (EU, 2015). This is the value considered and applied in this study.

3.5. Economic Feasibility Results

The purpose of this section is to compare the additional cost of LNG obtained in this study and those given by the three similar studies. The comparison is established only between the lower RFR average results of the present study and the highest results of the 3 projects used for comparison, for reasons that are noticeable later. Figure 8 shows RFR comparison between the RFR obtained here and the RFR values given by DMA (2012), T.A. Santos, C. Guedes Soares (2015) e Filippi, E. (2015).

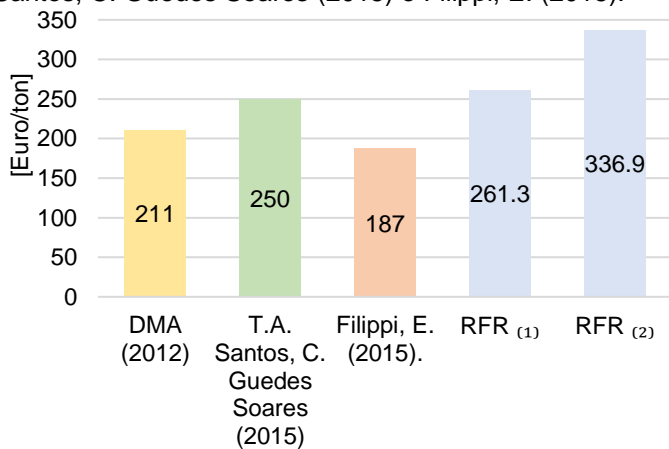


Figure 8 - RFR comparison between similar studies.

RFR (1) refers to the average value obtained by the system characterized by the bunker vessel of 1,530 m³, demand scenario 4.b and criteria quantity of 1,020 m³. RFR (2) refers to the average value obtained by the

system characterized by the bunker vessel of 1,530 m³, demand scenario 2.b and criteria quantity of 1,020 m³. Both results are obtained from a loan interest and an internal rate of return of 6 and 8%, respectively. It is concluded that the average RFR results obtained in this study, derived from 100 replications of the systems described above, are higher when compared to the RFR results given by the projects identified, even when considering the best hypotheses. For this reason It is believed that Portugal does not have yet the ideal conditions to compete with some countries belonging to the European Union (EU).

4. CONCLUSIONS

LNG allows to mitigate environmental problems and to comply with regulations applied in shipping. However it has its disadvantages when considering all the supply chain. It is believed that LNG is in fact a good alternative to petroleum derivatives but only in a short and medium term. In future cleaner fuels should be taken into consideration and fossil fuels should be neglected.

This paper presents an LNG demand forecast and a simulation of bunkering operations in some Portuguese ports. The main purpose is to understand if there is a possibility of a profitable and attractive LNG bunkering service in Portugal.

It is concluded that the 1,530 m³ bunker vessel is the best option to meet the LNG demand predicted for the Portuguese case. On average, the surcharge is around 14.3% lower when comparing with the 3,000 m³ bunker vessel. It is also concluded that in most cases the criterion applied, to define the next step of the bunker vessel in cases of absence of requests, corresponding to two thirds of the vessel's capacity is the one that leads to a lower surcharge.

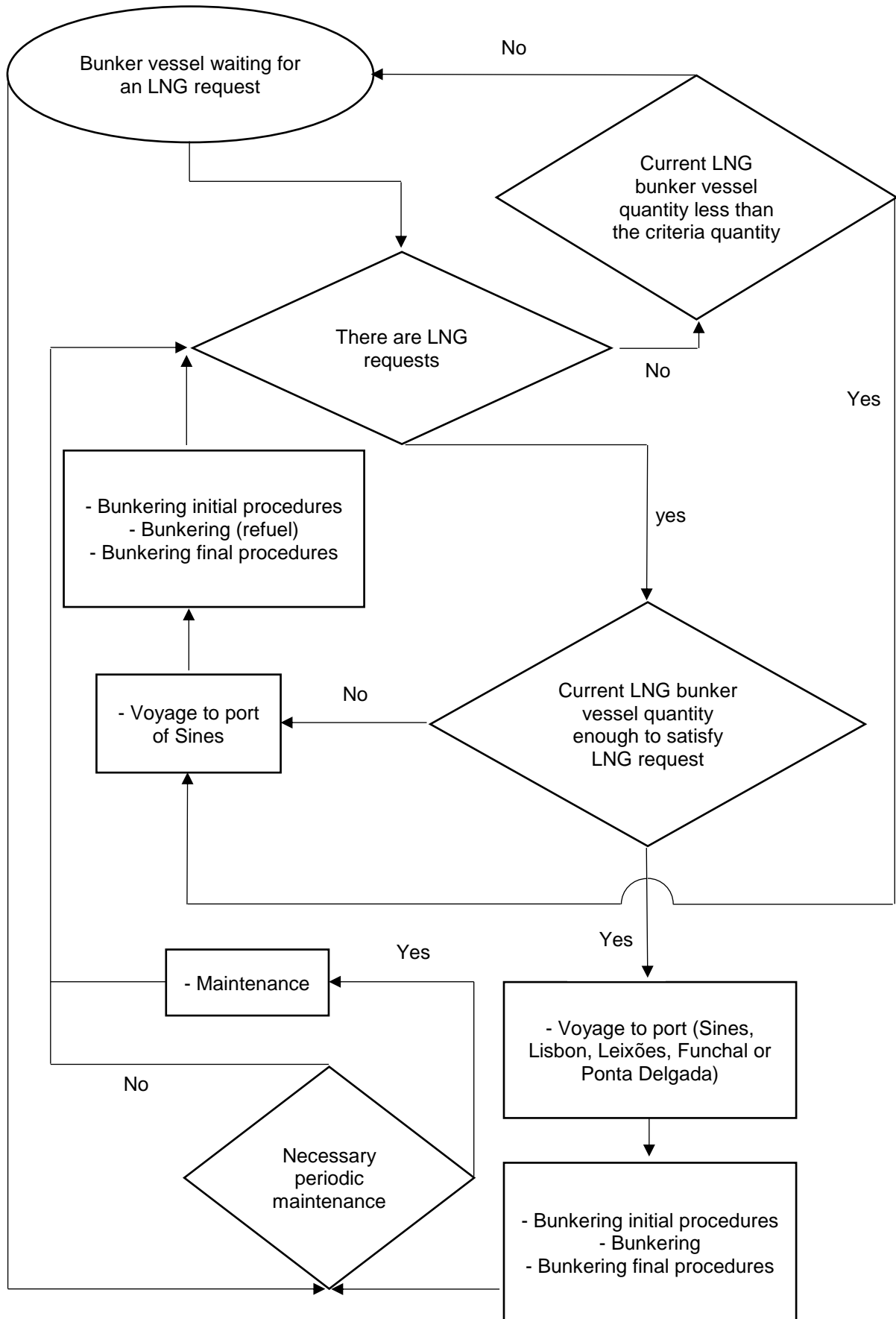
Even the lower surcharge obtained in this study (and in other studies) is very high and, therefore, it is difficult that LNG is a competitive fuel in terms of cost of bunkering operations. The values obtained are in line with values shown in the literature for other EU ports. The main reason is due to a very low demand forecast predicted in the ports under study. In order to demonstrate that, it is known that in the port of Antwerp the LNG forecast that generates greater consensus is around 156,000 tonnes in 2025 (Aronietis et al., 2016). It is an LNG forecast around 75% higher than the total forecast for the Portuguese case in 2030.

There are some main recommendations that can be considered for future work and may make this LNG bunkering service competitive and attractive for Portugal. Instead of using an LNG bunker vessel it is recommended to use multi-product vessel. In the port of Huelva there is already this type of vessel capable of supplying different types of fuels, LNG included (CEPSA, 2018). This is certainly the best option for cases where LNG demand is predicted to be low. Furthermore, most likely it is necessary to have port authorities or national government economic support, at least at the early stages of this LNG service. It is believed that these changes may make this LNG service feasible.

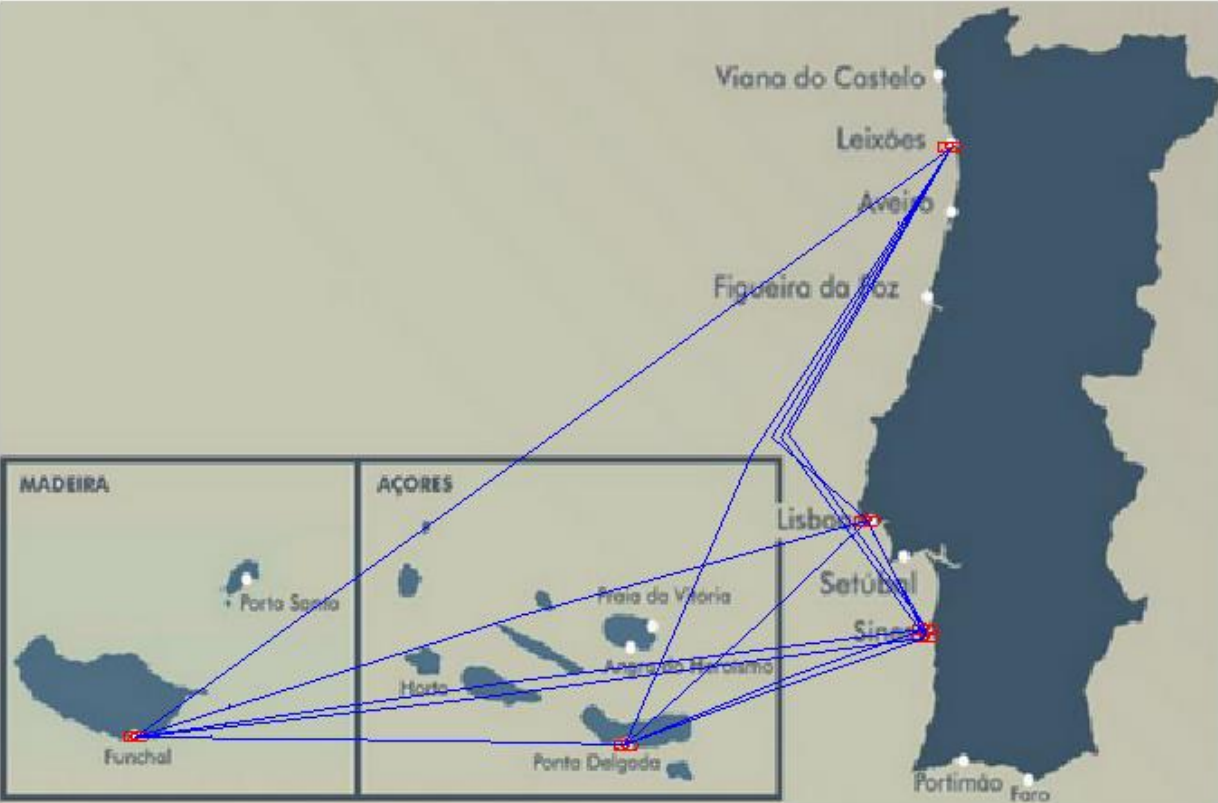
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ANNEX A– Voyage model flowchart applied to ARENA simulation software



ANNEX B– Map with Portuguese ports under study (obtained from the graphical simulation in ARENA)



Note: The figure above is merely illustrative. Distance between ports and the different routes do not reflect the reality.