School of Economics, Business and International Studies

Department of International & European Studies

M.Sc. in Energy: Strategy, Law & Economics

DISSERTATION

"NATURAL GAS AND LNG AND ITS TRANSPORTATION: ENVIRONMENTAL APPLICATIONS AND EUROPEAN REGULATORY FRAMEWORK''

AUTHOR

PANAGIOTIS CHRISTOFILOS

SUPERVISOR

Dr. PETROS LIACOURAS

Disclaimer of authenticity

Το έργο που εκπονήθηκε και παρουσιάζεται στην υποβαλλόμενη διπλωματική εργασία είναι αποκλειστικά ατομικό δικό μου. Όποιες πληροφορίες και υλικό που περιέχονται έχουν αντληθεί από άλλες πηγές, έχουν καταλλήλως αναφερθεί στην παρούσα διπλωματική εργασία. Επιπλέον τελώ εν γνώσει ότι σε περίπτωση διαπίστωσης ότι δεν συντρέχουν όσα βεβαιώνονται από μέρους μου, μου αφαιρείται ανά πάσα στιγμή αμέσως ο τίτλος.

The intellectual work fulfilled and submitted based on the delivered master thesis is exclusive property of mine personally. Appropriate credit has been given in this diploma thesis regarding any information and material included in it that have been derived from other sources. I am also fully aware that any misrepresentation in connection with this declaration may at any time result in immediate revocation of the degree title.

Acknowledgements

I would like to extend my sincere gratitude to my dissertation supervisor Professor Dr Petros Liacouras for his encouragement, inspiring guidance and his useful insight into my thesis, to Professor Dr Farantouris Nikolaos for his contribution on my research material and to Professor Dr. Metaxas Antonis for his extension of insight and extension of assistance.

ABSTRACT

The significance of liquefied natural gas (LNG) as a traded commodity has grown significantly in the past decades. Globally, the growing demand of natural gas for power generation, heating, cooking, large- and small-scale businesses, but also as a feedstock for the petrochemical industry to produce plastics, fertilizers, and many other products, and due to its lower environmental impact in comparison to oil and coal, has led natural gas to be considered as the bridge fuel of a more sustainable transition with regards to climate change, the Kyoto protocol provisions and the European Union's Green Deal and its targets for climate neutrality by 2050. The need for a cleaner fuel than coal and oil in terms of a more environmentally friendly fuel, the economic and its competitive nature has intensified the significance of natural gas. In order for the security of supply to be achieved as well as differentiation of energy sources, the transportation of natural gas in a liquid state has emerged during the last decades with a soaring demand in countries such as Japan, China, India and Korea with limited gas pipes infrastructures and limited reach to natural gas. The market for LNG has become more liberalized with third party access (TPA) privileges to different exporters while the fleet of LNG carriers has grown significantly in the past decades, lowering their average year ratio. The emergence of new players in the importing and exporting side as well as LNG contracts that have become more flexible, enabling at times arbitrage of LNG cargos, rediverting cargos to different importers. Although the main target of the developed countries should be the further penetration of renewable sources of power such as wind, solar and nuclear, due to the seasonality of renewable sources, natural gas has a pivotal role to play in the energy transition for the upcoming decades. The market of LNG is worth exploring and the Mediterranean region is responsible for more than 20 percent of the whole LNG consumption, importing LNG from over than 13 different countries in 2017. The European Union is committed to diversifying its energy sources in the last decades. The EU has been a pioneer in the development of the LNG chain in its territory, in the establishment of a liquid, liberalized and transparent natural gas market through the implementation of gas Directives and energy packages.

Keywords: LNG, Energy, pricing mechanisms, Natural Gas, Directive 1998/30/EC, Directive 2003/55/EC, Directive 2009/73/EC.

Contents

TABLE OF FIGURES

CHAPTER 1: INTRODUCTION TO NATURAL GAS AND LNG

1.1. Historical background of natural gas and division of markets.

During the 11th century the Chinese started drilling holes and utilizing natural gas in the Sichuan basin. The discovery of natural gas was accidental. In about 500 B.C., the Chinese used a bamboo pipeline system to transport gas that emerged from the surface and use it to boil sea water to procure drinkable water while retracting salt.[1]

In 1785, natural gas was commercialized in Britain, where it was used to light houses and streets. In 1816, Baltimore became the first city in the United States to utilize natural gas and light its streets. In 1858, Fredonia Gas Light & Water Company was granted authorization from New York City as the first natural gas corporation in the U. S. The difficulty to transport natural gas was resolved by the construction of underground pipelines. The first oil pipeline was built in 1862 at a well in Oil Creek Valley in Pennsylvania. In 1891, one of the first, major pipelines was constructed. It was 120 miles long, carrying natural gas from Indiana to the city of Chicago. In 1917 the first liquefaction facility was built, and LNG became a viable source of energy.

The first attempts to sell LNG in the 60s failed. The transportation of LNG cargos between gas tanks in Chicago, Illinois and Louisiana proved futile as there was no solid engineering for designed gas reservoirs. Additionally, a prototype gas tank collapsed in Ohio in 1944 which resulted to many deaths due to combustion. Another accident occurred in Staten Island in 1973 that led to another explosion and caused the subsequent collapse of the gas tank. Those accidents delayed the expansion of LNG in the United States. The first attempts to exploit LNG cargoes evolved around Europe and North Africa[2]. 63 years ago, the first trip of LNG through LNG vessel transpired. The Methane Pioneer sailed from Lake Charles, Louisiana, to Canvey Island, England, taking 27 days to cross the Atlantic Ocean in 1959. The "METHANE PRINCESS", about five times the capacity of the "METHANE PIONEER" started transporting LNG from Algeria to the Canvey Island and to la Havre in France in 1964. The first LNG plant was constructed in Algeria, and it became operational in 1964 exporting LNG to Europe. At that time Japan started importing LNG in 1969 from Alaska. Since then, Japan has become the largest importers of LNG only recently surpassed by

[1] Yang C.J. et al, (2013). China's fuel gas sector: History, current status, and future prospects, Elsevier,

[2] Karonis D., Lois E. & Zanikos F. (2014) Technology of Natural gas and oil

China[3] according to IEA. During the end of the 60s many LNG installations and gas tanks were designed as a measure to cover emergency periods of shortage in Europe and Northern America.

The global gas markets for LNG are the European region, the Asia-Pacific region, and the North American region. The largest market for LNG is the Asia Pacific region. China holds the reign as the largest LNG importer for the moment, with Japan, South Korea and Taiwan following. India is predicted to become a bigger LNG importer in the future.

In Europe, LNG has to compete with pipeline gas, that is produced domestically and with that, that is imported from Russia. The main European importing countries are Spain, the UK, Germany, France, Belgium, Greece and Portugal.

Between 1971 and 1980, four LNG import terminals were constructed in the U.S. soil, and the U.S. began importing LNG from Algeria. In the 1990s additional LNG terminals were constructed and several U.S. terminals were reactivated due to a forecast of a shortage of natural gas. In the 2010s and after the shale gas revolution the U.S. has become a major natural gas producer terminating its LNG imports. All the remaining long-term contracts and the LNG cargoes under these legacy contracts have been resold to the global markets. Now in the U.S there are more than 160 LNG facilities[4].

1.2. Composition of natural gas & LNG.

Natural gas can be produced from geological formations and has many compositions. “Natural gas has been formed by the degradation of organic matter accumulated in the past millions of years”[5].

Natural gas composition can be categorized into three different groups:

1. “Non associated gas while it occurs in conventional gas fields
2. Associated gas while it occurs in conventional oil fields
3. Unconventional gas. The types of unconventional gas are tight gas from reservoir rocks with low permeability that is retrieved by hydraulic fracturing is”[6], “coalbed

[3] Cocklin J. (2021). China surpassed Japan as world’s biggest LNG importer through October. NGI. Retrieved from https://www.naturalgasintel.com/china-surpassed-japan-as-worlds-biggest-lng-importer-through-october/a

[4] FERC: Natural Gas. Retrieved from https://www.ferc.gov/natural-gas/lng

[5] Retrieved from https://www.scribd.com/

[6] Retrieved from https://whatispiping.com/

methane, the methane absorbed into the solid matrix of the coal, natural gas from 'geopressurized' aquifers, methane clathrate compounds and deep gas"[7].

The main component of LNG as composition is methane CH_4 at about 70-90 % and the minor components are ethane C_2H_6, Propane C_3H_8, butane C_4H_{10} at about 0-20%, Carbon Dioxide CO_2 at 0-8% nitrogen N_2 and Oxygen O_2 at 0-0.2 % and hydrogen sulfide H_2S.[8] Depending on its origin, LNG composition may vary significantly.

Depending on the content of its components, LNG can be divided into distinct groups. The first category is 'Light LNG', where the methane stands between 90% and 95%. The second category is the Heavy LNG where the methane is below 90%. It has an ethane content up to 10%, propane 3–4%, butane near 1.5% and traces of pentanes. Nitrogen quantities should not exceed 1% because it contributes to the evaporation process.

Liquefied natural gas is the gas that has been cooled down to -260°F (-162°C) and is subsequently converted to a liquid state. In its liquid state natural gas takes up 1/600th of the space it would as a vapor, transported by LNG carriers much more efficiently and economically.

"LNG is odorless, non-toxic, non-corrosive and leaves no residues after it evaporates. LNG will not ignite until it becomes a vapor, and even then, the vapor won't ignite until it mixes with air. LNG vapor clouds do not detonate, they only burn. LNG does not contaminate the water or the soil in case of a release"[9].

1.3. LNG value chain.

The LNG Value Chain describes the cycle of transformation of natural gas into LNG. The stages of this chain are the production of natural gas, the processing, the conversion of natural gas to LNG, its transportation by LNG carriers, and finally the regasification process that connects the terminal with the pipelines.

---

[7] MT LNG. Liquified Natural Gas: General Knowledge. Retrieved from http://www.golng.eu/files/Main/news_presentations/rostock/Liquefied%20Natural%20Gas%20General%20Knowledge.pdf

[8] Kuczynski et al (2020). Journal: Energies, 13(19). Impact of Liquefied Natural Gas Composition changes on Methane number as a fuel quality requirement, Poland,

[9] Retrieved from https://cameronlng.com

The first stage of the LNG value chain is the extraction of natural gas from natural reservoirs which travels through small pipelines while impurities and useless components are removed. The extracted propane and butane are sold separately in their respective market.

The second stage is where the already processed natural gas ‘travels’ through pipelines to the liquefaction plant. This processed gas ought to be clean and without impurities before the liquefaction process commences.

In the third stage, the already purified natural gas is converted to a liquid state by reducing its temperature to about -260 degrees Fahrenheit or -162 degrees Celsius, and its volume is reduced by 600 times. After this chilling process, it is stored in large cryogenic tanks and then loaded into LNG carriers.

The fourth stage is the transportation of LNG by vessels. LNG is transported from storage tanks into specifically designed double hulled LNG carriers, as it will be thoroughly discussed in a later chapter, for shipment around the world. As a figure, “an LNG tanker carrying 3.5 Bcf of LNG can accommodate the need for natural gas of Spain”[10] for one day. After the LNG carrier reaches the regasification terminal, LNG is unloaded from the tanker and is gathered in cryogenic tanks again.

The last stage is the subsequent transfer of the LNG to a regasification plant, where it is heated by various systems that will be covered later on and reverts back into its original form to be fed into the connected pipeline system. Natural gas is then ready to be used by residential consumers, businesses, industrial facilities, and power generation plants. “Each process requires lots of capital and the investment revenue begins when the project is finished. Hence breakdowns and delays in any part of the chain have adversely affected capital recovery and project internal rate of return” (IRR)[11].

[10] U.S. Department of Energy: Liquified Natural Gas Value Chain. Retrieved from: https://www.energy.gov/sites/default/files/2020/10/f79/LNG%20Value%20Chain%20Fact%20Sheet_1.pdf

[11] Jensen J. T., (2004). The development of a global LNG market. Is it Likely? If so, When? Oxford Institute for Energy Studies.

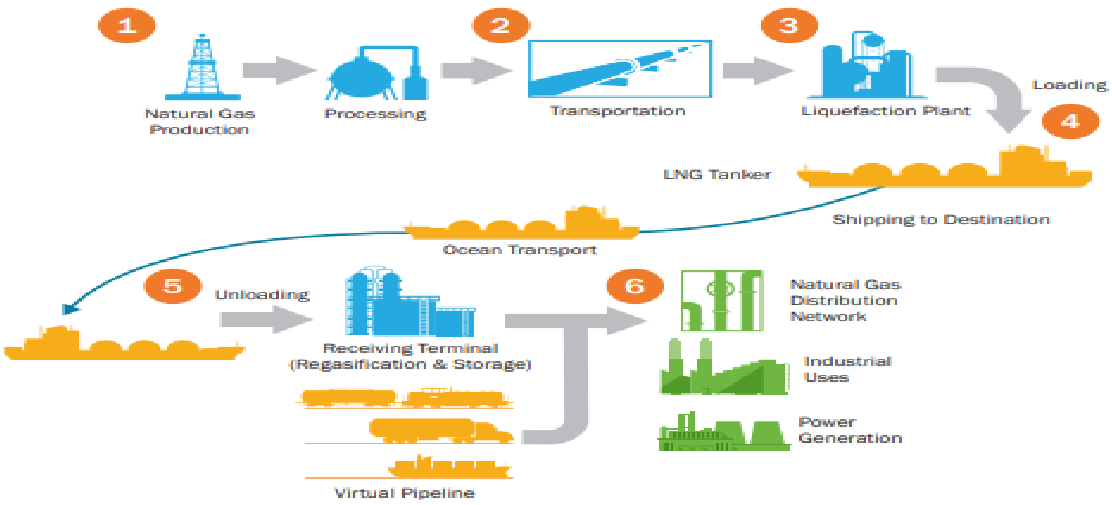


Figure 1. The LNG value chain (Source: US Department of Energy)

1.4. Liquefaction process.

In the liquefaction plant, referred as train as well, the natural gas is converted from its gaseous state to a liquid state. An LNG liquefaction plant performs three main processes, but many different liquefaction technologies exist and represent one of the highest costs in the LNG value chain:

1. In the first stage, the dust, slug, hydrogen sulfide (H2S) and mercury (HG) is removed. These elements are corrosive and can create problems in the heat exchangers.
2. In the second stage, the acid gas is removed, and dehydration takes place. Also, the carbon dioxide (CO2) and water are removed from natural gas. so that water won't turn into ice during the liquefaction stage.
3. In the third stage, the heavy hydrocarbons are separated, and liquefaction commences. All the heavy hydrocarbons (C5+) are removed by fractionation. Natural gas is then cooled to about -31°F or -35°C by using propane.[12]

[12] Mokhatab S. et al, (2014), Handbook of liquefied natural gas, Elsevier

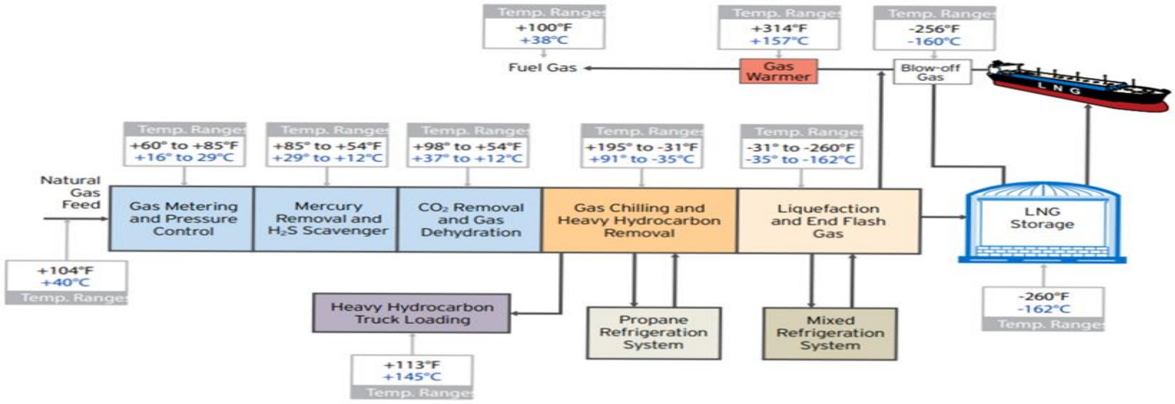


Figure 2. *Liquefaction process (Source: Cameronlng.com)*

The selection of the liquefaction process is very important to the LNG project due to its capital-intensive nature and should be considered during the initial feasibility study. Each licensor has different capital and operating costs that need to be well defined beforehand. During the selection of the technology the technical and economic elements of the investment must be reconsidered. Factors such as plant reliability and availability, energy efficiency, life cycle costs and the environmental impact must be well thought off. The owner's preferences, economic parameters, site conditions, and other technicalities are discussed before the licensor can readjust their initial design. Another important factor is the power consumption of the train (i.e., kW/ton of LNG). "This is of course crucial, since refrigerant compressors constitute the largest cost in a liquefaction train"[13]. That is why the licensors are constantly trying to improve their liquefaction technologies through innovations that could result in lower consumption costs.

Many successful refrigeration cycles exist for liquefying natural gas. Among these, the mixed refrigerant MR process is prevalent in the medium to large scale LNG liquefaction plants, but they are also popular in the small to medium plant market[14].

Below, different liquefaction processes are further analyzed:

1. First and one of the most popular refrigeration processes is the APCI propane precooled mixed refrigerant process known as C3-MR. It was engineered by Air Products and Chemicals Inc and it is the most popular with a market share of 75%

[13] Ibid as reference 10

[14] Roberts et al, (2015). Brayton refrigeration cycles for small-scale LNG. Air Products and Chemicals Inc.

since the late 1970s. APCI has modified several liquefaction trains in Qatar, increasing their size. According to the C3-MR process the natural gas is pre-cooled to -35°C using propane. Then it passes through the shell heat exchanger reducing its temperature between -150°C and -162°C.

2. The second solution for a liquefaction train is the cascade LNG process developed by Phillips Petroleum Company in the 1960s. This procedure uses propane and ethylene systems and a multiple stage methane refrigeration system. Firstly, the heavier components "are removed from the feed gas and the remaining methane-rich feed is routed through the methane refrigeration system. The heat exchanger designs are less complex than the proprietary spiral-wound heat exchanges used in the C3-MR process. Train sizes of liquefaction plants built to date with this technology are less than 5.0 MTPA"[15].

3. A third solution is the PRICO process developed by Black & Veatch, which is a mixed refrigerant process, and has been used in base load installations for over 40 years. The PRICO refrigeration system is a simpler application of mixed refrigerant cycle and the "number of equipment counts is lower than the propane precooled MR or cascade processes"[16]. "However, this process is not as efficient as the multiple-cycle processes and its suitability is argued[17] for large base load LNG plants". The PRICO process is preferably utilized in small-scale, mid-scale LNG plants and other offshore terminals.

4. A fourth choice is the mixed fluid cascade process developed by Statoil/Linde. It is developed for base load plants that can endure harsher environmental conditions. It was firstly used in the Snohvit plant in Norway. The MFC solution is a typical cascade process, theoretically improving the thermodynamic efficiency and operational flexibility. Up until now, the only gas liquefaction plant that has been build according to this process is in Norway. It has a capacity of 4.3 MTPA. "The MFC process consists of three pure refrigerants, methane, ethylene, and propane. First, natural gas is cooled to −35 °C in the propane cycle, and then it is cooled to

[15] Mokhatab S. et al (2013) Handbook of liquefied natural gas, GPP
[16] Mokhatab S. et al (2013) Handbook of liquefied natural gas, GPP

[17] Ibid as ref. 15

−90 °C in the ethylene cycle. Finally, it is liquefied to −155 °C in the methane cycle".[18]

5. A fifth solution is the Liquefin process developed by IFP and Axens. It is estimated that it generates efficiencies of up to 20% in comparison to other liquefaction solutions. The cost savings are presumed due to higher plant capacity, lower heat exchanger costs, use of plate-fin heat exchangers. However, no base load plant has been built yet and the industry is skeptical about the commercial benefits of the Liquefin technology[19].Studies carried by major gas companies show that the cost of the liquefaction plant using this technology can be decreased around 15%. But taking into consideration the capacity for the gas turbines, the cost per ton of LNG is lower to about 23 % when compared with competing processes.[20]

   This technology uses two refrigeration cycles to produce LNG. Each cycle uses a different mixture of refrigerants. Improved heat exchange in the liquefaction prosses and optimization of the mixed refrigerant cycles can balance the refrigeration power, giving the advantage of having the same compressor drivers for the refrigeration cycles. It is more suited well-for trains of range of 4 to 8 MTPA. Despite all the above advantages, the Liquefin™ process is still new and hasn't been tested fully[21].

6. The last choice for a LNG plant is the dual mixed refrigerant process provided by Shell that has developed a dual mixed refrigerant (DMR) process for natural gas liquefaction with two separate mixed refrigerant cooling cycles. In the first cycle, natural gas is precooled to –50C and in the second the final cooling and liquefaction of the gas. Is achieved. This technology is similar to the propane precooled mixed refrigerant (C3-MR) process, but the precooling stage is achieved by a mixed refrigerant of ethane and propane rather than pure propane. Since over a decade, the Sakhalin LNG plant in Russia has been running on Shell Dual Mixed Refrigerant Technology. The reported advantages are the maximization of LNG production in harsh environments, safety, efficiency, CO_2 emissions and operability.

[18] Wang X. et al (2009). Liquified natural gas, ScienceDirect,

[19] Ibid as ref.11

[20] Martin P.Y. et al. LIQUEFIN: AN INNOVATIVE PROCESS TO REDUCE LNG COSTS

[21] Chainho P. D. D. (2013). Dissertation: Advanced steady-state modelling and optimization of LNG production,

1.5. Regasification process.

After the transportation of LNG with LNG carriers the LNG is stored temporarily in LNG gas tanks and then loaded into the regasification systems. The choice of system for LNG regasification at an import terminal depends on its location, heat availability, demand, design safety and legal framework. For example, Ambient Air Vaporizers (AAV) are usually selected in areas with higher temperatures, while in cold areas intermediate fluid vaporizers (IFV) are preferred. The most common systems are the Open Rack Vaporizer (ORV), SCV the Submerged Combustion Vaporizer, the Ambient Air Vaporizer AAV and the Intermediate Fluid Vaporizer (IFV). The main principle is that LNG is reheated with at least one heat exchanger and converted back to its gaseous form as natural gas using two main techniques. In the first one a small percentage of the original LNG is burned in a submerged combustion vaporizer as a heating medium and the second entails the use of sea water or river water through an open rack vaporizer providing the heat for the regasification process.

The main regasification technologies are:

1. "Open Rack Vaporizer (ORV) – An ORV is a vaporizer in which LNG flows inside a tube and is heated by seawater, which is fed through the shell. The LNG flows in from an input nozzle near the bottom, passes through an inlet manifold and is recovered in an outlet manifold placed in the upper part of the vaporizer"[22]. Innovative tube structures are used to prevent the formation of ice in the lower part such as the Kobe Steel SuperORV. The ORV uses seawater as a heat source and is a high flow LNG vaporizer. The "main features of an ORV are the simple construction and operation, high turndown ratio and reliable safety aspect"[23]. The advantage of this system is that water is free, it requires small consumption in energy and no CO2 is produced during the process. The water is gathered in the lower part and its reinserted back into the sea.

[22] Retrieved from Home - Oil&Gas Portal (oil-gasportal.com)

[23] Xu. S. et al, (2016). Thermal design of intermediate fluid vaporizer for subcritical liquefied natural gas, Journal of Natural Gas Science and Engineering, Vol. 32. p 10-19, Elsevier

***Figure 3**. Open Rack Vaporizer (Source. Kobe & Steel LTD)*

2. The intermediate fluid vaporizer (IFV) is a regasification system in which the sea water acts as a heating source, vaporizes the LNG through a medium such as propane and it was developed by Osaka Gas Co. Ltd. A typical configuration involves three tubes, heat exchangers, an intermediate fluid vaporizer and a NG trim heater. Due to the use of "intermediate fluid, the IFV is not subject to freezing and has a wider temperature range of the heating medium"[24]. In comparison with other LNG vaporizers the IFV has the advantages of lower cases of icing and frosting, low requirement to seawater quality, less CO_2 emissions and lower sensitivity to ambient conditions.

***Figure 4**. IFV (Source: Kobe & Steel LTD)*

[24] Mokhatab S. et al, (2013) Handbook of liquefied natural gas, Elsevier

3. The submerged combustion vaporizer system (SCV) – contains "a submerged burner that burns a fuel gas necessary for the vaporization of LNG flow. It comprises a tank, the burner, a bundle of heat-transfer tubes, combustion-air fan and a fuel-supply control device"[25]. "The submerged combustion vaporizer utilizes the combustion heat from the produced natural gas or boil-off gas. Because of its compact structure and quick start-up ability, SCV is widely equipped among the world's LNG receiving terminals"[26]. The LNG flow in this system is warmed by flowing through tubes that are submerged in a water bath that is heated by exhaust gas. The overall thermal efficiency is very high.

4. The last regasification system worth mentioning is the Ambient Air vaporizer. It is the less complicated heat exchanger which vaporizes "liquified gas by using the heat absorbed from the ambient air. Due to this simple principle these vaporizers do not require external power"[27]. They have low maintenance cost and no movable parts. They are used in other applications for vaporizing other cryogenic fluids such as liquid nitrogen. Ambient air vaporizers have a smaller heating capability, and they are not suitable for base load LNG regasification plants. However, in comparison to other regasification systems that use sea water or fuel gas for heating, AAV technology is considered[28] more environmentally friendly.

[25] Retrieved from Home - Oil&Gas Portal (oil-gasportal.com)

[26] Qi C. et al, (2016). Performance analysis of submerged combustion vaporizer, Journal of Natural Gas Science and Engineering. Vol 31, p 313-319. Elsevier

[27] Retrieved from www.22u2.fr

[28] Cryonorm: LNG Ambient Air Vaporizer. Retrieved from https://cryonorm.com/liquefied-natural-gas/vaporizers/ambient-air/

Figure 5. *Ambient air vaporizer (Source: Cryonorm.com)*

According to the International Gas Union, at the end of 2020 global regasification capacity reached 947 MTPA. In the same year 8 new regasification terminals were commissioned reaching an additional 25.9 MTPA capacity. In the beginning of 2021, 11 new floating LNG terminals and 22 new onshore regasification plants were under construction adding an additional 157 MTPA of capacity with ¾ commissioned in Asia[29].

1.6. LNG demand.

Over the past decade, global gas demand has increased and is further expected to increase rapidly with governments willing to invest in cleaner energy to facilitate economic growth.

As indicated before, three LNG trade regions exist: the Asia-Pacific region, the Atlantic Basin region and Europe. At the first stages of the LNG trade, the three regions were logistically diverse with different suppliers and pricing mechanisms. According to GIIGNL the global demand for LNG has reached 360 million tonnes in 2020 from twenty exporting countries towards 43 importing countries. Demand in 2019 was reported at 358 million tonnes. The small increase in volumes in comparison to 2019 indicates the resilience of the global LNG market, in a period when the loss of global GDP was significant, as economies tried to prevent the spread of Covid-19**.** During this period, volatility in prices was observed,

[29] Mokhatab S. et al (2013). Advances and Innovations in LNG Industry: LNG ambient air vaporizer, Elsevier. Retrieved from https://www.sciencedirect.com/topics/engineering/ambient-air

reaching a significantly low point during the pandemic, returning to a record high in early 2021 due to several factors that include a rise in demand in Asia and Europe and unseasonal weather. “The upcoming expansion of LNG export capacity followed by strong investments in the LNG sector, suggests a limited period of supply-demand imbalances and price volatility in the coming years”[30].

Forty percent of volumes imported were on a spot or short-term basis in 2021. Still China has surpassed Japan in imports in absolute numbers. China and India increased their LNG imports by 11%, becoming price drivers. According to forecasts as demand continues to grow in Asia, global LNG demand is expected to reach 700 million tonnes by 2040 and at the same time the share of natural gas as primary energy, reached 24,7% of the global energy mix. As a result, more supply investment will be needed in order to cover this growing demand which partly is needed for the hard to electrify sectors.[31]

LNG is playing a significant role in Europe’s energy mix. Between 2012 and 2017 a low utilization of Europe’s LNG regasification plants was observed due to a higher Asian demand, diverting LNG cargoes away from Europe. Despite this fact, LNG imports to Europe grew in 2018 and were substantially increased in 2019. 48.91 million tonnes of LNG were imported in 2018 and 81,59 Mt in 2020 from Europe’s 15 LNG-importing countries representing 15.6% and 22.9%, respectively of the global LNG share.

Based on data from Bloomberg in January 2022 more than 20 LNG tankers were heading to the European region to cover the demand there due to higher prices in comparison to the Asia market, which was a rare occasion. The European market would pay a premium due to its winter season. An additional 14 tankers were waiting for the final orders in order to move the intended to the Asia Pacific market cargos to the European continent as high reserves have been maintained in Asian countries. The expectations for the American LNG have pushed down prices though prices have been running in a wild trajectory the last couple of months. Contracts on delivery of one month subsided to 98 € per MWh in January while on December 2021 they reached an average of 180 € per MWh.[32] For the biggest part of 2021 China, N. Korea and Japan supplanted the European market for the attraction LNG. The prices of LNG cargos according to Platts on Europe were 48,5 $ per million BTU while on the Asian markets were 41 $ per million BTU between October and December 2021.

[30] IEA, World Energy Outlook 2021

[31] Shell LNG Outlook 2021

[32] Stasinou N. (2022). Will the American LNG warm up Europe? Naftemporiki,

According to data from the BP energy Outlook 2021 the charts below represent the overall demand for LNG in Asia, Europe, the Americas and Middle East & Africa[33]:

MAJOR LNG IMPORTS 2020

- *ASIA*

Country	10^6T	GLOBAL SHARE	VARIATION 2020/2019
Japan	74.43	20.9%	-3.2%
China	68.91	19.3%	11.7%
South Korea	40.81	11.5%	1.7%
India	26.63	7.5%	11.0%
Taiwan	17.76	5.0%	6.6%
Pakistan	7.42	2.1%	-8.5%
Thailand	5.61	1.6%	12.2%
Bangladesh	4.18	1.2%	2.5%
ASIA	254.43	**71.4%**	3.4%

- *EUROPE*

Country	10^6T	GLOBAL SHARE	VARIATION 2020/2019
Spain	15.37	4.3%	-2.2%
United Kingdom	13.43	3.8%	-0.8%
France	13.06	3.7%	-16.1%
Turkey	10.72	3.0%	14.4.%
Italy	9.07	2.5%	-7.2%
Netherlands	5.33	1.5%	-8.0%
Portugal	4.07	1.1%	-1.1%
EUROPE	TOTAL 81.59	**22.9%**	-11.6%

33 BP, Statistical Review of World Energy 2021,

- *AMERICAS*

Country	10^6T	GLOBAL SHARE	VARIATION 2020/2019
Chile	2.69	0.8%	9.8%
Brazil	2.39	0.7%	3.2%
Mexico	1.88	0.5%	-61.50%
Argentina	1.37	0.4%	` 13.8%
United states	0.89	0.3%	-`13.6%
AMERICAS	TOTAL 13.8	**3.7%**	-16.3%

- *MIDDLE EAST & AFRICA*

Country	10^6T	GLOBAL SHARE	VARIATION 2020/2019
Kuwait	4.07	1.1%	14.5%
United Arab E.	1.46	0.4%	7.6%
Jordan	0.82	0.2%	-41.2%
Israel	0.57	0.2%	0.0 %
MIDDLE EAST & AFRICA	TOTAL 6.92	**1.9%**	-0.3%

1.7. Total reserves of natural gas and LNG supply.

Data from BP Energy Outlook 2021 show below the total global reserves and their trajectory through discovery of new fields and depletion of old ones.

REGION	2000 TRILLION CM³	2010 TRILLION CM³	2020 TRILLION CM³	SHARE OF TOTAL %
NORTH AMERICA	7.3	10.5	15.2	8.1%
S. & CENT. AMERICA	6.8	8.1	7.9	4.2%
EUROPE	5.4	4.7	3.2	1.7%
CIS	38.6	51.3	56.6	30.1%
MIDDLE EAST	58.3	77.8	75.8	40.3%
AFRICA	11.9	14.0	12.9	6.9%
ASIA PACIFIC	9.8	13.5	16.6	8.8%
TOTAL WORLD	138.0	179.9	188.1	100 %

According to IEA (world outlook 2021) spot natural gas prices have seen an increase and they reached a record high in Europe during 2021 which was ten times the record lows presented in 2020. According to IGU 2021 the growth in exports globally was caused by the

US that exported 11 MT more in 2020 and Australia that exported 2.4 MT more in comparison to 2019 levels. Australia, in 2020, became the largest LNG exporter in the world, exporting 77.8MT in 2020 in comparison to 75.4 MT in 2019, while Qatar exported 0.7 MT less in 2020 from 77.8 MT in 2019. The US, for this period, retained the 3rd position as one of the largest exporters of LNG at 44.76 MT, and Russia remains as the 4th largest exporter with 29.60 MT of exports in 2020. The largest exporting region has been the Asia Pacific region with 131.2 MT of exports.

Below we will briefly analyze the major exporters of LNG such as the USA, Australia, Qatar and Russia in 2020.

- **USA**

According to Energy Information Agency, U.S. LNG export capacity increased significantly between 2016 and 2020. After 2017 the United States became a net exporter of LNG due to increased natural gas production, increases in LNG export terminal capacity and through its extensive gas pipeline network. Between 2006 and 2015, US natural gas production has increased from 50,7 Bcf/day to 72,5 Bcf/day, and the US gas dependency subsequently fell dramatically from 15% to nearly 0%[34]. It was the shale gas revolution that drives the huge increases in US LNG exports in the last years and the expansion of their liquefaction trains.

In 2015 the US LNG export capacity stood at almost 1 billion cubic feet per day, reaching 10.8 billion cubic feet per day at the end of 2020. "In 2015, total U.S. LNG exports were about 28 Bcf towards seven countries. In 2020, U.S. LNG exports reached 2.390 Bcf to 40 countries, and LNG exports accounted for 45% of total U.S. natural gas exports. About half of LNG exports were shipped to five countries in 2020"[35].

The most significant destinations for US LNG exports in 2020 were: South Korea 316.2 Bcf representing 13,3% of overall exports, Japan 287.7 Bcf representing 12.1%, China 214.4 Bcf and 9%, Spain 200.0 Bcf a percentage of 9% and United Kingdom 160.2 Bcf representing a 6.7%. In 2021 46% of US LNG exports went to Asia and 37% to Europe. Expectations reflect that in 2022 an additional 16% increase will occur in comparison to 2021 levels averaging 11.3 Bcf/d.

[34] U.S Energy Information Administration. Natural gas explained: Liquified natural gas.

[35] Retrieved from https://www.eia.gov/

In 2020, the United States had the biggest export increase (+11 MT) due to the commissioning of 5 large-scale liquefaction plants in 2020.

USA LNG EXPORTS 2019-2020	10^6T 2020
ASIA	6.63
ASIA PACIFIC	12.72
EUROPE	18,51
LATIN AMERICA	5.15
NORTH AMERICA	0.76
MIDDLE EAST	0.99
TOTAL 2020	44.76
TOTAL 2019	33.75
INCREASE (%)	32,62%

- **AUSTRALIA**

According to GIIGNL, Australia was the 2nd largest LNG exporter in 2017, exporting 55.86 MT, after Qatar's 77.50 MT. Australia overtook Qatar as the world's largest LNG exporter in 2020 with 77.77 MT. In value terms, Australia in 1989 export capacity of LNG was worth around 100 million USD, representing 1.8% of the global LNG market share. In 1995, its LNG exports reached a total value of 1.4 billion USD, and its market share increased globally to a record high of 12.3%. In 2003, Australia's market share decreased to 5.4%. From 2003 to 2014, its exports increased eight times reaching a total value of 16.6 billion USD. Australia faces strong competition in the global LNG market.[36] In 2021 its market share accounted for 22% globally.

Australia is forced to reduce the cost of LNG production and increase its competitiveness against U.S.A and Qatar. Additionally, just like the European liberalized LNG market, "East Asia is expected to move away from oil indexation towards hub indexation, affecting Australia's LNG export prices in the near future"[37].

[36] Liu Y. et al, (2020).Dynamics of Australia's LNG export performance: A modified constant market shares analysis, Elsevier.

[37] Ibid as reference 35

Australia's exporting capacity is depicted in the following chart.

AUSTRALIA LNG EXPORTS 2019-2020	10^6 T 2020
ASIA	30.71
ASIA PACIFIC	46.92
EUROPE	-
LATIN AMERICA	0.07
NORTH AMERICA	0.07
MIDDLE EAST	-
TOTAL 2020	77.77
TOTAL 2019	75.39
INCREASE (%)	3,2%

- **QATAR**

In 2020 Qatar succeeded in utilizing almost 90% from its liquefaction trains. Qatar's investment of $30 billion in the North Field Expansion project is expected to push Qatar as the world's largest LNG producer by 2025. "QatarEnegy, claimed that the expansion project will increase Qatar's liquefied natural gas production capacity from 77 million tons per annum MTPA to 126 MTPA, through the North Field East (NFE) and North Field South (NFS) expansion projects, with the first LNG train expected to be operational in 2025"[38].

The North Field Expansion (NFE) project has also placed the Middle East, as the region with the largest natural gas investments in 2021. The project "involves the construction of four new LNG mega-trains with a capacity of 8 MTPA each. With the NFE project progressing, this will reposition Qatar as the world leader in terms of liquefaction capacity, overtaking Australia who currently has the most liquefaction capacity" [39]. Today Qatar operates 14 LNG trains with a total production capacity of 77 MTPA and a chartered fleet of 69 LNG vessels.

QATAR LNG EXPORTS 2019-2020	10^6T 2020
ASIA	26.54
ASIA PACIFIC	25.74
EUROPE	21.89
LATIN AMERICA	0.62
NORTH AMERICA	-
MIDDLE EAST	2.34
TOTAL 2020	77.13
TOTAL 2019	77.80
DECREASE (%)	0.86%

[38] Retrieved from Home - Offshore Energy (offshore-energy.biz)
[39] Qatargas, (2021). Pioneer magazine, issue 159.

- **RUSSIA**

Russia comes at the fourth place in LNG exports for 2020 exporting 29.60 MT up from 29.32 MT in 2019. Russian exported 12.58 MT to Europe, a decrease from 15.1 MT in 2019. Still Russia has achieved a high utilization rate for its liquefaction plants. Russia has 44.0 MTPA of proposed liquefaction capacity, in addition to Arctic LNG 2 that consists of a three-liquefaction train system of combined 19.8 MTPA[40] opposite the Yamal LNG site. "Twenty-one new Arc7 LNG carriers are being built for the Arctic LNG 2 project and were designed for year-round navigation along the Northern Sea"[41].

Below is the chart for Russia LNG export in MT:

RUSSIA LNG EXPORTS 2019-2020	10^6T 2020
ASIA	5.79
ASIA PACIFIC	10.71
EUROPE	12.58
LATIN AMERICA	0.08
NORTH AMERICA	-
MIDDLE EAST	0.42
TOTAL 2020	29.60
TOTAL 2019	29.32
INCREASE%	0.95%

Below is a chart accounting for all the LNG exporting countries and their global market share:

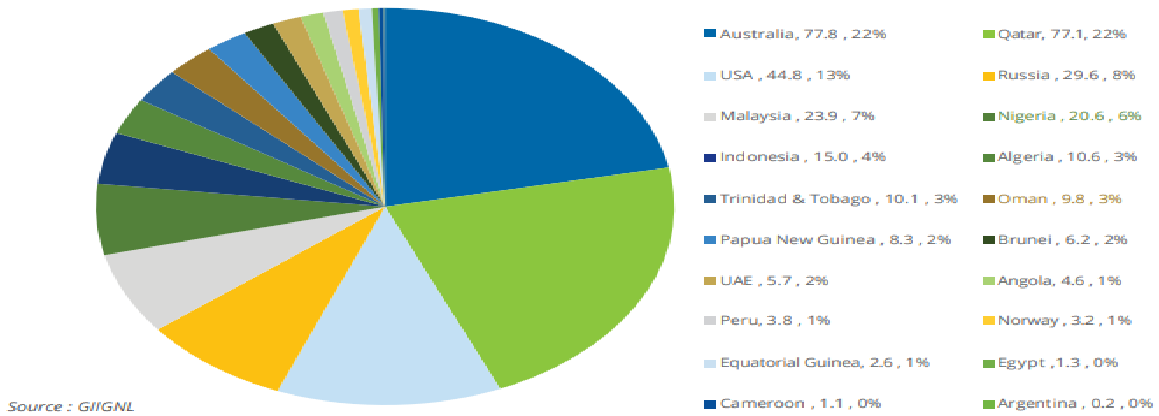


Figure 6. *Overall LNG exports by market (Source: GIGNL 2021)*

[40] Novatek, Project Arctic LNG 2.

[41] Retrieved from https://corporate.totalenergies.ru

1.8. LNG fleet and types of LNG carriers.

According to GIGNL, at the end of 2020, the total LNG tanker fleet consisted of 642 vessels. Of this amount, 43 were floating storage regasification units (FSRUs). Total cargo capacity stood at 95.2 million cubic meters at the end of 2020. In 2020, the average spot charter rate for a 160,000 cubic meters LNG carrier stood around at $59,300/day, compared to $69,300/day in 2019. A total[42] "of 47 vessels were delivered in 2020 while 40 LNG vessels were ordered, compared with 62 new orders in 2019". The orderbook at the end of 2020 consisted of 147 vessels of 22.7 million cubic meters and 7 of those were FSRUs. The orderbook of 2021 represented 24% of the existing LNG fleet and we can realise how investors and shipowners regarded natural gas as a trustworthy investment, capital-wise related to a predicted increase in demand for natural gas.

As the power crisis continues in Europe, factors like the new gas pipeline from Russia to China "Power of Siberia 1" and milder winter temperatures reduced demand for LNG in Asia. According to VesselsValue, in the last months, there was a steady shift of ships from the Pacific to the Atlantic Ocean, creating an oversupply in the Atlantic Ocean. The phenomenon of over sixty ships that were headed to the Asian market, abruptly turned around and diverted their course towards Europe due to the energy crisis in Europe coupled with high charter rates, was highly publicized[43].

Greece and Japan are in the top list of ownership and asset value. There are 142 Japanese owned LNG vessels at this moment, with a value of $18.4 billion. Greece, on the other hand, has 115 vessels but of total value of fleet worth $19.8 billion. "In 2020 a generic five-year-old Large LNG vessel was worth USD 131.31 M, but in 2021 this has grown to USD 152.74 M, a 16.3% rise"[44].

[42] GIGNL, (2021). Annual report.

[43] Delaney G. (2021). A Winter Write Up on the VLCC and LNG Markets, VesselsValue. Retrieved from https://blog.vesselsvalue.com/a-winter-write-up-on-the-vlcc-and-lng-markets/

[44] Retrieved from https://www.hellenicshippingnews.com/a-winter-write-up-on-the-vlcc-and-lng-markets/

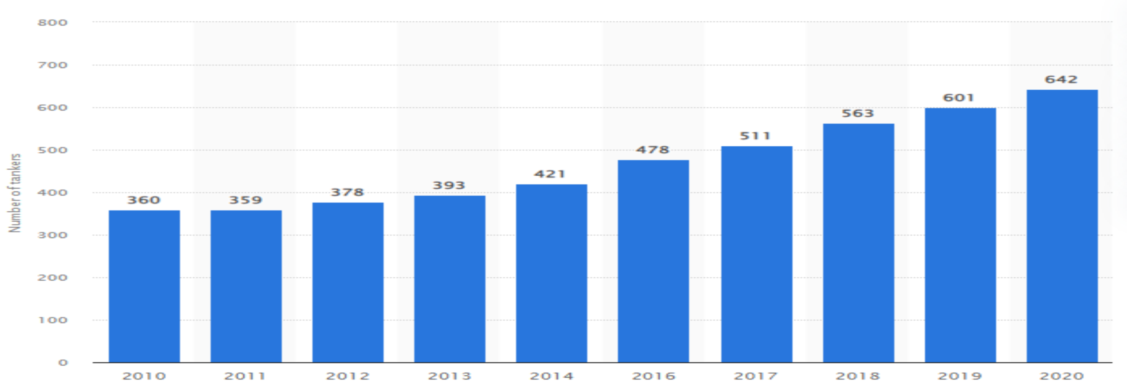


Figure 7*. Growth of LNG fleet (Source: Statista).*

As far as the LNG vessel's ownership by numbers is concerned, Nakilat – with its parent company Qatar Gas Transport Company Ltd. is the largest owner of LNG carriers in the world, with a fleet comprising of 69 LNG vessels. Their vessels are among the youngest and most modern gas carriers, since the formation of the company in 2004. Their LNG fleet comprises of 24 conventional carriers, 31 Q-Flex and 14 Q-Max[45] and it has a combined carrying capacity of almost 12% of the global LNG fleet.

In Greece, the largest shipping group, the Aggelikoussi group has three subsidiaries, Anangel maritime which operates in bulkers, Maran Tankers which controls a tanker fleet and Maran Gas which operates in LNG transport, owns, and operates 44 LNG vessels[46] and their list is completed by 10 new carriers, which are under construction, with a time horizon of 2025. Aggelikoussi Shipping Group is the largest private unlisted shipping group in the world. P. Livanos and his company GasLog Ltd owns 21 LNG carriers[47] while his partners own an additional 16 LNG vessels. Dynagas, a subsidiary of Dynacom Group of George Prokopiou, owns 10 LNG carriers[48].

The Greek shipping companies, based on gross tonnage, own 19,42% of the world fleet or 4.901 vessels, followed by the Japanese with 13% and the Chinese with 12%. The majority of Greek vessels are Ore & Bulk carriers by 46,09 % , oil tankers by 36,64% , LNG/LPG by 3,11%. Greek companies own "30.25% of the world tanker fleet, 14.64% of the world chemical and product tankers, 15.58% of the global LNG / LPG carriers, 20.04% of the world

[45] Nakilat: Our fleet. Retrieved from https://www.nakilat.com/our-fleet/

[46] Maran Gas Maritime INC.: Fleet list. Retrieved from http://www.marangas.com/fleet-list/

[47] GASLOG: Our fleet. Retrieved from https://www.gaslogltd.com/about-us/our-fleet/

[48] Dynagas LTD: Fleet and objective. Retrieved from http://www.dynagas.com/?page=obj

bulk carriers and 9.53% of the world containerships"[49]. In 2008 the Greek share by capacity was 14% while in 2021 the figure reached 19.42 %, consolidating the Greek position in international shipping. In the last years though despite their dominance in the oil tanker fleet, are turning their attention to the LNG market investing in new vessels.

According to the data[50] by Clarksons, Greek shipping companies have placed 40% of the new orders that are currently running in shipyards, mainly in Asia. A percentage that is impressive considering that the share of Greeks in the world fleet is currently around 19%. Greek shipowners continue to invest in new vessels: "Newbuilding orders by Greek interests in 2020 amounted to 104 vessels (over 1,000 gt) or 14.36 million dwt, which represents 11% of global tonnage on the current orderbook. Greek shipowners continue investing in new and energy efficient ships, with the average age of the Greek-owned fleet (9.54 years) being lower than the average age of the world fleet (9.87 years)"[51].

Below is a diagram about the growth in new LNG vessels according to their age.

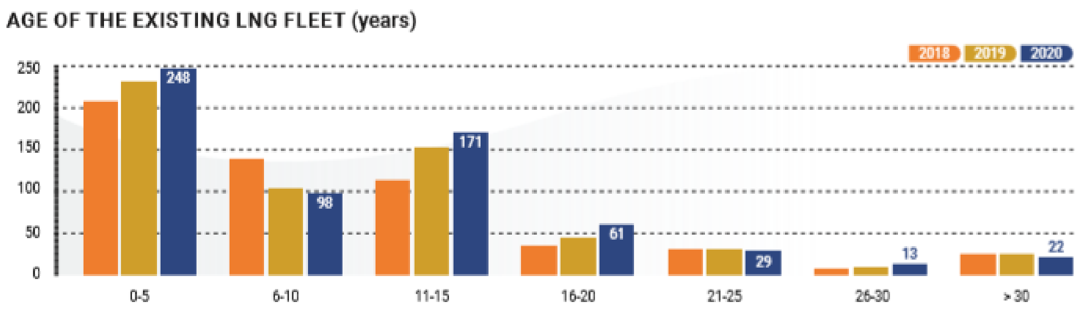


Figure 8. *Age of existing LNG fleet (Source: GIIGN 2021)*

Types of LNG Vessels.

Firstly, LNG ships can be distinguished based on their size: The smallest ones are the Med-max with a capacity of 75,000 cm, then there are the Conventional with a capacity of 125,000-149,000 cm, followed by the Atlantic-max with a capacity of 150,000-175,000 cm

[49] EEE: Greek Shipping and Economy 2021. Retrieved from https://www.ugs.gr/en/greek-shipping-and-economy/greek-shipping-and-economy-2021/

[50] Naftemporiki: A dynamic return of Greeks in the LNG carrier orderbook. Retrieved from: https://www.naftemporiki.gr/finance/story/1500209/dunamiki-epistrofi-ton-ellinon-se-paraggelies-gia-lng-carriers

[51] EEE.: Greek Shipping in numbers. Retrieved from https://www.ugs.gr/en/greek-shipping-and-economy/greek-shipping-and-economy-2021/

and finally the largest ones like Q-flex with a capacity of 210,000-216,000 cm and Q-max with a capacity of 250,000 cm and above. Q-Max vessels are equipped with a re-liquefaction system to control efficiently the boil-off gas.

Secondly LNG ships can be distinguished based on their transportation containment system. There are three types of LNG vessels[52]: **(a)** spherical tank systems (Moss Rosenberg Containment system); **(b)** the membrane containment system and **(c)** SPB prismatic containment system. More specifically:

1. Moss ships usually have 4-5 non-integrated insulated spherical aluminum tanks that protrude from the deck, typically around 40m diameter that are protected by large steel covers. The Moss Rosenberg project was started in 1971 by the Moss Rosenberg Verft shipyard from which it took its name and is widely known for its independent spherical tanks, which often have their tops exposed to L.N.G. tankers. Since the late 1990s, Moss spherical tankers have been the most popular, and their total capacity exceeded the capacity of all other tankers with different types of tanks[53]. By 2000, 54% of all L.N.G. had a global storage tank, the main reason being that the Japanese shipyards were licensed to build only this type of ship, and since the Japanese are also the largest importers of liquefied natural gas, it helped a lot to develop this type of tank. Tanks are usually insulated with many different layers, some of which are: fiberglass, aluminum foil (vapor permeable) and various types of foam. The tanks are heavily insulated with approximately 220 mm of polystyrene foam to reduce boil-off to a minimum. In the event of cracks appearing in the tank material, a small leak of liquefied natural gas into the insulation will be detected at an early stage by the gas detection system installed in the equatorial ring area and in the drip pan. The drip pan, installed directly below each cargo tank, is fitted with temperature sensors to detect the presence of LNG.[54]

[52] Dr Dagalidis A., (2013). Sectoral report 20, LNG vessels, Piraeus Financial Holdings.

[53] Spyridon R., (2018). Dissertation: Analysis of the market for LNG vessels & a turn to LNG fuel, Aegean University

[54] Liquified Gas Carrier. LNG vessel construction- Advantages of Moss Rosenberg technology. Retrieved from: http://www.liquefiedgascarrier.com/moss-rosenberg-containment-system.html

Figure 9. Moss Rosenberg tanks (Source: Marine Link, 2022)

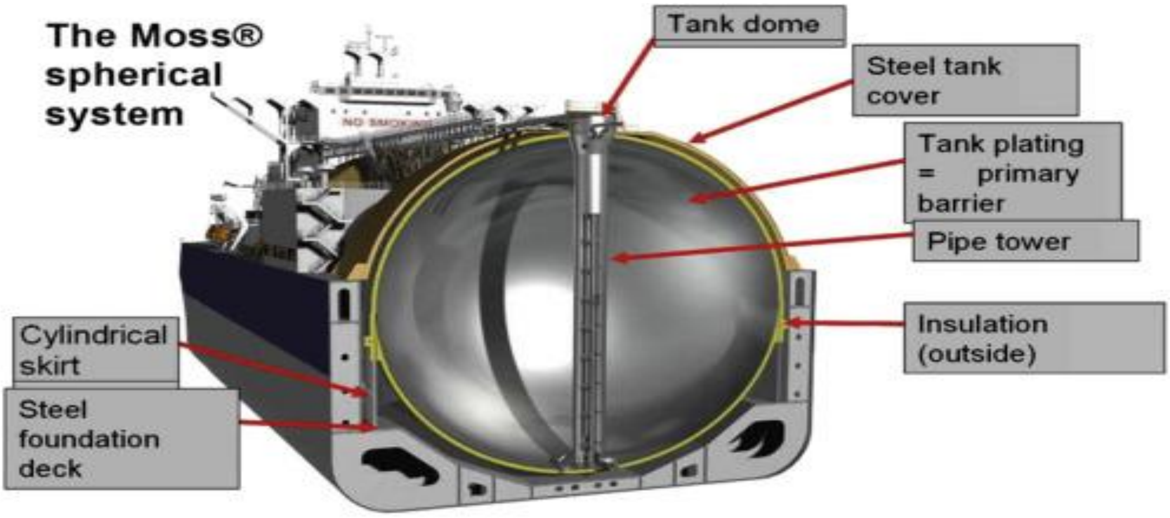


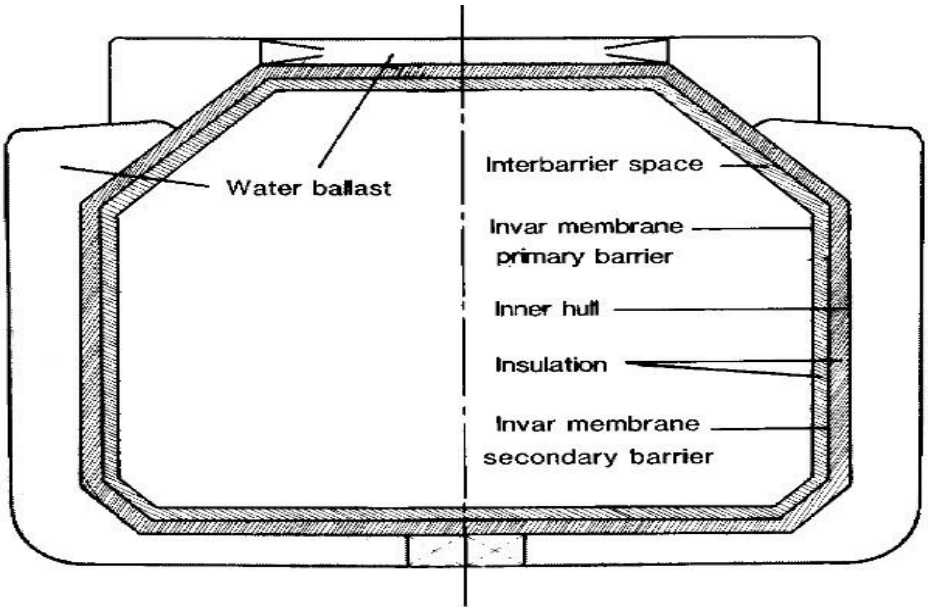
***Figure 10**. The Moss spherical system (Source: ScienceDirect.com)*

2. Membrane Containment System: In the LNG membrane tanks are integrated in the hull of the vessel. Such vessels with membrane tanks were developed during the 1960s. Tanks of this type are integrated in the ship and are not independent like the Moss tanks. The membrane type tank "system consists of insulated cargo tanks enclosed within the inner hull. Cargo tanks are separated from other compartments, and between them, by transverse barriers that are dry compartments"[55]. In this type of tank, the load is held by a thin flexible membrane made of stainless steel or nickel alloy. "The Gaz Transport membrane containment system GT NO96 consist of a

[55] Retrieved from http://www.maxwell.vrac.puc-rio.br/

grillage structure made of plywood and filled with perlite to maintain tightness and insulation"[56], while Technigaz's Mark3 membrane system consists of 2 layers or reinforced polyurethane foam separated by triplex. After their merger in 1994, the two French companies Gaz Transport και Technigaz, created a new tank system, combining the best materials from both systems. This system was named CS1 System (Combined System One).CS1 uses reinforced polyurethane foam insulation and two membranes, the first one is 0,7 mm thick made of invar, the second made of a composite aluminum glass fiber called triplex. Some vessels in this design have suffered secondary membrane leakage problems.

Figure 11. Membrane tank LNG vessel (Source: safety4sea.com)



[56] Mokhatab S. et al, (2014). Handbook of Liquefied Natural Gas: Membrane containment systems, ScienceDirect. Retrieved from: https://www.sciencedirect.com/topics/engineering/membrane-tank

Figure 12. Membrane tank (Source: sea-man.org)

3. Prismatic Containment System (SPB). They consist of independent aluminum containers located inside the hull. It is the newest design but also the most suitable for partial loading of ships, since these are independent containers located inside the hull. Large SPB tanks are subdivided into four spaces by a central shaft, a watertight bulkhead and a transverse bulkhead. The prismatic shape of the tanks ensures a large percentage of the ship's space utilization for the L.N.G. tanks, with the result that the deck is flat and does not protrude. Durable prismatic tanks comply with the principle of leakage before failure, so that if a crack occurs due to fatigue, it will spread slowly, buying time to take the necessary measures. A key advantage is the prism shape as it is the most efficient in terms of space utilization of all systems used. The construction materials are aluminum, stainless steel or nickel steel 9% aluminum is the lightest choice and has been selected for all ships built to date with this system. The main disadvantage of the SPB tank system was the high cost compared to the competitors, this was what prevented its expanded adoption by many shipping companies One of the latest innovations concerns technology that integrates gasification equipment in the tanker. Due to evaporation a tanker can lose 0.15% of liquefied natural gas every day. With the new technology the evaporating gas is captured and regasified.

Figure 13. Prismatic tank LNG vessel (Source: Japan Marine United Corporation)

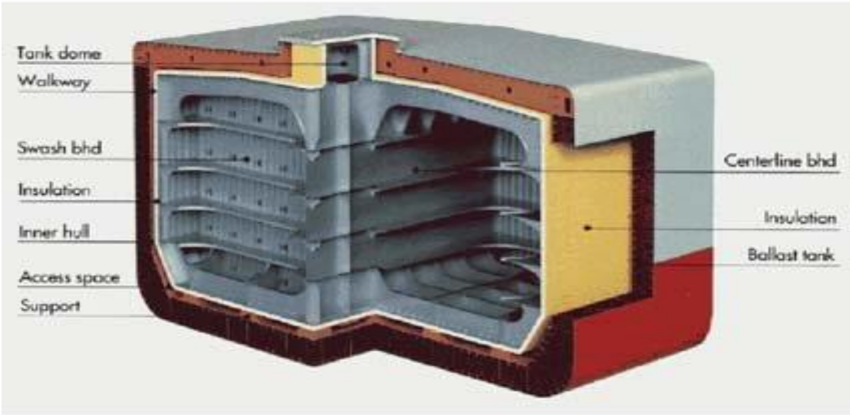


Figure 14. *prismatic tank (Source: researchgate.net)*

CHAPTER 2: THE ECONOMICS OF LNG

2.1. LNG pricing mechanisms.

LNG trade contracts fall under three categories: spot contracts, short-term contracts with an average of 2–5 years, and medium and long-term contracts which have a duration for over than 5 years up to 20 or more. In 1997 short term contracts accounted for 1.5% of international LNG trade and in 2003 they accounted for 8.9 % of the LNG trade. In 2021 the LNG trade in spot market or through short term contracts reached 40% of the global International LNG trade. At the infancy period of the LNG trade, LNG contract terms were identical to pipeline supplies with an average duration of twenty years. The growth of LNG trade coincided with the emerging European spot markets and since the last decade we have seen[57] the trade in spot markets rise with possibilities of diversion of cargoes to other markets.

The initial pricing mechanisms of LNG trade occurred through fixed prices relating to indices such as inflation or destination, they then shifted to Oil price Linked followed by gas-to-gas competition as will be further analyzed below. "Oil price Linked describes the linking of LNG prices to price indices of crude oil, refined oil and other oil products while Gas to Gas competition refers to linking of the LNG prices to spot prices in physical trading hubs such as the Henry Hub in the Louisiana in US or virtual hubs like the National Balancing Point (NBP) in UK and the Title Transfer Facility (TTF) in Netherlands"[58]. Gas hubs are marketplaces that are run by hub operators, where the title on natural gas is transferred to market players by the owners. In spot markets, gas to gas competition is the main pricing mechanism, or formed according to indices like Platts Japan Korean Marker (JKM), which is settled according to a market price while in short term and long-term contracts the pricing mechanism is oil price linked or in combination to gas to gas competition.

In the Asia Pacific LNG market, the most common contract formula is the Japanese Customs-cleared Crude oil price or JCC (also known as the Japanese Crude Cocktail) based on the value of crude oil delivered to Japan. "Buyers and sellers negotiate prices for delivered LNG that usually have three components: a negotiated fixed component, the JCC as published by

[57] Melling A. J. (2010) Natural Gas Pricing and its future: Europe as the battleground. Carnegie Endowment,

[58] Rui Chen et al. (2021). Evolution laws and new trends of global LNG pricing and their implications. Natural Gas Industry B.

the Petroleum Association of Japan, and a negotiated fraction used to multiply the JCC. The fraction normally discounts the JCC component"[59].

LNG pricing mechanisms developed gradually as the LNG market grew, as new players emerged, and changes in international energy markets occurred. Three stages can reflect[60] this development:

In the first stage fixed prices were the norm to the LNG trade. LNG trade occurred firstly in Europe in the 60s long before the North American and Asian markets were created. LNG trade was something new and no benchmarks or other concrete pricing principles existed. Buyers and sellers just negotiated a fixed price through long term agreements. The price reflected, from the buyer's point of view, the domestic natural gas price, the terminal gas cost and the regasification cost while from the seller's point of view key elements were the upstream production cost, liquefaction cost and shipping costs. Examples are the UK's imports of Algerian LNG, which covered a 10 % of overall volumes of UK's consumption back in 1964 and Japan's LNG imports from Alaska's Kenai project in 1969, both contracts estimated in fixed prices without inflation adjustments or any other provisions.

During the second stage oil price linked was the major trend from 1970 till 2000. Back then the pricing mechanism reflected the link between natural gas and other competing fuels such as crude oil, fuel oil and gasoline. "According to a survey from the International Gas Union (IGU)[61], LNG trade in oil linked prices accounted for 87% of the total LNG global trade volume in 2005, while LNG trade with gas–gas competition accounted for only 13%"[62]. Traded wholesale markets began in 1996 with the introduction of the National Balancing point reflecting the liberalized incentives of that period, gradually developing into a regional benchmark price. Up till today NBP and TTF are considered mature trading hubs with high liquidity and a significant number of market participants. With the construction of the Balgzand Bacton Line between Netherlands and the UK further integration[63] of the European markets is achieved through connecting the TTF with NBP.

---

[59] Retrieved from https://www.scribd.com/

[60] Chen R. et al, (2021) Evolution laws and new trends of global LNG pricing and their implications,

[61] IGU Releases 2017 Wholesale Gas Price Survey

[62] Chen R. et al, (2021), Evolution laws and new trends of global LNG pricing and their implications, ScienceDirect

[63] BBL company. Retrieved from https://www.bblcompany.com/

During the third stage and after 2010, the natural gas market became less related to the oil market, severing the price linkage between those two commodities. Oil price linked and gas–gas competition became parallel pricing mechanisms. Since the United States became a net LNG Exporter the prevalent pricing mechanism was gas to gas competition and linked to Henry hub prices. An example is the Long-term agreement that was signed by Total Energy linked with Platts JKM prices for the first time. Carbon neutral LNG "green premiums" of "carbon neutral" products are becoming a significant parameter of the trade prices, pathing the way. Currently, "carbon-neutral LNG makes up a slim portion of global LNG trade, with just 14 cargoes traded transparently since the first shipment was sold in 2019, compared to over 5,000 cargoes of LNG being delivered globally in 2020" [64].

Regionally, LNG oil linked trade is found in the Asia Pacific region. LNG trade linked with gas–gas competition is found in North America and in the European region. LNG exports from the US have been fully linked with gas–gas competition. In Europe, in 2019, the LNG trade linked with gas–gas competition has exceeded 68% of the volumes imported and 32% of the LNG trade is oil linked with a tendency to decline even further.

The UK, in 1996, completed the natural gas market reform which with the creation of the virtual National Balancing Point (NBP). The three legislative reforms in 1998, 2003 and 2007, led to a unified and highly integrated gas market, that will be further analysed in a following chapter. In North America the reform for a liberalized natural gas market occurred in the 1970s with the construction of an extensive system of pipelines, with third-party access privileges. A gas-to-gas competition market soon emerged with the Henry hub. Before gas-to-gas competition US imported LNG with prices linked to oil that were significantly higher than domestic gas, but the US government intervened blocking all the imports at that point. The matter was resolved and imports re initiated when the prices of LNG imports were linked to the local gas prices.

2.2. LNG Sale and Purchase Agreements (SPA's).

The LNG Sale and Purchase Agreement (SPA) is the legal agreement that links the liquefaction plant to the receiving regasification terminal. Sale and purchase agreements are not standardised, but several SPA contract models exist to facilitate major LNG importers

[64] Blanton E. and Mosis S. (2021) The carbon-neutral LNG market: Creating a framework for real emissions reductions, Columbia, Center on Global Energy Policy.

and exporters with various provisions. Most SPAs have become lengthy and detailed documents. There cannot be one single LNG SPA applicable to the entire LNG industry. When the global LNG trade will be fully liberalized, and LNG becomes a truly liquid commodity with hub indexation with Over the Counter contracts the possibility for a unified and standardized model of SPA will become[65] a reality. Traditionally, LNG SPAs have been long-term contracts with a average duration of 20-25 years between a committing seller and committing buyer. The commitment of these SPAs is in the form *"...the Seller commits to sell, and the Buyer commits to purchase* ...". As we have explained in the previous chapter, the liquefaction plant represents a huge investment worth of billions and SPAs help to justify such investments through reliable long-term customers that help secure the initial project finance by banks or other funds.

Banks are risk-averse lenders and won't offer project finance unless an LNG liquefaction plant presells most of its output to credit worthy buyers through SPAs. SPAs are important for buyers as well as they want to procure sufficient supply for their consuming needs at predictable prices.

In every SPA there is a provision for the volume the seller agrees to deliver to the buyer and the volume the buyer is obliged to take each calendar year. In an SPA there can also exist a clause for permitted reductions to the already agreed volume due to reasons of force majeure, inability from the seller to deliver them or volumes that are rejected for being off specification.

In most LNG SPAs there is a "take or pay" commitment, "where the buyer agrees to pay for the committed volume of LNG, even though if it is not taken at this point" [66]. The take or pay provision has been included from the begging of the LNG SPAs and it will continue in the future. On the other hand, to mitigate the risk of LNG not taken, the seller could charge the buyer any reduction in price plus the cost of sale. From the buyer's point of view, a buyer expects the whole quantity agreed at his terminal. Any shortfalls in quantity from the seller could be renegotiated either in money or a future discount. Another interesting provision is the cargo diversion provision that is being contained in recent SPAs. According to this provision the buyer or the seller can divert the cargo to be sold in a different market at a higher price. The costs at the terminal, pipeline tariffs should be considered just as well how the profit from the diversion of the LNG cargo would be split.

[65] International Energy Charter, (2017). Review on Potential Standardisation of LNG Sale and Purchase Agreements, ECS.

[66] U.S Department of Energy (2016). Understanding Natural Gas and LNG Options,

Another important provision worth mentioning regarding LNG SPAs is the pricing review clauses. These clauses aim at preserving a balance between long term contracts and the actual prices on the market often leading to disputes between sellers and buyers through the renegotiation process. They are triggered where specific market conditions are met.

In an SPA, technical provisions are also included such as the minimum specification for the "LNG heating value or non-methane components, quality testing of LNG, LNG vessel specifications and requirements, receiving terminal specifications and provisions for scheduling of cargos"[67]. Besides all these agreement terms, an SPA would also include specific terms of currency of payment, prepayment provisions, letters of credit or other corporate guarantees, the governing law of the SPA, arbitration provisions, transfer of title and risk, force majeure, and confidentiality clauses.

In addition to the point-to-point contracts that include a seller and a buyer at a predetermined destination, portfolio contracts, agreements that don't specify the origin of the supply or the destination for delivery are increasing. According to International Gas Union between 2016 and 2019 portfolio contracts[68] constituted 26 % of Global LNG trade. "The seller can optimize its portfolio by sourcing LNG from anywhere in its portfolio"[69], reducing transportation costs while the buyer can optimize its portfolio by deciding upon flexible and diverse destinations.

Another important point of the Sales and Purchase agreements is the provision in reference to the delivery point and shipping terms that allocate the risk and the cost from the buyer to the seller. Most sales and purchase agreements include one or more provisions that define the destination flexibility a buyer has. The International chamber of commerce has issued several incoterms (International Commercial terms) for buyers and sellers. The most used incoterm is delivered ex ship 'DES' but it has been replaced by the term 'DAT' delivered at terminal in most recent agreements meaning that the seller bears the title and the risk until the LNG is unloaded at the destination agreed. In such case the buyer has limited destination flexibility unless there is a diversion provision signed. Free on Board (FOB) means that buyer bears the title and the risk associated after the LNG is loaded on to the ship and at this point the buyer is responsible for any loss incurred. Unless there are other provisions that state otherwise, the

[67] Retrieved from https://www.energy.gov/

[68] Finizio S., Trenor J. A, and Jared T. (2020). Trends in LNG Supply Contracts and Pricing Disputes in the Asia Pacific Region, Oil, Gas & Energy Law Intelligence

[69] Retrieved from https://www.wilmerhale.com/

buyer has destination freedom and can resell the LNG in other markets or may choose another destination. Cost, Insurance, freight (CIF) refers to when the seller is responsible for "all the costs of transportation from the liquefaction factory to the destination market and the buyer retains the title and risk of the LNG at the liquefaction facility"[70].

2.3. LNG Arbitrage.

Conditions for an LNG arbitrage occur when the cost of shipping LNG between two destinations is less than the price spread between those two destinations. If the price, for example, of LNG at Sabine Pass is $5 per MMbtu, the price of LNG in Japan is $13 per MMbtu, and the shipping costs from Sabine Pass to Japan is $3 per MMbtu, then a $5 arbitrage opportunity exists. in cases of arbitrage, fuel consumption, boil-off, canal costs and the chartering of the ship should all be considered.

Natural gas prices have surged at the beginning of 2022 creating record highs in Europe and Asia with high coal prices and depleted European inventories. According to Lloyd's list a Flex LNG of 172,000 cubic meters shipped from the US Gulf to Japan created an arbitrage of $ 124 M while the US Gulf to Europe route yielded 100$ M profit. Another case of arbitrage is an LNG cargo of $20 M based on HH prices was worth $120 M in Europe and $144 M in Japan[71].

Also, arbitrage occurs when an importer country can re-export a part of the LNGs that has imported in a different market. In long term contracts sometimes the forecast of a country's demand is exaggerated so it is left with LNG cargo that can resell afterwards. An example is the US with its long-term LNG contracts with Qatar. Given the shale gas revolution of the U.S., the LNG imports in the U.S decreased drastically since U.S was able to produce its own gas and prices for natural gas decreased. The remaining volumes from Qatar are diverted to other destinations. This is one of the fundamental cases of arbitrage. Another case in 2007 is "when the Equatorial Guinea LNG project sold its entire LNG output on an FOB basis to Britain's BG for 15 years. This enabled the buyer to divert the cargoes and act as an aggregator, optimizing and reselling their cargo"[72]. Another case of arbitrage occurs when a

[70] Retrieved from https://www.energy.gov

[71] Wiese Bockmann M., (2021). LNG carrier rates top$260,00 per day as arbitrage profits exceed $100m. Lloyd's list.

[72] Dehvani J. and Yegorov Y., (2012). Is LNG Arbitrage Possible in Natural Gas Market? SSRN Electronic Journal.

third party referred to as arbitrageur can buy LNG from exporter or importer countries and sell it in a different market.

Arbitrageurs must take into consideration the transportation costs and face the risk of price changes during the transportation stage due to price volatility. Other cases of arbitrage include the redirection of LNG cargos. It can be considered a case of arbitrage if the cargo is on route to a specific market and changes destination while the buyer and the seller split the profit from the price difference in the markets. Finally, arbitrage can exist through the LNG reloading procedure. In such instance, the cargo is discharged at the storage tanks of the importing country and then reloaded into another LNG vessel. An example is the Zeebrugge LNG terminal that its contractual provisions don't include cargo diversions of LNG but still the LNG cargoes are delivered under DAT arrangement, so the contractual conditions don't violate the LNG contract. In this way[73] it can re- export the cargo without sharing the profit with the initial seller to higher priced markets.

According to Polina Zhuravleva[74] several factors can constitute barriers to Arbitrage. The most significant are further analyzed. The most significant barrier is of course the price differential between markets. Price spread must be high enough for the initial exporter and importer to split the profit. Another factor that hinders arbitrage is the lack of LNG supply. It is the case where a LNG seller is struggling to cover the demand and the buyer is in need of the physical delivery to maintain its security of supply. An example is Japan that doesn't have alternative sources of natural gas and is dependent on LNG to cover its needs.

Another barrier for arbitrage is the lack of price transparency. In Europe, where LNG is a significant source of energy, EU has been trying to liberalize the gas market though the 3 consecutive Directives that we will focus on another chapter. Lack of price transparency hinders the arbitrage trade and necessitates good connections between the traders.

Moreover, to have arbitrage you need to have experienced brokers and traders that only big companies possess. Another crucial factor that prevents arbitrage is the destination clauses like Ex ship and clauses that prevent diversion flexibility. As the supply grows, markets become more liquid and new liquefaction trains come online there will be higher incentive for the buyer to extend long contracts and provide more contractual flexibility at the same

[73] Zhuravleva P., (2009).The Nature of LNG Arbitrage: an Analysis of the Main Barriers to the Growth of the Global LNG Arbitrage Market. Oxford Institute for Energy Studies.

[74] Ibid as ref. 55

time. Sometimes technical restrictions and vessel specifications make arbitrage impossible. When the seller and the buyer sign an SPA, they agree on a specific LNG quality that refers to calorific value and a certain percentage of impurities. In case of a cargo that its quality is inferior it could be corrected by blending. Not every receiving terminal has quality correction equipment, and this constitutes additional cost. Another technical restriction is that not all LNG receiving terminals can facilitate Q- max[62] (266,000 cm) and Q-flex (average 200,000 cm) vessels.

Another category of barriers falls under the Regulatory and Market restrictions that refer to the level of the liberalization of a market and the level of third-party access. Not every LNG market is liberalized and sometimes the LNG ship authorization can be a lengthy procedure. Also, under the use it or lose it principle a terminal owner has allocated a minimum capacity volume. In case of low demand, the terminal operator will theoretically give access to infrastructure to third parties. During seasons of high demand, regulation may discourage the buyer from diverting a cargo to another market. At the same time though, this can motivate the buyer to procure cargoes from the spot market in order not to lose the offered capacity. Another barrier constitutes the lack of shipping capacity when the LNG vessels operate under tight schedules and there is not sufficient uncommitted shipping capacity. This is not the case nowadays where the LNG shipbuilding market for new vessels is thriving. Finally, reasons for limiting arbitrage can be a lack of regasification capacity at the receiving terminal and insufficient hedging instruments to provide a high level of security.

2.4. LNG and financial markets.

Before we explore the market for LNG derivatives some financial definitions such as derivatives, future and forward contracts should be further elaborated:

"Derivatives are financial instruments that transfer risk from one party to another. They derive their value from the value of an underlying right or interest. Underlying rights or interests include loans and bonds which involve interest rate and currency risk and commodities and equities which involve price risks. Underlying rights or interests can also be commodity indexes or relationships between prices like the spread between two benchmark natural gas prices"[75].

[75] Retrieved from https://www.docplayer.net

- Examples of derivatives are the futures, forwards, and swap contracts[76]:
  - A forward contract is a contract between two parties to buy or sell an asset at specific price on a future date. This type of derivative is not affected by price fluctuations and therefor the buyer and seller know the exact price for a given quantity of the commodity. This type of protection is called hedging. It is not standardized but highly customizable and can be used either for hedging or speculation.
  - A futures contract is similar to a forward contract in the way that protects the investor from price fluctuation thus reducing the price risk. It is a legal agreement to buy or sell a commodity asset or a security at a specified time in the future at a predetermined price. These contracts are standardized to facilitate trading on a futures exchange like the Intercontinental Exchange (ICE). The seller of the futures contract is taking on the obligation to deliver the underlying contract upon expiration date while the buyer is taking on the obligation to buy the underlying asset at expiration date.
  - A swap contract is used as a risk management derivative.[77] It involves two parties that exchange cash flows or liabilities from two different financial instruments. Swaps don't trade on exchanges, on the contrary they are OTC derivatives that are customized to the needs of both parties. Swaps are important tools for the global marketplace that can stabilize trade flows by allowing buyers to reduce shipping and logistics costs. Under a swap arrangement, a buyer will swap an LNG cargo produced in one part of the world with LNG sourced from a location that is closer to where the buyer wants LNG to be delivered.

Exchanges are marketplaces for the trade of securities, derivatives, commodities, and other financial instruments. Exchanges are regulated and are the place where interested parties feel secure because the transactions are subject to the statutory or contractual regime that is determined by well-defined rules, under the oversight of a financial regulator and thus the

[76] Heckinger R. (2013). Understanding Derivatives: Markets and Infrastructure. Federal Reserve Bank of Chicago. Retrieved from: https://www.chicagofed.org/publications/understanding-derivatives/index

[77] Weber H. (2019). Centrica loads first contracted LNG swap cargo from Dominion's Cove Point. S&P Global. Retrieved from https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/050219-centrica-loads-first-contracted-lng-swap-cargo-from-dominions-cove-point

structure of the market offers guarantee that the trade will be executed, cleared and settled as intended between the market participants.

- On the other hand, spot trading is a trade where the delivery is immediate, or a minimum time intervenes due to technical limitations. The most common commodities are traded on a marketplace that buyers and sellers interact. There can be a physical transaction or a financial transaction. It is a market where financial instruments such as commodities, currencies and securities are traded. Spot markets are the contrast of the derivatives market that instead trade in futures, forwards or options contracts. The spot price in these markets reflect the demand and supply of a specific market where the buyers and sellers post their buy and sell orders. The two main types of spot markets include the Over The Counter (bilateral trade between a seller and a buyer) and an organized market exchange. Example of a spot trading market is the New York Stock Exchange (NYSE).
- An over the counter (OTC) transaction refers to the process of how securities are traded directly (bilaterally) or indirectly via a broker network in opposition to a centralized exchange. OTC can carry extreme counterparty risk but has no extra fees, no regulation restrictions and low complexity which is estimated upon negotiation. In contrast organised exchanges don't carry counterparty risk but are heavily regulated, are highly complex needing for collaterals. Companies with OTC shares can raise capital through the sale of stock.

Historically, LNG has revolved around long-term contracts called SPA's, as we have seen in the previous chapter, and the pricing was highly linked to the crude oil price and more specifically in the Asian region. An increase in supply capacity from the US, Australia, Qatar and Africa has pushed the market into spot trading. For the time being long contracts that have been signed previously, remain (legacy contracts) until their expiration, but the market is shifting towards spot trading and short contracts. "LNG spot transactions, that are up for delivery in the next 90 days, accounted for around 25% of global trade volumes in 2018 and nearly 40% in 2021 according to the International Group of LNG Importers"[78]. When a natural gas hub has been established and physical trading has commenced, then the development of a futures market appears. "Futures markets are essentially paper markets, and there is no expectation that there will be any physical delivery of the volume of gas, although

[78] Retrieved from https://clydeco.com

any trade can go to physical delivery"[79]. The first natural gas futures market was created by NYMEX in 1990.

An LNG market with pricing independence has created a demand for LNG derivatives as a tool for managing price movements. Currently the most liquid LNG derivatives is the JKM futures contract, which settles against the monthly average of Platts JKM and clears through Intercontinental Exchange and CME Group. As we indicated the spot market is growing, linked to gas-on-gas competition and various indexes have been engineered nowadays. Indeed, the Platts JKM™ (Japan Korea Marker) LNG Price Assessment is the one that is very popular at this moment. S&P Global Platts developed the JKM index in 2009. This index has been increasingly used and it is an ongoing question whether JKM index will retain its popularity in the near future or other indices will be developed.

However, the LNG futures market has yet to reach liquidity when compared to oil futures. "According to a recent study of the Oxford Institute for Energy Studies open interest on ICE stood at around USD 3 billion for JKM futures, compared to USD 10 billion for natural gas futures delivered at the National Balancing Point and USD 145 billion for Brent oil futures"[80].

LNG derivatives and JKM futures are regulated by MiFID 2 and that creates an obligation to report all the derivative contracts. The volume growth of the JKM derivatives in 2018 reached a 256% y.o.y., in comparison to a growth of 295% in 2017. "A more liquid derivatives market tends to encourage physical spot trade as market participants feel more comfortable with taking physical positions that are not hedged against an associated commodity, but against LNG itself"[81]. The record of 46,349 lots of JKM derivatives, the equivalent of approximately 158 cargoes, were traded in 2019,[82] a big increase from the 201 lots that were traded in 2012. Total volumes of JKM derivatives in 2018 amounted to 36 million MT, over a third of physical short-term and spot transactions, an indication that there is plenty of growth potential in the JKM swap as a hedging instrument. Meanwhile, as the derivatives market matures, more and more financial entities are expected to join like traditional players with physical exposure, which could boost the pace of financial LNG derivatives growth in the coming years. In addition, for a derivatives market to function

[79] Retrieved from Columbia | SIPA Center on Global Energy Policy
[80] Hatcher C. and Marc P., (2019). The rise of LNG Derivatives, Clyde & Co.
[81] Retrieved from https://businessdocbox.com/
[82] Abreu A. (2019).New horizons: The forces shaping the future of the LNG market, S&P Global

properly, it needs an adequate number of commodity traders. Despite the growth in the LNG financial markets the majority of LNG portfolio hedging will continue to transpire at the already liquid hubs like NBP & HH.

"Platts Analytics estimates[83] that as much as 60%-80% of US LNG was either swapped or sold on spot/short-term basis in 2018. In a typical swap, a buyer will exchange an LNG cargo produced in one part of the world to another location that is closer to where the buyer wants the cargo to be delivered". Such arrangements allow both parties to reduce shipping and logistics costs. In 2019 the cleared derivatives trade volume equated to 27.7% of the total physical market while in 2018 paper trade amounted to only 7.7% of the physical market size[84]. An increase in paper trade is not surprising if we consider the annualized volatility of JKM during 2019. However, the interest on these derivatives contracts has continued to grow significantly in 2019. This indicates that the exposure to spot market pricing in the physical LNG market has also increased.

2.5. Market inclination towards an Asian hub development.

According to Patrick Heather,[85] for a hub to reach maturity some prerequisites need to exist. Firstly, the gas prices need to be deregulated and gas sales ought to become distinguished from the gas transmission process. Secondly the market allows for third party access to transport facilities and terminals. All the potential infrastructure users have non-discriminatory access. Thirdly the bilateral trading prevails between parties such as producers that can trade directly with end users and distributors. Also in a mature hub one important factor is the price transparency and the accurate depiction of volumes traded. Price reporting entities publish pricing information in a daily, weekly and monthly basis. In addition to price transparency a hub must offer standardized contracts and uniform trading rules. This makes trading more efficient and reduces transaction costs. Over the counter trading occurs and brokers and financial institutions engage in the market and offer liquidity. A mature hub also provides price indexation. Pre-reported prices add up to the liquidity and the index provide the indication for a reference price in long term contracts and the market is more balanced.

[83] Weber H. (2019). Centrica loads first contracted LNG swap cargo from Dominion's Cove Point. S&P Global. Retrieved from https://www.spglobal.com/commodity-insights/en/market-insights/latest-news/natural-gas/050219-centrica-loads-first-contracted-lng-swap-cargo-from-dominions-cove-point

[84] Roe C. and Konertz F., (2019). LNG derivatives take off, FIA.

[85] Heather P. (2015) The evolution of European traded gas hubs. The oxford Institute for Energy Studies.

Usually in such a hub, nonphysical traders enter the market to offer hedging instruments and take the price risk based on a hub index. Finally, a futures exchange is developed that offers a trading platform under specific exchange terms. Once the futures market is established, the futures market will set the benchmark prices. The "churn rate" is a measure of traded volume to physical throughput. It is a significant measure of liquidity. It is reported[86] that Gazprom requires a minimum "churn rate" of 15 to consider a hub as credible.

The first gas market hubs were developed in the United States and Canada because of the existence of a physical pipeline transmission system and interconnections that makes a physical gas trading hub possible. The same holds true for UK and Europe. The Asia Pacific is a different system where countries are dispersed with limited pipeline infrastructure, separate national gas markets with little connectivity between them. They rely heavily on LNG procurement to meet the demand of their domestic markets. There is only a small possibility for a pipeline-based model in the Asia -Pacific area. Only China has an extensive network with interconnections importing natural gas from Kazakhstan and Myanmar. Other countries in the Asia-Pacific region satisfy their internal demand through LNG.

The Asian-Pacific natural gas market is a complex and highly diverse market as we indicated before. Due to its geographical formation, it can't be interconnected by high pressure pipelines, like the other natural gas markets. Consuming countries in this region are China, Japan, India, Korea, Thailand, Indonesia, Bangladesh Australia, Malaysia, and Taiwan. In this region several different dynamics and prospects exist. "Firstly, there are the mature and liquid markets of Japan, Korea, and Taiwan, mainly supplied by LNG. Secondly, countries such as China and India, which are emerging and have considerable natural gas demand"[87]. Further on we will refer to the cases of Japan, China and Singapore as possible candidates for the development of a liquid LNG trading hub as the need for balancing the demand and supply in the region emerges.

[86] Shi X. and Variam H. M. P., (2018).Key elements for functioning gas hubs: A case study of East Asia. ScienceDirect.

[87] Retrieved from IEA – International Energy Agency

- ***Japan***

The Japanese domestic energy market has been going through a liberalization reform in the last couple of years. Liberalization[88] of the electricity market started in 2016, and liberalization of the natural gas market began in 2017. The Ministry of Economy, Trade and Industry published its LNG market development strategy in 2016. "It aims to delink LNG prices from crude oil prices and put less emphasis on long-term contracting"[89]. This strategy focuses on the development of a flexible and liquid LNG market, at the creation of an LNG trading hub attracting LNG trade and sending price signals. It also aims at abolishing destination clauses. As far as new LNG contracts is concerned, the restrictive destination clauses are expected to become obsolete. "The Japanese Fair-Trade Commission initiated a study that states that destination restriction clauses in existing LNG SPAs are likely to violate the Japanese Anti-Monopoly Act"[90]. To abolish such restrictions, legal and commercial measures should be taken. Also, the LNG third-party access regulation was implemented, to utilise all the remaining spare capacity and provide free access to infrastructure.

"The regulation prohibits owners of LNG receiving terminals from rejecting third parties without justifiable reason. Before the latest regime, third-party use of LNG terminal capacity had been at the discretion of each terminal owner. By the end of 2018, 18 out of 32 terminals were covered by third party access" (TPA).[91]

Japan at this moment has 33 operating LNG import terminals on the islands while its pipeline infrastructure connects the terminals and nearby markets. Japan has plenty, existing LNG terminals around the country and has an obvious advantage because of its tangible physical infrastructure. "A major step toward the development of a liquid trading hub would be the establishment of reliable price indexes based on competitive market forces. Japan will also try to promote standard practises and uniformity with other countries, improve access to LNG terminals and create a transparent price discovery mechanism, promoting further spot trading"[92].

---

[88] IEA (2013). Developing a Natural Gas Trading Hub in Asia,
[89] Retrieved from https://www.scribd.com/
[90] Retrieved from https://www.gti.energy/
[91] KPMG, (2017). Developing liquidity in the LNG market.
[92] Retrieved from https://pt.scribd.com

- ***China***

China, same as Japan, is trying to set in motion a strategic plan that would establish an LNG market hub, one that could facilitate the whole region, in Shanghai, China's largest city that receives LNG supplies and has an extensive pipeline infrastructure. Moreover, the pipeline network system in China is well developed and is connected to all its LNG terminals.

The Chinese market is in the middle of structural reforms that would help them adopt gas prices based on global market prices. "Three sets of prices prevail at the moment: domestic pipeline gas priced by formula, LNG and imported pipeline gas priced under bilaterally negotiated long-term contracts, LNG and imported pipeline gas priced in reference to oil prices such as JCC"[93]. China also still needs to open its LNG terminal and other infrastructure to third parties. (TPA)

In addition, the derivatives LNG market is developing. Shanghai has potential in becoming Asia's LNG trading hub. The disadvantages are the China's judicial system and corporate governance that has attracted negative feedback from the global community.

- ***Singapore***

Singapore is a global oil hub and financial center that has also established a trading market that provides the advantages to also become an LNG trading hub in the Asia- Pacific region.

The Singaporean government is promoting LNG infrastructure but also an LNG trading market. The energy market authority also has set out into creating a secondary gas trading market. In 2006, Singapore set the plan to build an LNG terminal that became operational in 2013 in Jurong island. The Singaporean government has recently decided to build a second LNG terminal. Normally to create an LNG market first you need to create liquidity, but Singapore created the SLlnG derivatives contract given the need for an LNG price index. In comparison to China and Japan Singapore's LNG demand is of course smaller. "It is possible that LNG will be imported and distributed in Asia through Singapore thanks to its geographic location"[94].

Singapore offers some advantages as an LNG market hub for Asia Pacific. Singapore is situated at a strategic location, and its port can facilitate large LNG tankers. Singapore's LNG infrastructure is not that advanced on the other hand. In the last couple of years, it has put efforts into enhancing and updating its LNG facilities and its storage capacity.

---

[93] Retrieved from https://www.scribd.com/

[94] Retrieved from https://kpmg.com

Conclusions

For the development of a trading hub there should be an extensive network of pipelines, storage tanks, physical delivery and a liquid spot price. As stated above, Singapore has developed an independent marketplace for spot LNG for Asia Pacific, with liquidity and transparency but has minimal infrastructure. There are three essential qualities to sum up, besides what Patric Heather describes in his papers, for developing such a hub. The first is that spot markets must be liquid and transparent with sufficient supply and trading volumes. Secondly, the spot market must entail a large community of market participants. And finally, it must be supported by a widely accepted price benchmark with a transparent methodology that can build market confidence.

China, Japan, and Singapore have been in the spotlight for a development of a potential LNG hub but none of these countries have succeeded in creating a competitive wholesale natural gas market. Singapore is more liberalized in this department but is lacking market players and liquidity. Japan and China still need to introduce regulated-third party access in their natural gas market and reduce their government superintendence.

Price signals for the Asia Pacific region cannot be easily defined because of the absence of a mature liquid hub in either China, Japan or Singapore. This absence of a physical market hub has not hindered the emergence of various LNG price indexes "and need not be a limiting factor in the future".[95] The liquidity in LNG trading in the Asia – Pacific region is lagging, and for this reason "the current LNG hub price indexes are all based on assessment and not on actual trading prices".[96] On a similar vein**,** numerous price benchmarks are available for LNG from the main price reporting agencies. "However, these benchmark assessments are largely based on participants' views on what the price would be if a trade were done and not on actual trades".[97]

---

[95] EIA, (2017) Perspectives on the Development of LNG Market Hubs in the Asia Pacific Region.

[96] Shi X. and Variam H. M. P., (2018). Key elements for functioning gas hubs: A case study of East Asia. ScienceDirect

[97] Fullwood M. (2018) Asian LNG Trading Hubs: Myth or reality, Columbia, Center on Global Energy Policy.

CHAPTER 3: THE ENVIRONMENTAL APPLICATIONS OF LNG

3.1. Environmental goals in the shipping sector.

80-90% of global trade is facilitated by international shipping and is responsible for about 70% of global shipping energy emissions. If "the international shipping sector were a country, it would be the sixth or seventh-largest CO2 emitter, responsible for nearly a 3% of annual global greenhouse (GHG) emissions, comparable to Germany"[98]. International shipping is responsible for nearly 9% of global emissions of the transportation sector. The greenhouse gas emissions of the shipping sector have increased from 977 million tonnes in 2012 to 1,076 million tonnes in 2018, an almost 10% increase. "The share of shipping emissions has increased from 2.76% in 2012 to 2.89% in 2018".[99]

The International Maritime Organization (IMO) reports that by 2050 maritime shipping activities would increase on an average of 75% compared to 2020. Up until now, 99% of fuels used in the shipping sector comes from fossil fuels, with heavy fuel oil (HFO) and marine gas oil (MGO) consisting 95% of total consumption. "In 2018 the fuel mix for international shipping consisted of 79% heavy fuel oil (HFO), 16% marine diesel oil (MDO), 4% liquefied natural gas (LNG) and less than 0.1% methanol"[100]. The shipping sector needs alternative fuels in order to lower emissions from its activities. The use of alternative fuels, such as LNG and hydrogen, are gaining momentum. We will analyse the use of LNG as an alternative fuel in the shipping sector in the next section.

The mission of the International Maritime Organisation is to promote sustainable shipping through cooperation with the relevant stakeholders. The key features of the Initial GHG Strategy of IMO "are a) to reduce the carbon intensity of international shipping, compared to 2008 levels, by 40%, by 2030, b) to increase that reduction to 70% by 2050, c) to reduce the GHG emissions from international shipping, compared to 2008 levels, by at least 50%, by 2050, d) to achieve zero GHG emissions coming from the shipping sector as soon as possible, within this century"[101].

---

[98] IRENA, (2021). A pathway to decarbonize the shipping sector by 2050.

[99] IMO, (2020). Fourth Greenhouse Gas Study.

[100] Ibid as reference 95

[101] IMO, (2018). Initial IMO GHG Strategy.

Japan, as one of the major players in global shipping and the shipbuilding sector, is working on a four pillar, pilot program which is based on its initiative "*Roadmap to Zero Emission from International Shipping*'' report[102] that came out in 2020.

- The report is based on three emission reduction solutions: **(a)** LNG, provided that LNG transitions to carbon recycled methane, a synthetic fuel produced from the captured CO2 and Hydrogen, **(b)** expansion of hydrogen as fuel, **(c)** adoption of ammonia as fuel, and **(d)** expansion of zero Emission Ships by 2050.

As the world's largest container shipping company, Maersk has a target of reaching carbon neutrality by 2050. Maersk won't be selecting LNG as a bridge fuel for the company's fleet. According to Søren Skou's, Chief Executive Officer of A.P. Moller – Maersk, comments *"We don't believe that LNG will play a big role for us as a transition fuel, because it is still a fossil fuel and we would rather go from what we do today straight to a neutral type of fuel. However, that will be years into the future I suspect,"*, Maersk will opt[103] for methanol as a solution for its new vessels, decarbonizing its fleet.

On 14 July 2021, the European Commission adopted a series of legislative proposals for its goal to achieve climate neutrality in EU by 2050 in accordance with the European Green Deal, known as ''Fit for 55''. According to EU's MRV Regulation 2015/757 (Monitor-Reporting-Verification) by 1st of January 2018, large ships over 5000 gross tonnage in the European Economic Area, are obliged to:

- "Monitor their CO2 emissions, fuel consumption and other parameters, such as distance travelled, time at sea etc".
- "By 30 April of each year all companies, whose ships have performed maritime transport activities in the European Economic Area, must submit to the Commission and to the States in which those ships are registered, a verified emissions report" and
- "All those ships performing maritime transport activities are to carry a document of compliance issued by THETIS MRV. Every year, the Commission publishes a report

[102] Shipping Zero Emission Project, (2020). Roadmap to Zero Emission from International shipping, Japan.

[103] Ovcina J. (2021). Maersk CEO: LNG won't play a big role for us as a transition fuel. Offshore Energy. Retrieved https://www.offshore-energy.biz/maersk-ceo-lng-wont-play-a-big-role-for-us-as-a-transition-fuel/

to inform the public about the CO2 emissions and energy efficiency information of the monitored fleet"[104].

The EU published[105] in July 2021 its update of the European Green Deal, as we have seen before, known as "*Fit for 55*". So far, the shipping sector hasn't been included in the EU'S Emissions Trading Scheme (ETS). The proposals issued on that new legislation among others, include the maritime transportation sector on EU's ETS.

In addition, the Kyoto protocol in its Annex B, commits[106] 37 industrialized countries, economies in transition and the European Union to limit and reduce greenhouse gases (GHG) emissions. There are 192 parties to the Kyoto Protocol and it is regarded as the basis for decarbonizing sectors such as this of shipping, along with the Paris agreement, a legally binding international treaty regarding climate change. Decarbonizing the shipping industry, by using alternative fuels such as LNG is compatible with Sustainable Development Goals (SDG's) 7 about '*affordable and clean energy*' and goal 13 about '*climate action*'.

The 26th Conference of the Parties (COP26), a United Nations Framework Convention on Climate Change (UNFCCC) was hosted in Glasgow in 2021. The COP26 Presidency has promoted several objectives: "to gather new 2030 emissions reduction pledges from countries, empower national adaptation efforts, enhance international collaboration, to mobilize $100 billion in annual financial support for developing countries, to finalize the detailed rulebook for the Paris Agreement and increase collaboration between governments, businesses, and civil societies" [107].

As far as LNG as a fuel is concerned and according to IMO's statistic reports[108] between 2017 and 2018, LNG consumption grew by 15%. Such growth, reveal that in the following years, LNG may attract higher traction, but LNG should not be regarded as the solution to decarbonize the shipping sector, it should only be considered as a bridge fuel towards transitioning to carbon neutrality. Upcoming policies, in the next years, will define the role and the scope LNG shall play against alternative, renewable fuels used in the shipping sector

---

[104] Retrieved from https://ec.europa.eu

[105] European Parliament, (2021) ``Fit For 55'' package under the European Green Deal.

[106] United Nations: Climate Change. What is the Kyoto Protocol?

[107] COP 26: The Glasgow Climate Pact. (2021). Retrieved from: https://ukcop26.org/wp-content/uploads/2021/11/COP26-Presidency-Outcomes-The-Climate-Pact.pdf

[108] IRENA (2021). A pathway to decarbonize the shipping sector by 2050.

as economies of scale unfold, new technologies become available and as they become more cost competitive.

3.2. LNG as marine fuel.

In the EU, ships generated[109] 13.5 % of all greenhouse gas (GHG) emissions from transport in 2018, significantly less than did road transport (71 %) and aviation (14.4 %). According to DNV, "3% of the world's final energy demand, including 7% of the world's oil, is for the moment consumed by ships"[110]. Despite a decrease in activity in 2020 due to COVID-19, shipping is expected to grow and continue to contribute to GHG emissions. For this reason, maritime stakeholders such as regulators, charterers, financiers, cargo owners and governments across the globe are opting for a more environmentally sustainable solution in the shipping sector.

In addition, "financial institutions require Environmental, Social and Governance reporting from their customers. This trend is driven by requirements related to the offering of financial instruments such as green and sustainability-linked bonds and low-carbon funds, and through direct disclosure regulations such as the EU Sustainable Finance Disclosure Regulation (SFDR), on sustainability-related disclosures in the financial sector".[111] Also, the Poseidon Principles is an initiative by major shipping banks to monitor the impact of their ships to the environment through their finance portfolios.[112] The Poseidon Principles are convergent with the ambitions of the IMO, including its initial target for GHG emissions to reduce the GHG emissions each year by at least 50% by 2050 compared to 2008 levels, as we have seen before. In 2020, the Climate Bond Initiative set the criteria for shipping activities in certified green bonds towards zero emissions in 2050. The Regulation (EU) 2020/852 "establishes a framework and definitions of what can be considered sustainable economic activities"[113]. It is expected in the future that poorly performing ships in terms of emissions and shipping companies will be less eligible on the charter market while searching for capitals and funding from major banks. Shipowners should have to ensure that their ship are in alignment of certain initiatives such as the Poseidon Principles or the Sea Cargo Charter that is

---

109 European Parliament (2021) Sustainable maritime fuels: 'Fit for 55' package: the FuelEU Maritime proposal.

110 Retrieved from https://www.dnv.com/

111 Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019

112 Poseidon Principles. Retrieved from: https://www.poseidonprinciples.org

113 Retrieved from https://ers.dnvgl.com/

implementing a 4-step procedure: Assessment of climate alignment, accountability, enforcement, transparency.

The International Maritime Organization (IMO) in 2008 launched its goals relating to the maximum sulphur content in vessel fuels to 0.5% by the 1st of January, 2020. Annex VI of MARPOL requires "vessels to either use fuels containing less than 0.5% sulphur or install exhaust-cleaning systems ("*scrubbers*") to limit a vessel's airborne emissions of sulphur" [114].

The next fuel transition for ships can prove to be difficult. A step away from fossil-based fuels is considered in the right sustainable direction coupled with the need to tackle climate change. Still, the shipping industry doesn't know yet in which fuel is transitioning to, making the future uncertain. Promising alternative fuels, towards 2050 carbon neutrality, include ammonia from electrolysis (e-ammonia), blue ammonia, and bio-methanol. Moreover, bio-Marine Gas Oil, bio-LNG, and synthetic liquefied natural gas (LNG) could pose alternative solutions.

In June 2021, the IMO released several regulations in relation to existing ships: the Energy Efficiency Existing Ship Index (EEXI) concerning the technical efficiency of ships, the Carbon Intensity Indicator (CII) rating scheme concerning the operational efficiency, and the enhanced Ship Energy Efficiency Management Plan (SEEMP) concerning the management system. These new regulations will commence from 1 January 2023.

Indicatively, *advantages* of using LNG as a marine fuel are:

1. No sulphur in its molecular formula meaning there is no SOx emissions or Particulate Matter;
2. Lower Co2 emissions;
3. "Compared to hydrogen and ammonia, LNG has lower implications in toxicity and safety";
4. "Low NOx emissions if Low-pressure DF engine is used" [115]; and
5. Less risk of explosion as a fuel.

with *disadvantages* being:

[114] Parfomak P. W. et al (2019). LNG as a Maritime Fuel: Prospects and Policy. Congressional Research Service

[115] DNV: LNG as marine fuel. Retrieved from: https://www.dnv.com/maritime/insights/topics/lng-as-marine-fuel/index.html

1. Slip methane that is the un-combusted methane leak, high GHG risk;
2. Still and emitter of CO2;
3. Special treatment is required for storage and transportation;
4. High NOx emissions if high pressure DF engine is used;
5. "Capital investment is also required in equipment other than engines, such as fuel tanks 2 to 3 times larger than conventional ones and re-liquefaction equipment"; and
6. "Cost at the time of new construction is 10 - 30% higher compared to conventional fueled vessels"[116].

Globally, the number of LNG-fueled vessels has increased from 18 vessels in 2010 to 175 currently in service, with another 200 vessels on order back in 2020.

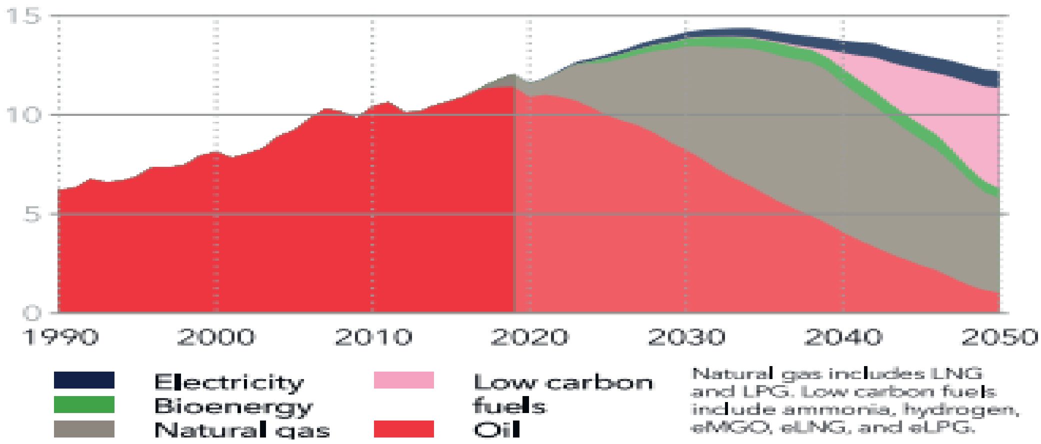


Figure 15. *Estimation of fuel demand by 2050 (Source: IEA 2020)*

The World Bank is placed negatively and states in its report[117] about the decarbonization of the maritime sector:

> "*Liquefied natural gas (LNG), on the other hand, is likely to play a limited role in the decarbonization of the shipping sector, and countries should avoid new public policy supports LNG as a bunker fuel, reconsider existing policy support, and continue to regulate methane emissions to put shipping on a Paris-aligned GHG emissions trajectory"*

[116] Retrieved from https://mfame.guru/
[117] The World Bank. Charting a Course for Decarbonizing Maritime Transport. Retrieved from: https://www.worldbank.org/en/news/feature/2021/04/15/charting-a-course-for-decarbonizing-maritime-transport

The World Bank report questions the benefits of using LNG as a fuel. On one hand LNG has lower carbon content, "yet it remains unclear whether there is a true holistic lifecycle GHG benefit of using LNG in comparison to other fossil fuels. The reason for this is that LNG is liquefied methane, and methane is itself a highly potent GHG"[118]. According to the Intergovernmental Panel on Climate Change (IPCC), "over 20-year and 100-year time horizons, methane is 86 times and 36 times respectively more potent than CO2"[119].

3.3. POSEIDON MED II

As we have seen already in previous chapters, LNG as a fuel is gaining traction and the EU is promoting its use in the maritime industry. In this framework, the project POSEIDON MED II was created, concerning the areas of Eastern Mediterranean and Adriatic Sea, led by QEnergy and coordinated by DEPA S.A. The project is co-funded by the European Union and it involves 5 countries Greece, Cyprus, Italy, Croatia and Slovenia and six European ports: Piraeus, Limassol, Venice, Heraklion, Igoumenitsa including the Revithousa LNG terminal. Main goal is to promote the use of LNG as marine fuel and create LNG bunkering facilities transforming those ports into bunkering LNG hubs. It brings together top experts from the energy, financial and marine sectors in order to collaborate for designing an integrated and sustainable LNG value chain. POSEIDON MED II is the continuation of POSEIDON MED and ARCHPELAGO LNG projects under the 'Connecting Europe Facilities' program. In order to work, this project requires the collaboration of every stakeholder involved through a holistic approach.

According to European Commission its main objectives[120] "are to: **(a)** facilitate the adoption of the regulatory framework for the LNG bunkering, **(b)** design the extension of Revithoussa LNG terminal, **(c)** design and construct an LNG fuelled feeder vessel, **(d)** develop a sustainable LNG trading and pricing pattern, **(e)** develop financial instruments to support the port and vessel installations, and **(f)** develop synergies with other sectors".

---

[118] Retrieved from www.environmentportal.in

[119] Retrieved from https://splash247.com/

[120] European Commission. Poseidon Med II. Retrieved from: https://ec.europa.eu/inea/sites/default/files/fiche_2014-eu-tm-0673-s_final.pdf

Some of the benefits of the project are to help reduce the environmental impact[121] of Heavy Fuel Oil and meet the requirements of Annex VI of the IMO MARPOL Convention about the limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and the requirements of Directive 2012/33/EU regarding the sulphur content of marine fuels as we have seen in previous chapter. The project can contribute towards the implementation of Directive 2014/94/EC on deployment of alternative fuels infrastructure and the Clean Power for Transport Package.

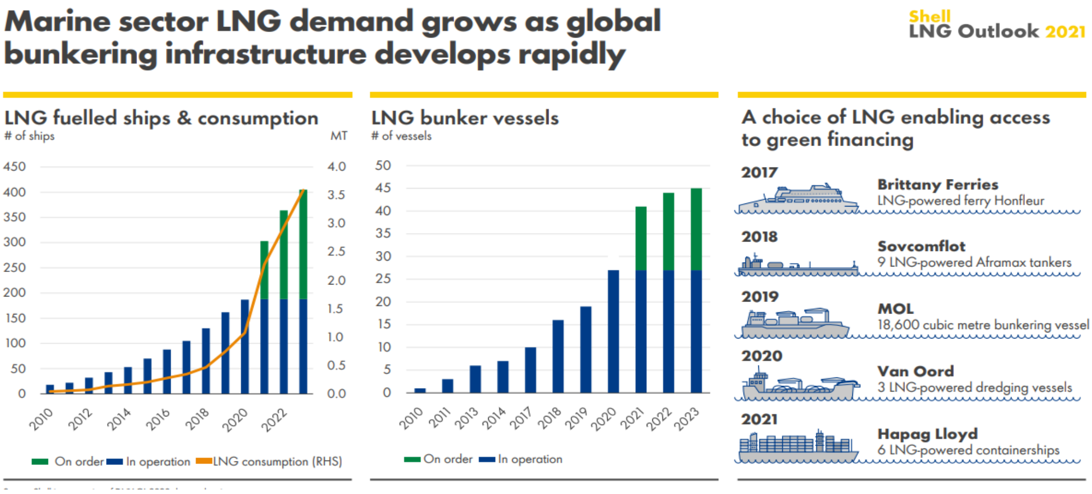


Figure 16. *Marine sector LNG demand (Source: Shell)*

[121] PPA. PoseidonMed II . Retrieved from: https://www.olp.gr/el/prostasia-perivallontos/evropaika-programmata/energa/item/12523-poseidomed2

CHAPTER 4: THE REGULATORY FRAMEWORK OF NATURAL GAS AND LNG.

4.1. Introductory remarks on energy and the European regulatory framework of natural gas.

Energy related dialogue in European level started with the communities of European Coal and Steel Community in 1951, European Atomic Energy Community in 1957 and the European Economic Community in 1957. While atomic energy and coal were regarded a field of common policy between the first six member states Belgium, France, Germany, Italy, Luxembourg and the Netherlands, natural gas and oil remain unregulated and were subject to internal, national policy actions. After the creation of the first energy communities follows the period after 1964 when a common vision for an integrated energy market was envisioned based on competition and the free choice of consumers. It was the stage[92] where national subsidies on coal were receding and the rapid deployment of nuclear plants for electricity generation took place. The next stage is the period during the energy crises in 1973 and 1979. European Comission aimed at the reduction of the energy dependence on oil and its energy imports. The means to achieve this were measures of energy savings, energy efficiency and the utilization of nuclear power. The next stage involves the signing of the Single European act, the first major revision of the treaty of Rome, in 1986. A unified internal energy market was created, followed by the Maastricht Treaty of 1992, that established as a clear target, according to article 3, the implementation of measures in the energy sector that further established the principle of solidarity between member states. The final stage is the Lisbon Treaty that introduced a separate chapter for the common European energy policy. The article 194 of the Treaty for the Establishment of the European Union (TFEU) establishes the main aims of EU's energy policy**[122]** that are:

- "to ensure the functioning of the energy market";
- "to ensure security of energy supply in the Union";
- "to promote energy savings, energy efficiency";
- "the development of renewable forms of energy; and

[122] Iliopoulos K. P., (2014). Issues of European Energy Law. Sakkoulas N.

- the establishment of interconnection of energy networks.

These aims constitute the EU's energy policy.[123]

According to the White paper[124] of the European Commission of 1995, the European commission shall focus on the goals of security of supply, competitiveness, and the protection of the environment and that the energy market integration should be a central part in the European energy policy. Another important landmark in European energy issues was the European Council of Brussels of 24 March 2006 that discussed matters over "competitiveness and the Internal Energy Market, diversification of the energy mix, solidarity, sustainable development, innovation and technology and external energy policy".[125]

In the 1980s and 1990s, liberalization and privatization of European gas markets came up on the political world. The first initiatives to liberalize European gas markets faced strong opposition from the industry that was trying to maintain the monopolistic environment in the gas market. In the beginning of 2000, the European gas market[126] consisted of national markets with heterogeneous regulatory regimes.

During the 1980s and early 1990s, reports from the UK gas and electricity sector showed that more than often, the privatization would only result to the substitution of public by private monopolies. Throughout the decades of the 1980's and 1990's the European electricity and gas markets were operated by national monopolies that were vertically integrated national companies. On one hand the energy sector value chain includes high sunk costs for the development and maintenance of infrastructure and a national vertically integrated company would easily facilitate such costs. On the other hand, national monopolies would distort competition by having no rivals, setting prices at their own volition, hindering entrance to other entrants, and causing problems relating to inefficiencies and under investments of the grid or lacking guarantees for service standards.

One of the first attempts to regulate the electricity and gas sector was the Directive 90/377/EEC '*on electricity and gas price transparency*' that was adopted in 1990. It develops

---

123 European Parliament. Energy policy: General principles.

124 Commission of the European Communities, (1995).White paper.

125 Commission of the European Communities, (2006).Green paper.

126 Haase N., (2008). European gas market liberalization: Are regulatory regimes moving towards convergence? Oxford Institute for energy Studies

a community procedure providing price transparency to the industrial consumers of gas and electricity. Another relevant Directive towards liberalization is the 91/296/EEC '*on the transit of natural gas through grids*' that was adopted in 1991. This Directive aimed at maximizing and facilitating electricity and gas exchanges across non neighboring countries.

At that period, there was no competition and trade between member states in the electricity and gas sector with the only exception of the UK and the Scandinavian countries that had commenced the liberalization process of their energy sectors long before the first Gas Directive 98/30/EC. Electricity prices in Europe were significantly higher[127] than in other places in the world. The development of a single legislative framework was a very difficult task because of the varying characteristics of national energy markets. France and Italy had a highly centralized electricity sector while other countries had already been through the liberalization procedure. Market structures also varied. In order to eradicate the monopolistic texture of the natural gas market and ensure competition, the European Commission issued three main consecutive Directives 98/30/EC, 2003/55/EC and 2009/73/EC.

The aim of these Directives was to create a single European gas market, although the market characteristics differed across Member States. United Kingdom, Germany and Finland commenced the liberalization process trying to unbundle activities in the supply chain and to fully transpose the EU Directives into national legislation. Greece, Belgium, Denmark, France and Spain chose a gradual market opening. Finally, at the time the Directives were implemented countries like Czechia and Latvia were still restructuring[128] their energy markets.

The three Directives aimed at the liberalization of the European gas market. The advantages among others were that consumers could choose their suppliers benefiting from lower prices and provided for competition amongst producers. The Directives proposed by the European Commission were founded on the following principles:

Firstly, the functioning of competition while respecting public service objectives. Secondly, the introduction of competition to the electricity and gas markets, given the time to compete under new market rules and thirdly, the Directives did not introduce a concrete system to all

---

[127] Commission of the European Communities (1999). Second report from the commission to the Council and the European Parliament.

[128] Polemis M. L. and Fafaliou I. Liberalization of the European Natural Gas Market: Myth or Reality? Evidence from Greece, Research Topics in Agricultural and Applied Economics. Vol.1, p168-163.

Member States. Fourthly, the Commission “had chosen an approach based on Article 100a of the Treaty, which necessitates agreement between Member States, followed by dialogue with the Council, the European Parliament and the Economic and Social Committee” [129].

Objectives of the proposed internal market which has been gradually implemented throughout the European Community with the three consecutive Gas Directives, were: to provide more choices to all consumers be it citizens or businesses, the provision of new business opportunities and increase the cross-border trade in the European Union through efficiency improvements, good service standards and at the same time enhancing security of supply and sustainability. The European Union applied the principles of competition, third party access, unbundling, and independent regulators for the liberalization of the Gas market to create an internal market. We will focus on each one of the Directives to analyze the regulatory innovations and the legal framework that was implemented in the gas sector.

4.2. First gas directive 98/30/EC.

The first Gas Directive was the first initiative towards the introduction of a harmonised set of rules for the EU’s gas sector. It established common rules for the internal market with a transposition deadline into national laws by August 2000. This Directive introduced several changes to the functioning of the gas market regulating matters such as unbundling of accounts, Third Party Access, abolishment of exclusive rights, LNG, public service obligations with the objectives of transparency and non-discrimination. Member States would “require the owners of gas pipelines to allow third parties to use their pipelines under regulated conditions (r TPA) or through negotiations of individual contracts with third parties (n TPA).”[130] The first gas directive contains 32 recitals but did not provide any provisions on interconnectors between Member States. We will further elaborate on certain Articles of the first Gas Directive.

[129] Commission of the European Communities. (1998). Report from the Commission to the Council and the European Parliament on State of liberalization of the energy markets.

[130] Leigh Hancher & Anna Marhold (2019), A common EU framework regulating import pipelines for gas? Exploring the Commission’s proposal to amend the 2009 Gas Directive. Journal of Energy & Natural Resources Law.

LNG

All the Member States should ensure, according to article 5, that technical rules should be developed "for the minimum technical design and operational requirements for the connection to the system of LNG facilities, storage facilities, other transmission or distribution systems, and direct lines" [131]. The interoperability of systems should be ensured, and those technical rules shall be objective and non-discriminatory. Article 7 states that "every transmission, storage, or other LNG undertaking shall maintain reliable, secure and efficient transmission, storage and LNG facilities safeguarding the environment and shall not discriminate between system users and more specifically in favour of its related undertakings"[132]. Essential is the provision of sufficient information to any other transmission, distribution or storage undertaking to ensure that the transport and storage of natural gas is performed in compliance to secure and efficient operations. Finally, Article 8 provided for the "confidentiality of commercially sensitive information of the transmission, storage and LNG undertakings" throughout their usual business.

Market opening

The Directive ensures "that the market shall be opened to competition progressively, guarantying that the high gas consuming industry will be given the possibility to choose freely its supplier as eligible customers" [133]. In a ten-year horizon, the market would be liberalized for at least 33% of the total gas consumption during three phases. The first phase was until August 2000 and referred to all gas fired power generators and final consumers with a minimum of 25 million cubic meters of annual consumption. This would lead to a market opening of 20% in each Member State. The second phase was until August 2003 and referred to all gas fired power generators and final consumers with a minimum of 15 million cubic meters. The percentage of the market opening would reach at least 28%. The last phase was until 9 August of 2008 and referred to all gas fired power generators and final consumers with a minimum annual consumption of 5 million cubic meters. At that point the market opening would have reached 33% of the annual gas consumption of the national gas market.

[131] Directive 98/30/EC, Art.5

[132] Directive 98/30/EC. Art.7

[133] Directive 98/30/EC, Art.18

Access to the system & TPA

“Eligible customers will have the possibility to negotiate and conclude supply contracts with any natural gas undertakings, being inside or outside the territory of the Member State. Access to the system for the execution of these contracts will be possible based on two procedures, negotiated access, regulated access or a combination of those two while the choice was left to the Member States. Both procedures must operate in accordance with objective, transparent and non-discriminatory criteria”[134].

According to Articles 15 and 16, when “Member States choose the negotiated Third Party Access the conditions for access to the system are negotiated between eligible customers and the natural gas undertakings. These undertakings are required to publish the main commercial conditions for the use of the system on annual basis. In the case of negotiated Third Party Access eligible customers and natural gas undertakings have a right of access to the system based on published tariffs and other obligations for use of that system”[135].

According to Article 17, “access to the system may only be refused in case of lack of capacity, when this could impede gas undertakings to carry out some public service obligations, and when this would create some serious economic and financial problems with take-or-pay contracts. In the case where a dispute would arise on the conditions for access to the system, it will be possible to refer the case to a dispute settlement authority that shall be appointed by the Member States. Member States must ensure that these rules guarantee a fair and open access” [136] to infrastructure while ensuring the competitiveness of the natural gas market avoiding any abuse of dominant position.

Public service obligations

“Member States have the right to impose on natural gas undertakings public service obligations in the general economic interest. According to Article 3 these obligations must fall within the framework of five specific areas: security, including security of ·supply, regularity, quality, price of supply and protection of the environment. Member States must ensure that these obligations are established under objective, transparent and non-discriminatory criteria”[137]. These public service obligations can be carried out by long term

[134] European Commission, official website (europa.eu)
[135] Directive 98/30/EC, Art.16
[136] Directive 98/30/EC. Art.17
[137] Directive 98/30/EC. Art.3

planning taking into consideration the possibility of third parties wanting to access the system. Member States should monitor the take or pay contracts to balance the supply and demand.

Unbundling of accounts

According to Article 13 paragraph 3 of the Directive, "integrated natural gas undertakings shall keep separate accounts for their natural gas transmission, distribution, and storage activities in their internal accounting, as they would be required to do if these activities were carried out by separate undertakings with the aim to avoid discrimination, cross-subsidization, and distortion of competition. These internal accounts shall include a balance sheet and a profit and loss account for each activity"[138]. Paragraph 4 of the same Article states that the undertakings should also "specify the rules for the allocation of assets and liabilities, expenditure and income, depreciation cases"[139] according to their national accounting rules. These rules shall be amended only in exceptional cases. Article 22 states that "Member States shall create efficient mechanisms for regulation control and transparency to avoid abuse of dominant position"[140], predatory behaviors, or discriminatory practices.

4.3. Second Gas Directive 2003/55/EC.

By 1999, the Commission had already published two reports in relation to the state of the energy sector liberalization, the first[141] in 1998 and the second[142] in 1999. The second report which came out after the first Gas Directive adoption, regarded the liberalization of the European gas market as problematic. The Commission published the report with the ascertainment[143] that *"it is evident that the electricity and gas directives are only a start and much remains to be done for the completion of an internal energy market*". The first Gas Directive only led[144] to moderate market opening, with different degrees of liberalization to interoperate among Member States. Moreover, the unbundling of monopolistic activities in

---

138 Directive 98/30/EC. Art.13
139 Directive 98/30/EC. Art.13
140 Directive 98/30/EC. Art.22
141 Commission of the European Communities (1998). Report from the Commission to the Council and the European Parliament.
142 European Commission (1999). XXIX Report on Competition Policy.
143 Herweg N. (2017). European Union policy making. The regulatory shift in natural gas market, Springer.
144 Eberlein B. (2008) The Making of the European Energy Market: The Interplay of Governance and Government, Cambridge University Press.

vertically integrated undertakings failed as the first Directive wasn't forceful enough. The first directive also failed to set rigid rules for cross-border trade.

In February 2000, the Commission published its contribution to the special European Council meeting in Lisbon in 2000. Behind the European Council meeting was the incentive[145] "*to agree a new strategic goal for the Union in order to strengthen employment, economic reform and social cohesion as part of a knowledge-based economy*" and importantly to reform underperforming sectors. The energy market was included in the list of underperforming sectors.

Market developments, the choices made by the Member States and the difficulties identified in the European Commission's Annual Benchmarking reports led[146] the Commission to amend the first Gas Directive 98/30/EC with a second Directive 2003/55/EC which was adopted in 2003. This Directive extends the liberalization of the gas market to all non-domestic consumers by 2004, and to all customers by 2007. It further includes measures to legally separate transmission network management from procurement activity, strengthens the role of Member States' Regulators, requires the publication of network charges, enhances utilities especially for vulnerable consumers, establishes measures to ensure security of supply, limits the optionality of third-party access and introduces capacity sharing principles and congestion management procedures, as well as transparency requirements. We will further elaborate on the relevant Articles.

LNG

Article 6 provides for the "technical safety criteria and those technical rules establishing the minimum technical design and operational requirements for the connection to the system of LNG facilities, storage facilities, other transmission or distribution systems, and direct lines, shall be developed and made public. These technical rules shall ensure the interoperability of systems and shall be objective and non-discriminatory"[147].

Article 7 states that "natural gas undertakings which own transmission, storage or LNG facilities need to designate one or more system operators. Member States shall take the measures necessary to ensure that transmission, storage and LNG system operators shall be independent regarding their legal form, organization and decision making from other

[145] Lisbon European Council, 23&24 of March 2000,Presidency Conclusions.

[146] RAE, European Law. Retrieved from: http://oldsite.rae.gr/site/categories_new/gas/regulation/community.csp

[147] Directive 2003/55/EC Art.6

activities not relating to transmission"[148] and also preserve the confidentiality of other sensitive information and not disclose them in a discriminatory way. According to Article 8, "each transmission, storage and LNG system operator shall operate, maintain and develop secure, reliable and efficient facilities with regard to the environment and refrain from discriminating between system users particularly in favor of its related undertakings. The operators should also provide any other transmission system operator"[149], storage operator and any other LNG system operator sufficient information to make sure that the transport and storage of natural gas is compatible with a secure and efficient operation while providing other users information to ensure their efficient access to the system. In this second Gas Directive the role of the independent transmission system operator (TSO) is introduced in comparison to the first Gas Directive.

Same as in the first Gas Directive, according to Article 17, natural gas undertaking shall "keep separate accounts for their transmission, distribution, LNG, and storage activities as if those operations were performed by a separate undertaking with the aim to avoid cross-subsidization, discrimination and distortion of competition. The undertakings shall keep separate accounts for supply activities for eligible and non-eligible customers and other non-gas activities while the revenue from ownership of the transmission and distribution network shall be specified in these accounts"[150].

Market opening

According to Article 23, the time horizon for opening the gas market to competition to the free choice of eligible customers had been set to 1 July 2004 for all non-household customers and to 1 July 2007 for all customers. Member states shall publish the criteria for the definition of eligible customer by 31 January each year.

Public service obligations and customer protection

According to Article 3, Member States shall ensure, that natural gas undertakings shall aim to achieve "a competitive, secure, and environmentally sustainable market in natural gas, and shall not discriminate between these undertakings in relation to their rights or obligations. Member States may impose on undertakings operating in the gas sector public service obligations which may relate to security, including security of supply, regularity, quality and

[148] Directive 2003/55/EC Art.7
[149] Directive 2003/55/EC Art.8
[150] Directive 2003/55/EC Art.17

price of supplies, and environmental protection, including energy efficiency and climate protection. Such obligations shall be clearly defined, transparent, non-discriminatory, guarantying equality of access for EU gas companies to national consumers. In relation to security of supply, energy efficiency and for the fulfilment of environmental goals, member states may introduce the implementation of long-term planning, taking into account the possibility of third parties seeking access to the system"[151]. This is the same provision as in the first Gas Directive.

"Member States shall take appropriate measures to protect final customers and shall ensure that there are adequate measures to protect vulnerable customers, including measures to help them avoid disconnection"[152]. In this Directive, consumer protection is introduced.

Third Party Access

According to Article 18, member states shall "implement a system of third-party access to the transmission and distribution system, and LNG facilities based on published tariffs, applicable to all eligible customers including supply undertakings, and applied without discrimination and objectivity between system users. Member States shall ensure that these tariffs, and the methodologies used for their calculation shall be approved prior to their entry into force by a regulatory authority and made public"[153]. We can observe that the optionality between regulated and negotiated third party was made obsolete and that regulated third party access prevailed. The option between regulated and negotiated access to storage facilities remained. According to the same Article, "TSOs carrying out their functions, including cross border transmission shall have access to the network of other TSOs. The provision of this Directive shall not prevent the conclusion of long-term contracts for reasons of security of supply as long as they comply with competition rules"[154].

The Article 19 provides that "Member States may choose between regulated and negotiated access to storage. In the case of negotiated access, member states shall take the necessary measures for natural gas undertakings and eligible customers either inside or outside the territory covered by the interconnected system to be able to negotiate access to storage and

[151] Directive 2003/55/EC Art.3
[152] Retrieved from https://eur-lex.europa.eu
[153] Directive 2003/55/EC Art.18
[154] Ibid as reference 149

linepack, when technically and/or economically necessary for providing efficient access to the system, as well as for the organization of access to other ancillary services"[155].

In 2003, national regulatory authorities established The Council of European Energy Regulators (CEER) following the signing of an MoU 'on the establishment of the Council of European Energy Regulators' in 2000. The main activities of the Council of European Regulators coincide with the responsibilities of national regulators, such as ensuring access to energy infrastructure in a nondiscriminatory way, energy system integration, sustainable and efficient infrastructure, congestion management mechanisms, cross-border trade and information transparency. Also in 2003, by a Commission's decision, the European Regulators Group for Electricity and Gas (ERGEG) was created, having an advisory role,[156] to strengthen the cooperation between national regulators and was given the task to oversee the application of the provisions of Directives 2003/54/EC and 2003/55/EC. On a similar vein, the establishment of the Madrid Forum is important where key stakeholders such as national regulatory authorities, national governments, gas suppliers and traders, Commission, consumers, gas exchanges are gathered to converse in gas related topics and regulation.

On 28 September 2005 the EU Regulation 1775/2005 '*on the conditions for access to the gas transmission networks*' was also adopted. The scope of the Regulation was to establish harmonized principles for transparent tariffs while the methods used to calculate them must represent the costs actually paid. Other targets were access to the network, the establishment of third-party access services by using harmonized transportation contracts, capacity sharing and congestion management, as well as defining transparency requirements. The Regulation establishes[157] non-discriminatory rules on the conditions of access to the gas transmission networks to ensure the proper functioning of the internal gas market.

After the transposition of the Second Directive to national laws and after some years in 2006, the Commission released the findings[158] of the sector inquiry of the public consultations with regard to the Directive 2003/55/EC. In terms of market concentration, the majority of respondents agreed that the EU markets were highly concentrated posing a problem that led

[155] Directive 2003/55/EC Art.19

[156] Commission Decision of 11 November 2003 on establishing the European Regulators Group for Electricity and Gas

[157] Regulation (EC) No 1775/2005 of the European Parliament and of the Council of 28 September 2005

[158] Commission of the European Communities. (2007). Communication from the Commission, Inquiry pursuant to Article 17 of Regulation (EC) No 1/2003 into the European gas and electricity sectors.

to higher prices and market foreclosure. Not only the wholesale and retail markets were dominated by major national undertakings, making the entrance of new players practically impossible but the access to network capacity and storage capacity proved problematic. The Commission at this point launched several individual antitrust investigations in order to ascertain cross subsidies and predatory behaviour by dominant undertakings. Another issue that came up is the vertical foreclosure caused by long-term contracts between producers and suppliers and their effect on investments. Historical gas market players favoured the continuation of such contracts, but the findings resulted in poor congestion management procedures while those contracts were active. Strict use it or lose it (UIOLI) clauses should be included in long-term contracts. Many respondents were concerned that TSOs favoured their own supply businesses and that such contracts led to the dominance of pipeline capacity making market entry difficult because of problems to the effective access of natural gas infrastructure (transit, storage and transmission) and lack of anti-hoarding measures.

The results of this inquiry, according to many respondents, was that there was also a lack of market integration. In order to achieve market integration there should be a sufficient number of players, higher volumes and liquidity, boosting operational integration and efficiency.

Another problem resulting after the implementation of the second Directive was that of limited transparency. Greater transparency would increase the utilization of infrastructure, increase liquidity, provide confidence in price signals. Many entrants, traders and customers recommended greater transparency to allow entrance by providing support to the development of the wholesale market by giving information on pipeline capacity and storage facilities. Finally, the issue of regulated tariffs came up. Many respondents commented that prices might be set below the wholesale price benchmark and that would hinder the competition, preventing new entrants from entering the market and in particular in member states such as France, Spain and new Member States.

In Greece, Law 3428/2005 transposed the 2003/55/EC Directive. One important provision of this Law was the prolonged period of market opening that allowed further competition in the natural gas market. It established that power producers and co-generators with annual consumption of 100 GWh could choose their supplier freely. Another important provision was the establishment of the Hellenic Gas Transmission System Operator (DESFA).

4.4. Third Gas Directive 2009/73/EC.

On July 2009, the third Directive (2009/73/EC) was adopted, which was part of the Third Energy Package and aimed to the effective separation of gas transmission system operators from generation and supply activities through three alternative models: ownership unbundling, independent system operator (ISO) and independent transmission system operator (ITSO). The aim of this separation is to apply the principle of "*non-discrimination*" to all new stakeholders, by ensuring institutional and operational independence of the TSO. The Commission favors the complete ownership separation of companies that own and operate transmission systems as this ensures the independence of transmission system operators from vertically integrated companies in line with the objectives of the Third Energy Package.

Main goals of the third Gas Directive were to facilitate cross-border energy trade by promoting regional cooperation, achieving greater market transparency regarding network operation and procurement, ensuring the independence of national regulators and increasing solidarity between member states in order to procure security of supply. It reaffirmed Third Party Access, ownership unbundling and market supervision. It also established the mandatory cooperation of Transmission System operators to harmonize rules governing energy transmission in Europe. The third Gas Directive "remains the most important secondary legislation regulating the internal market for gas to date"[159]. The Third Energy Package provides that only one National Regulatory Authority may exist in a Member State.

Member States completed the transposition of the Third Package into national law by March 2011 except for the separation of gas transmission system operators, for which the deadline was March 2012. The Third Energy Package also included the Directive 2009/72/EC for the electricity sector, the EU Regulation 713/2009 '*on the establishment of the Agency for the cooperation of Energy Regulators*' (ACER), the Regulation 714/2009 for the electricity sector and finally the Regulation 715/2009 that amended the Regulation 1775/2005.

Moreover, Article 10 contains rules on the designation and certification of transmission system operators TSOs.

[159] Leigh Hancher, Anna Marhold (2019). A common EU framework regulating import pipelines for gas? Exploring the Commission's proposal to amend the 2009 Gas Directive. Journal of Energy & Natural Resources Law.

LNG

The regulatory authorities are required[160] to "ensure that technical safety criteria are defined and that technical rules establishing the minimum technical design and operational requirements for the connection to the system of LNG facilities, storage facilities, other transmission or distribution systems, and direct lines, are developed and made public. Those technical rules shall ensure the interoperability of systems and shall be objective and non-discriminatory. The Agency (ACER) may make appropriate recommendations towards achieving compatibility of those rules, where appropriate"[161].

Article 12 states "that each Member State shall designate or shall require natural gas undertakings which own storage or LNG facilities to designate one or more storage and LNG system operators"[162]. It follows the previous gas Directive on this regard. Article 13 describes the basic tasks of transmission, storage and/or LNG system operators that are: "**(1)** to operate, maintain and develop reliable and efficient transmission, storage and LNG facilities to secure an open market safeguarding the environment, **(2)** refrain from discriminating between users and particularly between its related undertakings, **(3)** provide any other transmission-storage-LNG system operator with sufficient information to ensure that transport and storage of natural gas is carried out in a secure and efficient way and **(4)** to provide system users with information to access the system efficiently"[163].

Article 29 states that unbundling procedures on DSOs "shall not prevent the operation of transmission, LNG, storage, and distribution combined system operator"[164] such as DESFA in Greece. Article 30 describes how "the member states, or any other competent authority designated by them, including the National Regulatory Authorities can have the right of access to the accounts of natural gas undertakings"[165] as set out in Article 31.

According to Article 31 regarding unbundling of accounts, "natural gas undertakings, whatever their system of ownership or legal form, shall submit to audit and publish their annual accounts in accordance with the rules of national laws. Natural gas undertakings must keep separate accounts for each of their transmission, distribution, LNG, and storage activities as they would be required to do if those operations were performed by separate

[160] Directive 2009/73/EC, Art. 8
[161] Retrieved from https://dokumen.pub
[162] Directive 2009/73/EC. Art 12
[163] Directive 2009/73/EC. Art. 13
[164] Directive 2009/73/EC Art.29
[165] Directive 2009/73/EC Art.30

undertakings, to avoid discrimination, cross-subsidisation, and distortion of competition" [166]. They shall also keep accounts "for other gas activities not relating to transmission, distribution, LNG, and storage. Revenue from ownership of the transmission or distribution network shall be specified in the accounts. Where appropriate, they shall keep consolidated accounts for other, non-gas activities"[167]. This provision requires the same account unbundling as in the previous gas Directives. Finally, Member States must implement "a system of third-party access to the transmission and distribution system, and LNG facilities for all eligible customers based on published tariffs, including supply undertakings, and applied objectively and without discrimination between system users" [168].

Another important provision is Article 36 about new infrastructure and the exemption mechanism for refusal of TPA to users for a defined period of time. More specifically, the exemption is allowed under the following five conditions, "namely: **(1)** the investment must enhance competition in the supply segment and enhance security of supply, **(2)** to allow investments that are connected to high levels of risk to proceed, **(3)** the infrastructure must be owned by a natural or legal person whose legal form shall be separate from the system operators in whose systems shall be build, **(4)** charges must be imposed on users of that infrastructure, and **(5)** the exemption must not be detrimental to competition or it effects severely the functioning of the internal market of natural gas" [169]. According to par. 3 of the same Article the regulatory authority may decide on this exemption on a case-by-case basis.

The application in Greece

The Greek market of electricity and natural gas is regulated by the Law 4001/2011 *"For the operation of Energy Markets for Electricity and Natural Gas, for Research, Production and Hydrocarbon transmission networks and other provisions*", (Government Gazette A '179 / 22.8.2011) which replaced the Law 3428/2005. Law 4001/2011 transferred to the Greek legal order the Third European Energy Package, i.e. the Directives 2009/72 EC and 2009/73 EC and the Regulations 713/2009, 714/2009 and 715/2009 with the goal of further integration of the internal market in electricity and gas and the creation of equal access conditions for all electricity and gas companies operating within the European Union. The model of the

[166] Directive 2009/73/EC, Art. 31

[167] Directive 2009/73/EC. Art.31

[168] Directive 2009/73/EC, Art. 32

[169] Directive 2009/73/EC Art.36

Independent Transmission Operator (ITO) was adopted for the natural gas Transmission Operator, which is the company DESFA and was enforced with the Law 4001/2011. DESFA, stands in accordance with the requirements of the legal framework of the 3rd energy package but in order to ensure its independence, it is equipped with all the necessary resources and fixed assets: it owns the infrastructure of the transmission network. DESFA SA also owns the LNG Facilities on the island of Revithousa, that is managed under a regulated third-party access regime.

4.5. Remarks about the Gas Directives.

The Second and the Third Gas Directive treat all Member States equally in terms of market opening while the First Gas Directive defines different stages of market opening. The provisions regarding third party access became more severe. The First Gas Directive introduced negotiated and regulated TPA, while the Second and Third Gas Directives regulating the matter only require regulated TPA, except for the access to storage facilities, where Member States could elect negotiated TPA. The first gas Directive introduces account unbundling, while the Second Gas Directive adds functional and legal unbundling of its distribution and transmission activities.

The main target of the Third Energy Package was to confront the problems as suggested in the sector inquiry and the Commission's assessment on the two previous packages as we have seen previously. The objectives of the packages were to create an integrated, transparent European energy market, enhance competition through better regulation, unbundling of energy related activities, improve security of supply by establishing incentives for new investments in infrastructure and secure consumer protection. The Third Energy Package contains the most important Regulations and Directives applied in the energy sector until today. It aimed to strengthen the conditions for competition that previously had been hindered by Vertical Integrated Undertakings that dominated the market, controlled the essential facilities, and enjoyed significant market power. According to Article 10 of the Directive 2009/73/EC a candidate TSO must be first certified by a National Regulatory Authority (NRA) before it can start to operate. It must first apply to an NRA for the commencement of the certification process or upon a request from the Commission. "The designation of all TSOs shall be notified to the Commission to be published in the Official Journal of the European Union. The certification process has given the Commission the tool to dictate regulation at a national level meaning direct access to regulates in the area of competition law".[170] According to Article 36 par.8 of the same Directive the NRA should notify the Commission for any exemption request to access of new infrastructure and then the Commission would reach a decision whether to approve it or require the NRA to withdraw it. It is another example of direct access dictating rules over the NRAs and TSOs. Another innovation that the Third Energy Package introduced was the creation of independent National Regulatory Authorities with the objectives of regulating access to gas, certify TSOs compliance with unbundling rules and approve network plans. Notably, the transposition of the provisions contained in the Third Energy Package proved challenging for all Member States that none of them succeeded in fully transposing them by March 2011 which was the deadline.

As a consequence, the Commission opened a large number of EU Pilot cases and infringement procedures towards Member States for failing to implement the Directives.

4.6. Third Party Access.

In order to create an open and non-discriminatory energy infrastructure based on free competition a necessary condition is that third party access (TPA) rights should be granted to competing companies, for the transportation, delivery and trade of natural gas. According to the Commission, "TPA rights are crucial because network owners or operators keep strong relations with energy producers and suppliers and they usually avoid granting access to third parties, especially in areas where they will be competing with the TSO itself or an affiliated company"[171]. The cost of a new network is practically inconceivable due to environmental and social reasons and is strongly related to natural monopoly structures. TPA is distinguished between negotiated and regulated access as we saw previously through the elaboration of the Gas Directives. First Gas Directive introduced an optionality between regulated and negotiated TPA and regarded them as equals. Second and Third Directives imposed regulated access but still the negotiated access remained on the table for the access to storage facilities only. According to the preamble of the third Gas Directive: "*Only the removal of the incentive for vertically integrated undertakings to discriminate against competitors as regards network access and investment can ensure effective unbundling*"[172].

[170] Hancher L. and Salerno F. (2017). Analysis of Current trends and a First Assessment of the New Package, EE Research Handbook, Chapter 4, SSRN.
[171] Retrieved from https://works.bepress.com/
[172] Retrieved from eur-lex.europa.eu

The process of ownership unbundling is related to third party access. Entrance barriers[173] to the market should be kept to a minimum so that new entrants would emerge and compete to the benefit of consumers.

The changes of global liquefied natural gas markets, including the recent need to create an Asian trading hub as we saw in a previous chapter, the increased flexibility through an expansion of spot and short-term trade, liberalization efforts in the Asian markets and the appearance of new exporters and importers deems necessary the unobstructed access to existing regasification terminals. In 2017, "around 420 million tons per annum (MTPA) or 54 percent of global regasification capacity offers[174] some kind of third-party access. However, this access happens in practice mainly in Europe". Access to LNG terminals is quintessential for the liberalization process in the Asia market. A functioning and open trading hub requires free access to the LNG infrastructure and their respective pipelines. Whether the regasification terminal remain inaccessible by new entrants is a question of market maturity.

In Europe, U.S., Singapore and partially in Japan, countries that have already undergone a liberalization process, capacity offering TPA is established. In practice though, TPA is mostly implemented in Europe.

Third Party Access to regasification terminals is an essential process in order to expand the free trade of LNG, to accelerate the spot and short-term trade of LNG, help importers to resell their extra quantities under contractual agreements with destination clauses that hinder the process. In practice, however, third parties often face regulatory and operational obstacles in their uninterrupted access. This holds true for countries such as Japan. China only offers limited TPA, while Korea is lagging in that respect. The LNG terminal in Singapore offers TPA.

As we can recall from the Third Gas Directive and from article 36, the national regulator may grant exemptions to Third Party Access to developers of new import facilities. Up until now, only six cases exist that exempt EU's regasification terminals. Three are in the United Kingdom (Grain LNG, Dragon LNG and South Hook LNG), in France (Dunkerque), in Italy (Rovigo), and one in the Netherlands (Gate). Where a TPA exemption has been granted,[175]

---

[173] Diathesopoulos M. D. (2010) Third Party Access and Refusal to Deal: How sector regulation and competition law meet each other, SSRN.

[174] Six S. and Corbeau A.S. (2017). Third-Party Access to Regasification Terminals: Adapting to the LNG Markets' Reconfiguration, KAPSARC.

[175] King & Spalding, (2018). LNG In Europe. An Overview of LNG Import Terminals in Europe.

“the owner of the LNG terminal can negotiate contracts directly with its primary shippers/customers while the national regulator monitors anti-hoarding mechanisms and ensures that shippers have access to a sufficiently transparent secondary market”[176].

[176] Retrieved from https://globallnghub.com/

CHAPTER 5. Discussion & Conclusions

DISCUSSION

We have seen how the LNG though short-term contracts and spot market increased to a 40% in 2021 of total trade. The results of this study indicate that there is a steady availability of LNG from the major exporters to meet the growing demand by importers through shorter term contracts. This is further suggested by the rise of the global LNG fleet to facilitate the growing demand for LNG. The recent expansion of Qatar's, U.S.A.'s, Russia's and Australia's liquefaction trains show that investments have already been sanctioned to satisfy the growing demand for LNG. These results are consistent with the recent decision of EU to phase out of the Russian energy dependency and is based on a large extent on the spot markets to cover its extended demand for LNG and to replenish its natural gas inventories. This is a perfect opportunity for further R&D on renewable sources of energy to further facilitate their penetration in European markets and worldwide. Hydrogen is considered by many Governments, scholars and energy institutions as the fuel of the future, therefor further research should be undertaken in this field in order to help transition to carbon neutral solutions in alignment with the Paris Agreement.

There is also abundant room for progress in determining in which fuel the shipping industry is transitioning to. In 2018 the fuel mix for international shipping consisted of 79% heavy fuel oil (HFO), 16% marine diesel oil (MDO), 4% liquefied natural gas (LNG) and less than 0.1% methanol. LNG as we have seen before, carries enough advantages to be considered sustainable in relation to NOx and SOx emissions. Further studies should be realized in order to find ways to reduce the methane slip that does occur at this moment on engines that use LNG as a fuel and subsequently constitute a high GHG risk. Investments should be made for bio- fuels in the shipping sector same as in the aviation sector that is responsible for more than 2% of human induced emissions and 12% of global fuel consumption in the transportation sector.

We have seen that the new legislation 'Fit for 55' will entail the shipping sector under the European's Trading Scheme obligations. It is a step in the correct direction as International Shipping is responsible for almost 3% of all anthropogenic GHG emissions and this fact will help further promote efficient vessels and more efficient DF engines. Furthermore, the Poseidon Principles and Green Bonds Principles will require the stakeholders to revolve around greener investments. The transportation sector contributes significantly to the total

GHG emissions and unfortunately there is not sufficient data in the literature to cover the field of LNG as a fuel in road transportation so there is ample space for further research.

We have also explored the possibility of a new gas hub in the Asia region as emerging economies as China and India will increase the LNG demand in order to cover their energy needs. Further liberalization processes should occur in China, as its Governance is characterized as problematic in terms of TPA and overall transparency. The problem with the emergence of an Asian gas hub is further perplexed by the fact that the Asia Pacific region is a different system where countries are dispersed with limited possibility for pipeline interconnection.

In 2005, 87% of all LNG trade was oil linked and only 13% represented gas to gas competition. This further indicates the market inefficiencies for the LNG trade. After 2010 the natural gas market became less related to the oil market. These findings confirm the association between physical competition and the liberalization of the European and American natural gas market. The emergence in 1996 of the NBP reflect the commencement of liberalization of the European gas market, developing a regional benchmark price. We can see how gas to gas competition is linked to physical infrastructure. Both NBP and TTF are connected to physical transmission systems in the UK and Netherlands respectively. The same applies for the U.S.A. and the Henry hub and its Sabine pipeline systems that includes nine interstate and four intrastate pipelines.

The European Commission issued three consecutive Directives 1998/30/EC, 2003/55/EC and 2009/73/EC to regulate and liberalize the European natural gas market. This effort has been continuing and arduous. The unbundling of monopoly activities in vertically integrated companies failed as the first Directive wasn’t forceful enough. The provisions regarding third party access (TPA), and unbundling have become stricter in the second and third gas Directives. The First Gas Directive introduced negotiated and regulated TPA, while the Second and Third Gas Directives only required regulated TPA. The First Gas Directive introduced account unbundling for vertically integrated natural gas undertakings, while the Second Gas Directive introduces functional and legal unbundling of its distribution and transmission activities. This eradicates the possibility of cross subsidization and safeguard the value of free competition to the benefit of consumers.

The main target of the Third Energy Package was to confront the problems that arose in the sector inquiry and the Commission’s assessment on the two previous Directives. The objectives of the third energy package were to create an integrated, transparent European energy market, enhance competition through better regulation, unbundling of energy related activities, improve security of supply by establishing incentives for new investments in infrastructure and secure consumer protection. The Third Energy Package contains the most important Regulations and Directives applied in the energy sector until today. It aimed to strengthen the conditions for competition that previously had been hindered by Vertical Integrated Undertakings that dominated the market, controlled the essential facilities, and enjoyed significant market power in the wholesale and retail sectors. Interestingly, the transposition of the provisions contained in the Third Energy Package proved challenging for all Member States that none of them succeeded in fully transposing them by the proposed deadline. Consequently, the Commission opened a large number of EU Pilot cases and infringement procedures towards Member States for failing to abide by the Directives.

The strengths of this study lie on a qualitative analysis and review of various published articles from renowned scholars and organizations such as IMO, IRENA and the European Commission and large bibliographic databases such as ScienceDirect. LNG has been used for over 50 years, its contribution has been recognized thoroughly and is attempted to be demystified through existing literature. The contribution of this work lies on the combination of an analysis of basic economics and the regulatory framework of natural gas and LNG on a European level. Finally, we have explored the applications of LNG in an environmental context. Further research can be developed in the field of road transport and the use of LNG as fuel in heavy tracks that cover long distances that was beyond the scope of this present study. From the early stages of its value chain exploration and liquefaction that constitute investments worth of billions. We have explored through the various liquefaction options as well as through the regasification options.

Limitations of this dissertation has been the lack of a quantitative approach to the problem of selecting a suitable, sustainable, substitute fuel for vessels in international shipping. A certain limitation on providing questionnaires from major international shipping companies about the degree of environmental protection that are willing to provide through green investments regarding their fleets and their willingness to use LNG as marine fuel. This could prove to be invaluable data for future research. Moreover, the pricing formulas for LNG were hard to define as they are developed on a demand and supply basis having no global reference price. Limited access to financial data was a crucial part in defining whether the American LNG, through this energy crisis, is cost competitive to LNG from other destinations and weather it will be able to provide a steady flow to meet EU's demand in the case that EU will try to become independent from Russian imports. As we have concluded before, there is still ambiguity regarding the selection of a sustainable carbon free fuel. Further research may be conducted on the field of exploring which of the fuels, available at this present day, are suitable cost-wise and can be produced in larger quantities taking into consideration the necessary respective investments.

CONCLUSIONS

Natural gas and LNG is an abundant, clean, accessible, and versatile form of energy saving around 500 million tonnes of CO_2 since 2010 through coal to gas switching. During the pandemic of Covid-19 the reliable supply of LNG continued uninterrupted proving the resilience and flexibility of the natural gas sector.

In 1997 short term contracts accounted for 1.5% of international LNG trade and in 2003 they accounted for 8.9% of the LNG trade. In 2021 the LNG trade in spot market or through short term contracts reached 40% of the global International LNG trade. As the LNG markets have become more liquid and mature, gas to gas competition has been enabled in the U.S. and European markets. We have explored the possibility of a new gas hub emergence in Asia with possible candidates China, Japan and Singapore that have undergone some sort of liberalization processes in the last couple of years with Singapore leading in this front.

Liquefaction, mainly, and regasification processes represent a huge cost investment in the LNG value chain and to secure capitals from large financial institutions, trustworthy clients are required through the conclusion of long-term SPA's. These legacy SPA's provided for destination clauses that hinder arbitrage opportunities. Nowadays, in many cases these clauses are abolished offering more contractual liberty and flexibility that is long needed in LNG contracts.

Natural gas proven reserves are spread out throughout the globe. Middle East owns 75.8 trillion cm representing 40.3% of total reserves, followed by the CIS region that owns 56.6 trillion cm or a 30.1 % with Russia owing the highest percentage. After those, comes the N. America region with 8.1% of total proven reserves. In 2020 the U.S increased their LNG exports by a significant amount of 32.67 % year over year (y.o.y) while Australia surpassed Qatar, as a bigger exporter of LNG, with an increase of 3.2% y.o.y versus Qatar's increase of 0.86%. On the demand side, China surpassed Japan as the biggest importer of LNG in 2020 as Japan is trying to run its nuclear plants once again after the Fukushima accident and phase out of natural gas in the long term. China and India led the recovery in demand of natural gas during the current pandemic.

We have also seen that major Greek ship-owners turn their focus on the LNG market, placing large orders on Asia's shipbuilding industry in companies such as Daewoo, Samsung Heavy Industries and Hyundai Heavy Industries with a Greek percentage of nearly 40% on their orderbooks. The Greek fleet of LNG vessels is constantly growing and at the same time lowering their average year ratio. The shipping industry contributes at around 3% on all anthropogenic GHG emissions and is in search of a new sustainable marine fuel other than HFO and MDO. Candidates for this transition are Hydrogen, e- ammonia, blue ammonia synthetic LNG, bio-Methanol and bio-LNG, but their development in sufficient quantities won't take place in the immediate future not being cost competitive at the moment. For these reasons the shipping industry is focusing on the deployment of LNG as marine fuel that has minimum SOx and NOx emission and is compatible with the new Regulations issued by IMO and the European Union. Notably, World Bank advises the stakeholders to shy away from the use of LNG as fuel and search for carbon neutral alternatives to reach the IMO targets, as envisaged through its initial GHG strategy that came out in 2018.

The development of a single legislative framework, for the liberalization of the electricity and gas market, applicable to all European energy markets proved a difficult task because of the varying characteristics of national energy markets.UK and the Scandinavian countries had already undergone the liberalization process when EU issued the first gas Directive 98/30/EC. To eliminate the monopolistic structure, established through vertically integrated undertakings, EU issued three consecutive gas Directives: 98/30/EC, 2003/55/EC, and 2009/73/EC. The advantages were that consumers could choose their suppliers freely, benefiting from lower prices and at the same time providing for competition among producers, better service standards, enhanced security of supply and sustainability. Through the principles of competition, unbundling, third party access and independent national regulators EU aimed at the liberalization of the European gas market and at creating an internal market for natural gas.

The European Commission is committed to growing Europe's LNG sector through investments and that has been visible in 2018 and 2019 that included a grant of €124 million from the EU's Connecting Europe Facility (CEF) for the newly inaugurated Krk Island LNG terminal and an additional €116 million grant for the Cyprus LNG terminal at Vassilikos. The financing for Klaipeda FSRU in Lithuania was provided by a €87 million loan from the European Investment Bank. The Alexandroupolis FSRU will become Greece's fourth entry point for natural gas. It is planned to supply up to 8.3 billion cubic meters annually and offer an LNG storage capacity of 170,000 cubic meters. The Alexandroupolis FSRU will serve as an energy hub in the Balkans, enhancing EU's overall energy security. It has also been granted a grant of 101 million from Connecting Europe Facility program and an additional 150 million from the European Investment Bank as a Project of Common Interest (PCI).

The intention of EU in financing new LNG terminals is evident. The LNG terminals across the borders of EU provide sufficient regasification capacity although they are not evenly distributed amongst Member States increasing the supply vulnerability of the European Union. In conclusion new investments in LNG infrastructure should be planned and the terms of access to already existing ones should be further liberated while integrating markets across borders through the Trans-European Networks for Energy policy (TEN-E).

Finally, the current war in Ukraine that started on 24 February 2022 and the sanctions imposed by the USA, the UK and the EU against the Russian Federation as a result of the situation in Ukraine is predicted in all media reports and by all analysts at present to cause a shift in the geopolitical scenery around energy in the next years. The most common definition of energy security is the 4A dimension: Availability, Affordability, Accessibility and Acceptability. During this energy crisis that Europe is going through, in the last couple of months parameters of the energy security are put into a stress test. IEA's Governing Board recently announced that a total amount of 61.7 million barrels would be released, making it the largest stock release in IEA history through the collective emergency response mechanism. Russia, besides being the biggest exporter of natural gas (more than 40%), second biggest exporter of crude oil (27%), and major coal exporter (46%), is the main supplier of the European Union. In 8/3/2022 the European Commission published its communication over the new REPower EU plan with the goal to phase out the EU's dependency on Russian natural gas, oil, and coal. Main targets of this proposed plan are to: diversify its energy sources, to accelerate the production of green energy and reduce overall energy demand. It also requires the existing storage infrastructures to be filled up to at least 90% of capacity. The REPower EU is based on two pillars: 1) diversify gas supplies via higher LNG imports from Qatar, U.S.A., Egypt, west Africa, increase pipeline imports from non-Russian suppliers such as Norway, Algeria, Azerbaijan and 2) reduce faster the dependence on fossil fuel by increasing the share of renewables.

Through this geopolitical storm, the role of LNG is highly significant and will continue to be throughout the next decades.

.

Bibliography

- Abreu A., (2019). *New horizons: The forces shaping the future of the LNG market*, S&P Global. Retrieved from: https://www.spglobal.com/commodity-insights/plattscontent/_assets/_files/en/specialreports/lng/lng-market-new-horizons-report.pdf
- BBL company, *Connecting Energy Markets.* Retrieved from *https://www.bblcompany.com/*
- Blanton E., Mosis S., (2021). *The carbon-neutral LNG market: Creating a framework for real emissions reductions,* Columbia, SIPA. Retrieved from: https://www.energypolicy.columbia.edu/sites/default/files/file-uploads/Carbon-neutral%20LNG%20commentary,%20design%20reflow,%207.02.21%20.pdf
- Castellanos G. et al (2021). *A pathway to decarbonize the shipping sector by 2050, IRENA.* Retrieved from: *https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Oct/IRENA_Decarbonising_Shipping_2021.pdf*
- Chainho P.D., (2013). Dissertation: *Advanced steady-state modelling and optimization of LNG production*. Retrieved from: https://www.google.com/search?q=Advanced+steady-state+modelling+and+optimisation+of+LNG+production%2C+Pedro+Daniel+Dias+Chainho%2C+dissertation%2C+2013&oq=Advanced+steady-state+modelling+and+optimisation+of+LNG+production%2C+Pedro+Daniel+Dias+Chainho%2C+dissertation%2C+2013&aqs=chrome..69i57.1553j0j4&sourceid=chrome&ie=UTF-8
- Chen R. et al, (2021). *Evolution laws and new trends of global LNG pricing and their implications,* ScienceDirect. Retrieved from: https://www.sciencedirect.com/science/article/pii/S2352854021000747
- Commission Decision 11 November 2003 *on establishing the European Regulators Group for Electricity and Gas.* Official Journal of the European Union. Retrieved from: https://www.ceer.eu/documents/104400/-/-/103f4b81-3f79-299f-f247-3d6e3d8e2f64
- Commission of the European Communities (1998). Report from the Commission to the Council and the European Parliament: *on State of liberalization of the energy markets*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:51998DC0212&rid=26981
- Commission of the European Communities (1999). *Second report from the commission to the Council and the European Parliament: On the state of liberalization of the energy markets.* Retrieved from: http://aei.pitt.edu/4658/1/4658.pdf
- Commission of the European Communities (2006). *Green Paper: A European Strategy for Sustainable, Competitive and Secure Energy.* Retrieved from: https://europa.eu/documents/comm/green_papers/pdf/com2006_105_en.pdf

- Commission of the European Communities (2007). Communication from the Commission: *Inquiry pursuant to Article 17 of Regulation (EC) No 1/2003 into the European gas and electricity sectors.* Retrieved from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0851:FIN:EN:PDF
- Commission of the European Communities, (1995). *White paper: An energy policy for the European Union.* Retrieved from: https://op.europa.eu/en/publication-detail/-/publication/bc335af2-4ed1-4690-8a0d-797613dbd5f0/language-en
- Congressional Research service, (2019). *LNG as a Maritime Fuel: Prospects and Policy*. Retrieved from: https://sgp.fas.org/crs/misc/R45488.pdf
- Cryonorm official website: LNG Ambient Air Vaporizer. Retrieved from *https://cryonorm.com/liquefied-natural-gas/vaporizers/ambient-air/*
- Dehvani J, Yegorov Y., (2012). *Is LNG Arbitrage Possible in Natural Gas Market?* SSRN Electronic Journal. Retrieved from: https://www.researchgate.net/publication/272357960_Is_LNG_Arbitrage_Possible_in_Natural_Gas_Market
- Delaney G., (2021), VesselsValue. Retrieved from https://blog.vesselsvalue.com/a-winter-write-up-on-the-vlcc-and-lng-markets/
- Diathesopoulos M., D., (2010).*Third Party Access and Refusal to Deal: How sector regulation and competition law meet each other*. Retrieved from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1732210
- Directive 2009/73/EC of the European Parliament and of the Council (13 July 2009) *concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC*, Official Journal of the European Union. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0073&from=EN
- Directive 98/30/EC of the European Parliament and of the Council *concerning common rules for the internal market in natural gas.* Official Journal of the European Communities. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31998L0030&from=EN
- DNV: *Annual Report 2020*. Retrieved from: https://annualreport.dnv.com/2020
- DNV: *LNG as marine fuel*. Retrieved from: https://www.dnv.com/maritime/insights/topics/lng-as-marine-fuel/index.html
- Dr Dagalidis A., (2013). Sectoral report 20: *LNG vessels*, Piraeus Bank. Retrieved from: ΚΛΑΔΙΚΗ ΜΕΛΕΤΗ 20 ΔΕΞΑΜΕΝΟΠΛΟΙΑ LNG Αύγουστος ...http://www.piraeusbankgroup.com › sectoral-LNG - Αναζήτηση (bing.com)
- DYNAGAS's LTD official website. Retrieved from http://www.dynagas.com/?page=obj
- Eberlein B., (2008). *The Making of the European Energy Market: The Interplay of Governance and Government.* Cambridge University Press. Retrieved from: https://eclass.uoa.gr/modules/document/file.php/PSPA113/1koutalakis.pdf
- ECS, (2017). Review: *Potential Standardisation of LNG Sale and Purchase Agreements*, International Energy Charter. Retrieved from: https://www.energycharter.org/fileadmin/DocumentsMedia/Other_Publications/20171115-Final_LNG_Report.pdf

- EIA, (2017). *Perspectives on the Development of LNG Market Hubs in the Asia Pacific Region.* Retrieved from: https://www.eia.gov/analysis/studies/lng/asia/pdf/lngasia.pdf
- European Parliament, (2021). Sustainable maritime fuels: 'Fit for 55' package: The fuelEU Maritime proposal. Retrieved from: https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/698808/EPRS_BRI(2021)698808_EN.pdf
- European Parliament, *Energy policy: general principles.* Retrieved from: *https://www.europarl.europa.eu/factsheets/en/sheet/68/energy-policy-general-principles*
- European Parliament. *Legislative Train: ''Fit For 55'' package under the European Green Deal.* Retrieved from: https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/package-fit-for-55
- Fan H. et al (2020). *Safety philosophy and risk analysis methodology for LNG bunkering simultaneous operations. A literature review*. Elsevier. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0925753520305464
- Federal Energy Regulatory Commission's website, updated in March 2022. Retrieved from https://www.ferc.gov/natural-gas/lng
- Finizio S., Trenor J.A., and Tan J., (2020) *Trends in LNG Supply Contracts and Pricing Disputes in the Asia Pacific Region*. Oil, Gas & Energy Law Intelligence. Retrieved from: https://www.ogel.org/article.asp?key=3890
- Fortsakis T., Farantouris N. E., (2016). *Energy Law*. Nomiki Bibliothiki.
- Fullwood M., (2018). *Asian LNG Trading Hubs: Myth or reality*, Columbia, SIPA. Retrieved from: https://energypolicy.columbia.edu/sites/default/files/pictures/Asian%20LNG%20Trading%20Hubs_CGEP_Report_050318.pdf
- GASLOG's official website. Retrieved from https://www.gasloglt.com/about-us/our-fleet/
- GIGNL (2021). Report: *The LNG Industry- GIIGNL Annual Report*. Retrieved from: https://giignl.org/wp-content/uploads/2021/11/GIIGNL_Annual_Report_November2021.pdf
- Haase N., (2008). *European gas market liberalization: Are regulatory regimes moving towards convergence?* Oxford Institute for Energy Studies. Retrieved from: https://www.oxfordenergy.org/wpcms/wp-content/uploads/2010/11/NG24-EuropeanGasMarketLiberalisationArerRegulatoryRegimesMovingTowardsConvergence-NadineHaase-2008.pdf
- Hatcher C., Marc P., (2019).Article: *The rise of LNG Derivatives*, CLYDE&CO. Retrieved from: https://www.lexology.com/library/detail.aspx?g=6a314555-672b-4543-b927-6707c9290732
- Heather P., (2015). *The evolution of European traded gas hubs*. The Oxford Institute for Energy Studies. Retrieved from: https://a9w7k6q9.stackpathcdn.com/wpcms/wp-content/uploads/2016/02/NG-104.pdf
- Heckinger R., (2013). *Understanding Derivatives: Markets and Infrastructure*. Retrieved from https://www.chicagofed.org/publications/understanding-derivatives/index

- Hellenic Shipping News. Article: a winter write up on the VLCC and LNG markets. Retrieved from https://www.hellenicshippingnews.com/a-winter-write-up-on-the-vlcc-and-lng-markets/
- Herweg N., (2017). *European Union policy making. The regulatory shift in natural gas market*, Springer. Retrieved from: https://link.springer.com/book/10.1007/978-3-319-49400-5
- IGU, (2017), Survey: *Wholesale Gas Price*. Retrieved from: https://www.igu.org/news/igu-releases-2017-wholesale-gas-price-survey/
- IMO, (2020). *Fourth Greenhouse Gas Study 2020.* Retrieved from: https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx
- IMO, *Initial IMO GHG Strategy 2018.* Retrieved from: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx
- Jamison C., (2021). Article: *China Surpassed Japan as World's Biggest LNG Importer Through October*, NGI. Retrieved from https://www.naturalgasintel.com/china-surpassed-japan-as-worlds-biggest-lng-importer-through-october/a
- Jensen T. J., (2004). *The development of a global LNG market. Is it Likely? If so, When?* Oxford Institute for Energy Studies. Retrieved from: https://a9w7k6q9.stackpathcdn.com/wpcms/wp-content/uploads/2010/11/NG5-TheDevelopmentofAGlobalLNGMarketIsItLikelyIfSoWhen-JamesJensen-2004.pdf
- Johanson N., et al, (2013). Dissertation: *Driving factors of LNG financial derivatives*, KTH School of Industrial Engineering and Management. Retrieved from: https://www.diva-portal.org/smash/get/diva2:645047/FULLTEXT01.pdf
- Karonis D., Lois E., Zanikos F., (2014). *Technology of Natural gas and oil*. Chapter 4. Retrieved from: https://docplayer.gr/5553980-Kefalaio-4-ygropoiisi-fysikoy-aerioy.html
- Kate W. et al (2013). *Developing a Natural Gas Trading Hub in Asia*, IEA. Retrieved from: http://members.igu.org/old/gas-knowhow/publications/other-publications/Developing%20a%20Natural%20Gas%20Trading%20Hub%20in%20Asia.pdf
- Konstantinos Iliopoulos P., (2014). Book: *Matters of European Energy Law*, Sakkoulas N.
- King & Spalding, (2018). *LNG In Europe. An Overview of LNG Import Terminals in Europe*. Retrieved from: https://www.kslaw.com/attachments/000/006/010/original/LNG_in_Europe_2018_-_An_Overview_of_LNG_Import_Terminals_in_Europe.pdf?1530031152
- KPMG, (2017). *Developing liquidity in the LNG market*. Retrieved from: https://assets.kpmg/content/dam/kpmg/jp/pdf/jp-en-lng-liquidity-market.pdf
- Kuczynski S., et al, (2020). Article: *Impact of Liquefied Natural Gas Composition changes on Methane number as a fuel quality requirement*, Poland, MDPI. Retrieved from: https://www.mdpi.com/1996-1073/13/19/5060

- Kulovic N., (2022). Article: *Momentous milestone for QatarEnergy as contract for North Field expansion goes to McDermott.* Retrieved from: https://www.offshore-energy.biz/momentous-milestone-for-qatarenergy-as-contract-for-north-field-expansion-goes-to-mcdermott/
- Liquified Gas Carrier: *LNG vessel construction - Advantages of Moss Rosenberg technology*. Retrieved from: http://www.liquefiedgascarrier.com/moss-rosenberg-containment-system.html
- Lisbon European Council meeting (2000). *Presidency Conclusions*. Retrieved from: https://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/00100-r1.en0.htm
- Liu Y. et al (2020). *Dynamics of Australia's LNG export performance: A modified constant market shares analysis*, Elsevier. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0140988320301481
- Mallouppas G., Yfantis A.E., (2021) Journal, Issue 4: *Decarbonization in Shipping Industry: A Review of Research, Technology Development, and Innovation Proposals.* Journal of Marine Science and Engineering. Retrieved from: https://www.mdpi.com/2077-1312/9/4/415
- Maran Gas Maritime’s INC official website. Retrieved from http://www.marangas.com/fleet-list/
- Martin P. Y. et al. *LIQUEFIN: An innovative process to reduce LNG costs*, Axens. Retrieved from: http://members.igu.org/html/wgc2003/WGC_pdffiles/10508_1045736680_32648_1.pdf
- Melling A. J. (2010) Book: *Natural Gas Pricing and its future- Europe as the battleground*, Carnegie Endowment. Retrieved from: https://carnegieendowment.org/files/gas_pricing_europe.pdf
- Metaxas A. et al (2018). Transformation of EU and Eastern Mediterranean Energy Networks: Legal, Regulatory and Political Challenges. European Energy Studies, CLAEYS & CASTELS. Retrieved from: https://www.academia.edu/39749664/_Transformation_of_EU_and_Eastern_Mediterranean_Energy_Networks_
- Metaxas A. (2021). *Η αυξανόμενη σημασία της αγοράς του LNG και οι μείζονες απορρέουσες νομικές και ρυθμιστικές προκλήσεις*.Oikonomikos Taxidromos. Retrieved from: https://www.ot.gr/2021/09/22/apopseis/i-ayksanomeni-simasia-tis-agoras-tou-lng-kai-oi-meizones-aporreouses-nomikes-kai-rythmistikes-prokliseis/
- Mokhatab S. et al, (2014). *Handbook of liquefied natural gas*, Elsevier. Retrieved from: https://books.google.gr/books?id=nQswAAAAQBAJ&printsec=frontcover&hl=el#v=onepage&q&f=false
- Moller A.P., (2021) Press release: *Maersk accelerates fleet decarbonization with 8 large ocean-going vessels to operate on carbon neutral methanol*. MAERSK. Retrieved from: https://www.maersk.com/news/articles/2021/08/24/maersk-accelerates-fleet-decarbonisation
- Mpregou E. (2014). Dissertation: *The market of LNG and it’s trajectory in Greek Shipping.* Aegean University. Retrieved from: https://hellanicus.lib.aegean.gr/handle/11610/9647

- MT LNG, Liquified Natural Gas: General Knowledge, Akademia Morska. Retrieved from: http://www.golng.eu/files/Main/news_presentations/rostock/Liquefied%20Natural%20Gas%20General%20Knowledge.pdf
- Naftemporiki, (2019). Article: *A dynamic return of Greeks in LNG carrier orders*. Retrieved from https://www.naftemporiki.gr/finance/story/1500209/dunamiki-epistrofi-ton-ellinon-se-paraggelies-gia-lng-carriers
- Nakilat's official website. Retrieved from https://www.nakilat.com/our-fleet/
- Novatek's Official site: *Project Arctic LNG 2*. Retrieved from: https://www.novatek.ru/en/business/arctic-lng/
- Ovcina J., (2020). Article: Maersk CEO: LNG won't play a big role for us as a transition fuel. OFFSHORE ENERGY. Retrieved from https://www.offshore-energy.biz/maersk-ceo-lng-wont-play-a-big-role-for-us-as-a-transition-fuel/
- Panagiotidis D. (2013). Dissertation: *A global perspective of Liquified Natural Gas vessels capacity*. Erasmus University Rotterdam. Retrieved from: https://thesis.eur.nl/pub/41240
- Patanou E. (2018). Dissertation: *Third Party Access to European LNG regasification Terminals*, International Hellenic University. Retrieved from: https://repository.ihu.edu.gr/xmlui/handle/11544/29213?show=full
- Polemis M. L., Fafaliou I., *Liberalisation of the European Natural Gas Market: Myth or Reality? Evidence from Greece*. Research Topics in Agricultural and Applied Economics, volume 1. Retrieved from: https://www.unipi.gr/unipi/images/various/akad_tmim/oikon_epist/B.1_Research_Topics_in_Agricultural_and_Applied_Economics.pdf
- Poseidon Principles: *A global framework for responsible ship finance*. Retrieved from: https://www.poseidonprinciples.org/finance/#home
- PPA: *POSEIDONMED II*. Retrieved from: https://www.olp.gr/el/prostasia-perivallontos/evropaika-programmata/energa/item/12523-poseidomed2
- QATARGAS (2021) Magazine: Issue 159. Retrieved from: https://www.qatargas.com/english/MediaCenter/The%20Pioneer/The%20Pioneer%20159%20English.pdf
- Qi C. et al (2016). *Performance analysis of submerged combustion vaporizer*, Elsevier. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S1875510016301093
- RAE. *Community Law*. Retrieved from http://oldsite.rae.gr/site/categories_new/gas/regulation/community.csp
- Rafael Spyridon, (2018). Dissertation: *Analysis of the market for LNG vessels & a turn to LNG fuel*, Aegean University. Retrieved from: https://hellanicus.lib.aegean.gr/bitstream/handle/11610/21278/%CE%A0%CF%84%CF%85%CF%87%CE%B9%CE%B1%CE%BA%CE%AE%20%CE%B5%CF%81%CE%B3%CE%B1%CF%83%CE%AF%CE%B1%20%CE%A1%CE%B1%CF%86%CE%B1%CE%AE%CE%BB%20%CE%A3%CF%80%CF%85%CF%81%CE%AF%CE%B4%CF%89%CE%BD.pdf?sequence=5&isAllowed=y

- Regulation (EC) No 1775/2005 of the European Parliament and of the Council of 28 September 2005 *on conditions for access to the natural gas transmission networks*, Official Journal of the European Union. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32005R1775&from=EN
- Regulation (EU) 2019/2088 of the European Parliament and of Council of 27 November 2019 *on sustainability-related disclosures in the financial services sector*. Retrieved from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019R2088
- Roberts M., Saygi-Arslan O. (2016). *Brayton refrigeration cycles for small-scale LNG*. Air Products and Chemicals Inc. Retrieved from: https://www.google.com/search?q=Brayton+refrigeration+cycles+for+small+scale+lng&oq=Brayton+refrigeration+cycles+for+small+scale+lng&aqs=chrome..69i57j0i54612.14749j0j4&sourceid=chrome&ie=UTF-8
- Roe C., Konertz F., (2019). *LNG derivatives take off*,. S&P Global. Retrieved from: https://www.fia.org/marketvoice/articles/lng-derivatives-take
- Salermo M. F., Hancher L., (2017), *Analysis of Current trends and a First Assessment of the New Package*, Chapter 4 in the EE Research Handbook on EU Energy Law and Policy. Retrieved from: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2956308
- Shahrukh M., et al (2019). *Evaluating the Benefits of LNG Procurement through Spot Market Purchase*. National University of Singapore. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/B9780128186343502885
- Shell LNG Outlook 2021. Retrieved from: https://www.shell.com/energy-and-innovation/natural-gas/liquefied-natural-gas-lng/lng-outlook-2021.html#
- Shi X., Variam M.P., (2018). *Key elements for functioning gas hubs: A case study of East Asia*. ScienceDirect. Retrieved from: https://www.sciencedirect.com/science/article/pii/S2352854017302036
- Shipping Zero Emission Project (2020). *Roadmap to Zero Emission from International shipping*, Japan. Retrieved from: https://www.mlit.go.jp/common/001354313.pdf
- Six S., Corbeau A.S, (2017). *Third-Party Access to Regasification Terminals: Adapting to the LNG Markets' Reconfiguration*, KAPSARC. Retrieved from: https://www.kapsarc.org/research/publications/third-party-access-to-regasification-terminals-adapting-to-the-lng-markets-reconfiguration/
- Stasinou N., (2022). *Article: Will the American LNG warm up Europe?* Naftemporiki. Retrieved from : https://www.naftemporiki.gr/finance/story/1817090/tha-zestanei-tin-europi-to-amerikaniko-lng?fbclid=IwAR05zXz0q6wfpd0fBMWLQZbCIVX5JZnBXrvf5jDKv5-ZvPhzKmMl1NKFWRo
- Statistical Review of World Energy (2021), BP. Retrieved from: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf
- The World Bank: *Charting a Course for Decarbonizing Maritime Transport* (2021). Retrieved from https://www.worldbank.org/en/news/feature/2021/04/15/charting-a-course-for-decarbonizing-maritime-transport

- U.S Energy Information Administration. *Natural Gas explained: Liquified natural gas*. Retrieved from: https://www.eia.gov/energyexplained/natural-gas/liquefied-natural-gas.php
- U.S. Department of Energy: *Liquified Natural Gas Value Chain*. Retrieved from: https://www.energy.gov/sites/default/files/2020/10/f79/LNG%20Value%20Chain%20Fact%20Sheet_1.pdf
- UN Climate Change Conference UK 2021. *COP 26 The Glasgow Climate Pact*. Retrieved from: COP26-Presidency-Outcomes-The-Climate-Pact.pdf (ukcop26.org)
- UNCTAD, (2021). *Review of Maritime Transport*. United Nations publications. Retrieved from: https://unctad.org/webflyer/review-maritime-transport-2021
- Union of Greek Shipowners, (2021) Report: Greek Shipping and Economy. Retrieved from https://www.ugs.gr/en/greek-shipping-and-economy/greek-shipping-and-economy-2021/
- United Nations: *What is the Kyoto Protocol?* Retrieved from: https://unfccc.int/kyoto_protocol
- US Department of Energy, USEA (2016). *Understanding Natural Gas and LNG Options*, Power Africa. Retrieved from: https://www.energy.gov/sites/prod/files/2016/12/f34/Understanding%20Natural%20Gas%20and%20LNG%20Options.pdf
- Wang X., Economides M., (2009). *Liquified natural gas: Mixed Fluid Cascade Process*, ScienceDirect. Retrieved from: https://www.sciencedirect.com/topics/engineering/mixed-fluid-cascade-process
- Weber H., (2019). Article: *Centrica loads first contracted LNG swap cargo from Dominion's Cove Point*, S&P Global. Retrieved from https://www.spglobal.com/platts/en/market-insights/latest-news/natural-gas/050219-centrica-loads-first-contracted-lng-swap-cargo-from-dominions-cove-point
- Wiese-Bockmann M., (2021). Article: *LNG carrier rates top $260,00 per day as arbitrage profits exceed $100m*, Lloyd's list. Retrieved from: https://lloydslist.maritimeintelligence.informa.com/LL1138547/LNG-carrier-rates-top-260000-per-day-as-arbitrage-profits-exceed-100m
- World Energy Outlook 2021. Retrieved from: https://www.iea.org/reports/world-energy-outlook-2021.
- Xu S. et al, (2016). *Thermal design of intermediate fluid vaporizer for subcritical liquefied natural gas*, Elsevier. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S1875510016302542
- Yang C.J, Zhou Y., Jackson R., (2013). *China's fuel gas sector: History, current status, and future prospects*, Elsevier. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S0957178713000702
- Zhuravleva P., (2009). *The Nature of LNG Arbitrage: An Analysis of the Main Barriers to the Growth of the Global LNG Arbitrage Market*, Oxford Institute for Energy Studies. Retrieved from: https://www.oxfordenergy.org/publications/nature-of-lng-arbitrage-and-an-analysis-of-the-main-barriers-for-the-growth-of-global-lng-arbitrage-market-2/