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New Technologies for Natural Gas Supply in the Baltic Sea – Economic Aspect

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Abstract:

Purpose: *Modern technology is contributing to the development of projects and modifications to existing Liquefield Natural Gas (LNG) import terminals that enable efficient distribution of liquefied natural gas. When considering Small Scale LNG (SSLNG), it is important to consider the amount of LNG demand and how the feedstock will be distributed. This paper describes SSLNG technology initiatives that guarantee fast and attractive returns in the medium term.*
Design/Methodology/Approach: *In the first part of the paper, theoretical background of LNG is described. The SSLNG supply chain and the main actors in the distribution process were characterized.*
Findings: *The method of determining the LNG price, which depends on many components, was determined. Distribution costs were classified with reference to the SSLNG fleet in terms of the type of propulsion used. The benefits of implementing SSLNG were indicated. In the next part of the study, the predicted number of vessels which will use LNG as propellant was simulated. This made it possible to determine the price of LNG. The analysis was performed using the Monte Carlo method on the example of the Baltic Sea with a forecast to 2026.*
Practical implications: *SSLNG technology with reduced investment requirements and a short commissioning period reduces the uncertainty of project timing. Depending on the choice of LNG management, different actors are involved in the supply chain. The analyses presented here show that participants in the distribution process have a significant impact on network integration. SSLNG enables the addition of capacity to have the ability to handle increased demand for LNG. Thus, it is possible to synchronize the supply chain.*
Originality value: *For the first time, to our knowledge, determining the situation, anticipating, monitoring, and responding to changes is the basis for designing SSLNG for optimal use.*

Key words: *Liquefied natural gas, small scale LNG, marine fuel, Baltic Sea.*

Paper Type: *Research study.*

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1. Introduction

Given the continuous economic development and population growth around the world, the demand for energy has been increasing regularly in recent years. Liquefied natural gas (LNG) is one of the primary energy resources in the global market. LNG consumption is projected to be 15% of global gas consumption by 2040 (www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2019.pdf). The increasing demand of natural gas is influenced by its cleanliness, ease of transportation, and lower greenhouse gas emissions compared to other fossil fuels. These positive advantages of LNG are attracting attention in the current energy crisis (Lee *et al.,* 2020).

Liquefied natural gas (LNG) is formed by cooling to a temperature below -162°C and liquefying it under atmospheric pressure. The liquefaction process goes through several purification stages which makes LNG a clean fossil gas and the CO2 emission of such gas is much lower than other fossil fuels. Another critical factor determining the use of LNG is the introduction of regulations against pollution in maritime transport (Bittante and Saxén, 2020). In January 2020, the MARPOL Annex VI Convention, concerning the emission of pollutants in shipping, came into force. It aims to significantly reduce emissions of nitrogen oxides and sulfur oxides (NO_X and SO_X) pollution on board ships. The recent entry into force of the convention has focused global attention on new transportation systems, thus seeking more energy-efficient and sustainable modes of transport. One way to achieve greener ships is to upgrade on-board engines to meet current regulations and needs (min. use of gas turbine) (Barsi *et al.,* 2020).

Ensuring the strategic energy independence of certain regions is also an important aspect. Unfortunately, the whole distribution cycle from well to LNG regasification is complex and consists of many stages (Katebah *et al.,* 2020). Special infrastructure for transportation and storage is required. Large-scale LNG transportation infrastructure ("liner shipping") has been in place for decades, with typical tanker sizes of 150,000 m3. This type of logistics network requires consideration of many important aspects, i.e., energy security and cost flexibility (Bittante and Saxén, 2020). However, only recently has there been an increased interest in small-scale LNG supply chains to serve medium and small customers in underdeveloped areas. This type of small-scale supply chain is characterized by:

- small-capacity vessels (1,000 m^3 to 40,000 m^3),
- cargoes that can be split into smaller batches and delivered to individual receiving ports,
- generally shorter distances,
- terminals receiving LNG from ships, with smaller storage tanks (<50,000 m3) that are filled weekly or several times a month.

Due to the specific infrastructure (ships, storage facilities, gas handling equipment, etc.) and moderate volumes delivered, small-scale LNG chains have high relative investment costs. This emphasizes the need for optimal design of the offshore natural gas supply chain (Bittante and Saxén, 2020).

2. Liquefied Natural Gas

2.1 New Technologies - Small Scale LNG

Liquefied natural gas from production centers to consumers is transported by bunker ships, ocean-going vessels, trucks, and storage units and pipelines. For customers with heavy fuel requirements, SSLNG technology is an excellent solution. SSLNG can be used to create "virtual gas pipelines" in the absence of traditional infrastructure due to geographic isolation or seasonal and inconsistent crude demand. SSLNG is considered a liquefaction or regasification facility. At small scale, LNG transportation is between the transport terminal (liquefaction plant) and the import terminal (regasification plant). Small-scale LNG import terminals are designed primarily to plan for the fuel needs of specific industries. Global small-scale production is estimated to be around 25 MTPA. Growth potential will exceed 6% per year. By 2020, more than 10% of global production will be used as bunker fuel (2012 – 2015 Triennium Work Report (June 2015) Small Scale LNG Produced by: International Gas Union). The feedstock end uses for SSLNG are:

- marine fuel,
- fuel for heavy road transport,
- electricity generation in off-grid locations.

Currently, SSLNG is widely developed in the US, Europe and China. The Philippines and Indonesia are widely developing and have great potential to develop SSLNG in their area. This is due to the demand and geographical conditions (location on many small islands) („Small-scale LNG”- MAN- Autor Dipl.-Ing. MBA Carsten Dommermuth). Compared to alternative fossil fuels, SSLNG technology carries many environmental benefits in terms of CO2, SOx, NOx and particulate matter emissions. Therefore, it is regarded as a green fuel in Europe. Especially, areas with stricter environmental regulations stimulate the use of SSLNG as bunker fuel (ECA areas), (en.wikipedia.org/wiki/Liquefied natural gas, „Small-scale LNG demand grows in Baltic” states 08 Apr 2020 John Snyder). The lack of barriers to entry and the low capital expenditure open up opportunities to implement new technologies (relative to large projects where most rely on proven solutions to prevent unplanned costs). There are many benefits of running SSLNG over large projects. In SSLNG installations (2012–2015 Triennium Work Report (June 2015) Small Scale LNG Produced by: International Gas Union):

1. unmanned installations are used. In few cases, minimal personnel are required (maintenance and unloading operations).

2. Many small LNG plants use existing infrastructure, which reduces the cost of the overall project. There is no need for an installation with dedicated power generation (the plant can be connected to the public power grid).
3. fewer requirements for offshore infrastructure. Large amounts of space in SSLNG are required for transmission systems (for safety reasons).
4. Small emergency shutdown systems and couplers for emergency shutdown.

SSLNG relies on fast and creative technological solutions that are necessary, for economic efficiency. An example of this is the storage range, which generally runs at a pressure of 3-10 bar. The storage capacity for SSLNG ranges from 500 m3 to 5 000 m3. Therefore, the following types of tanks are operated in SSLNG (2012–2015 Triennium Work Report (June 2015) Small Scale LNG Produced by the International Gas Union):

- pressure tanks:

spherical tanks,
cylindrical tanks,

- atmospheric tanks:

flat bottomed,
cylindrical tanks,

- Floating Storage Units (FSUs):

in-hull storage (usually atmospheric storage).
pontoons (may contain pressurized storage shells).

Technological differences between SSLNG and large installations we can include:

- Replacing single refrigerant liquefaction technology with a nitrogen expansion cycle (making the process more advantageous in small plants and in floating equipment).
- The ability to use electric motor drives instead of using gas turbine drives for the compression process. In smaller plants, this will provide further economic savings (analyses indicate a 36% reduction in capital expenditure and an increase in plant availability of approximately 3 - 4%), (European Gas Market Developments: „Assessment of Market Trends in Liquefied Natural Gas” -UNECE Economic Commission for Europe Energy Series No. 48 – March 2017).

3. Distribution of LNG

The large-scale LNG supply chain consists primarily of facilities for liquefaction, transportation, regasification, and end users, of which SSLNG has a wide range. Therefore, one of the challenges of SSLNG is value chain management. This is an important factor that is considered as one of the main success criteria for SSLNG solutions. If poorly planned, it can prove to be very costly.

Depending on the choice of how the crude is distributed, using a small-scale LNG network, different players are involved. SSLNG has been providing its services in the global market for a short period of time and therefore requires supplementation from various parties. With regard to overhead costs, not only commercial and logistic actors, but also governments and regulators have an influence. Depending on the business model, these actors, also influence the integration into the overall network. The main actors include (2012–2015 Triennium Work Report (June 2015) Small Scale LNG Produced by: International Gas Union):

- gas suppliers and LNG producers,
- vessel owners and operators and intermediaries,
- terminal owners and operators,
- representatives of large companies,
- governments and regulators.

The authors have attempted to analyse the economic factors determining new technologies used for gas distribution in maritime transport. The first part of the literature presented a theoretical approach to the LNG issue. The basis of a critical review of the literature on the presented research problem has been carried out.

The second chapter contains the characteristics of the research area, the economic analysis, as well as the algorithm for determining the price of LNG. This allowed to establish a theoretical and methodological benchmark to which the results of the own research project could be related. This resulted in a search for answers to the questions: How should a given issue be approached so as to enrich the existing discussion on it.

In the third part, a simulation study was carried out to estimate the demand for LNG. Monte Carlo were used. The method used in the literature reproduces real conditions - taking advantage of the physicality and complexity of the actual location of the research process in a concrete, real environment (the Baltic Sea) so as to be able to take advantage of the possibility to observe and control the phenomena at the location chosen for the simulation. Based on the simulations, a final economic analysis has been carried out in terms of new technologies applied in the Baltic Sea for LNG in shipping.

The next section attempts to discuss the results obtained from the simulations. The discussion of results is an overview chapter. It contains interpretations and description of the meaning of the results. This chapter will help to explain why the research came out as it did, what new has been contributed to the scientific output in the given topic of new LNG technologies. The final section of the paper summarizes the research problem presented in the literature.

4. LNG Supply Chain

4.1 LNG Supply Chain in the Baltic Sea Region

The density of shipping lines in the Baltic Sea is relatively high and although the basin is about 1/900th of the world's oceans and seas, it concentrates as much as 15% of the world's transport and amounts to more than 2,000 sea vessels. The need to adapt to new requirements for the use of LNG requires the construction of new LNG-fueled ships or the modernization of ships in service (Bogacka, 2012). Renewal of the maritime fleet takes time (in 2019, there were six LNG-powered ships in operation worldwide, increasing to 12 the following year, and 27 more are on order or under construction), (The Maritime Executive ,,Nauticor and Novatek to Develop Small-Scale LNG in the Baltic”). In 2018, there was an 11.5% increase in LNG-carrying ships and at the end of the year there were 525 ships (2019 IGU World LNG report - 2019 Edition).

Projects are being implemented for the construction and expansion of LNG terminals (expansion of the existing LNG terminal in Świnoujście by 2021) and means of transport to ensure proper distribution (plan to build a floating terminal in the port of Gdańsk, where work is likely to start in 2021) and LNG storage. Poland has eight LNG bunkering stations. Re-gasification stations are also being built in off-grid locations.

The development of the bunkering network along the Polish coast contributes to the establishment of international cooperation between national companies. Numerous national projects have led to the development and introduction of LNG regionally:

1. Hamburg-based Nauticor and Russia's Novatek Green Energy have signed a letter of intent to jointly develop LNG supply infrastructure in the Baltic Sea region. The intention of these companies is mainly to develop infrastructure at ports along the German Baltic coast and to improve LNG bunkering with bunker vessels and trucks **(**The Maritime Executive ,,Nauticor and Novatek to Develop Small-Scale LNG in the Baltic”).
2. In Lithuania, with the Energy and Climate Action Plan 2021-2030, the development of LNG bunkering stations and LNG-powered road and maritime transport is promoted and supported **(**,,Small-scale LNG demand grows in Baltic” states 08 Apr 2020 John Snyder).
3. Cooperation has been established between Klaipedos Nafta (KN), the operator of the Klaipeda LNG terminal in Lithuania, and Polish Oil and Gas Company (PGNiG). The aim is to strengthen the small regional LNG hub in the Baltic Sea (,,Small-scale LNG demand grows in Baltic” states 08 Apr 2020 John Snyder).

The literature covers the characterization of bunkering methods for marine vessels in regulatory and technical aspects. It describes the units used for LNG carriage (transport), LNG bunkers and LNG ports located in the Baltic Sea area enabling or planning to provide ship bunkering services (Herdzik, 2014). On the other hand, to a small extent, it addresses the issue of profitability of establishing LNG bunkering networks (Aymelek *et al.*, 2015) in Baltic Sea ports in terms of economics or the possibility of developing such networks (Herdzik, 2014). Moreover, the literature does not cover the issues related to the LNG distribution model in the southern part of the Baltic Sea. There have been no studies determining the price of LNG taking into account the real demand for LNG as bunker fuel in the Baltic Sea until 2026. Which is an important aspect due to the expected increase in demand for LNG in areas under strict control of sulfur emissions (Grzelak, 2015; IGU, 2016) which include the waters of the Baltic Sea. Therefore, the subject of the study was undertaken.

4.2 Economic Analysis

The LNG logistics chain model includes stages:

- Extraction of natural gas and its transportation from the field to the liquefaction facilities through the pipeline system in the gas exporting country. The costs of extraction vary due to the geological conditions of the country, the characteristics of the deposits, the distance to the terminal, and also the labour costs.
- Liquefaction of natural gas, LNG storage and loading. The price is determined by the amount of liquefaction and regasification costs (technologies used, natural gas logistics).
- Maritime transport of LNG to the gas off-take point. Transport costs are a very important component of the LNG purchase. It is about 10 - 30% of the final price paid for natural gas (Figure 1). There are several factors that contribute to transportation costs, so the price is more complicated. These include, among others, the cost of renting the methane carrier (where the costs depend on the situation on the natural gas markets, which is closely linked to the economic situation), fuel costs and charter fees constitute 80-90% of the LNG transportation costs. Therefore, the price of oil on the market affects the price of gas at a given moment, port fees, freight charges, as well as fees for passing through channels or insurance.
- unloading and re-gasification of LNG at the unloading (import) terminal.
- delivery of gas to end customers via the pipeline system in the importing country or by tankers (rail or road transport).

The annual unit rate for LNG (USD/t) depends on many factors. The difference can manifest for the same capacity factor, which depends on the location (Table 1) (www.naturalgasintel.com).

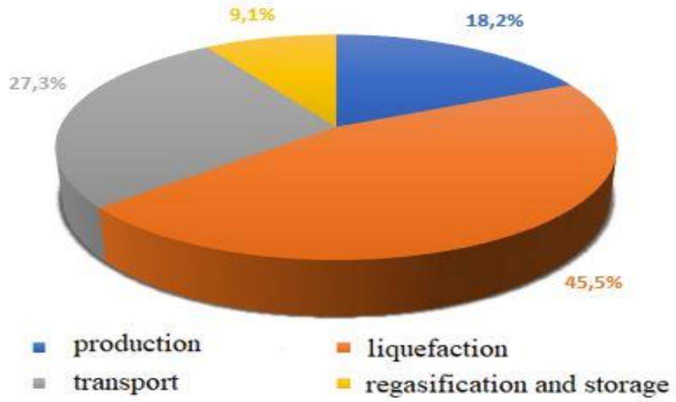
Table 1. *World LNG estimated landed prices*

World LNG estimated landed prices (01.2020)		
Continent	*Region*	*Annual LNG unit rate (USD/t)*
Europe	*Belgium*	*5.32*
	UK	*4.66*
	Spain	*4.53*
South America	*Canaport*	*6.83*

	Cove Point	*4.43*
	Lake Charies	*2.21*
	Altamira	*4.60*
North America	*Bahia Blanca*	*5.05*
Asia	*India*	*5.22*
	Korea	*5.42*
	China	*5.42*

Source: *Own study.*

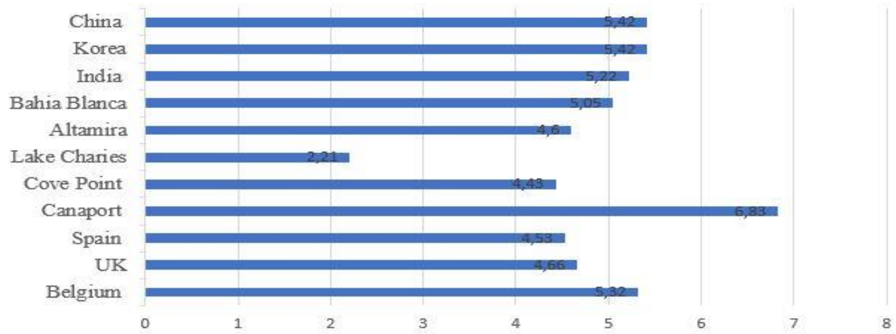
Figure 1. *Percentage list of LNG chain link costs*



Source: *Own study.*

In Europe alone, for example, the price difference between Spain and Belgium is $0.39. In the USA between Lake Charles and Cove Point it is as high as $2.21 (Figure 2).

Figure 2. *Location-dependent LNG price differential graph (USD/t)*



Source: *Own study.*

The purchase of LNG is tied to a fixed-term contract (1-5 years). In order to increase the competitiveness of mature ports, flexible and short-term transactions are allowed. Most of the LNG volume sold is done with long-term contracts. When concluding term contracts, two types of LNG price indexation are distinguished:

- gas,
- crude oil.

This means that the price for the raw material increases according to gas prices communicated to the general public by hubs:

- Title Transfer Facility (TTF) - Dutch virtual gas buying and selling point.
- Brent crude oil prices (oil from 15 oil fields located in the North Sea),
- crude oil quotations.

Statistics from 2014 - 2016 show that for households the average price of natural gas was 41.3 €/MWh. For industry, it is almost twice as high at 70.7 €/MWh (Table 2). Industries experienced a price decrease of 7%. Households represent a price increase until 2008 and a decrease between 2014 and 2016 (DNV GL data, 2017).

4.3 Algorithm for Determining the LNG Price

The LNG price in short-term contracts or occasional bunker fuel transactions is independent of changes in gas or oil prices and can be calculated by using the formula:

$$price\ of\ LNG = \alpha \times i + e \tag{1}$$

where

α– freight element;

i– gas emission index,

e – logistics element.

Explanation:

Freight element: market value of LNG;

Logistics element: delivery costs including shipment to the bunkering place (it is essential to optimize the route that is particularly important in the entire logistics process the duration of service; the route should be planned to optimize the above components considering all relevant factors;

Gas emission rate: a comparative test related to crude oil (Brent, fuel oil, heavy fuel oil) or stated by:

- TTF,
- Henry Hub (HH),
- Platts LNG Japan Korea Marker (JKMTM),
- UK National Balance Point (NBP).

To put it simply, the total value of LNG price taking into account the various components, can be written by the formula:

$$\text{price of LNG} = \alpha \times \text{TTF index} + \\ + \text{transhipment costs} + \text{storage costs} + \text{distribution costs} + \text{service fee} \quad (2)$$

where

- coefficient α – 1.03-1.15 (includes the supplier's margin or boil-off gas fuel price);
- TTF index – charge per energy unit with logistics costs and service fee (may be given for the next day and for the next month);
- LNG price depends, *inter alia*, on the location (distance of the gas source) and the method of bunkering (ship-ship, truck-ship etc.).

LNG price is a variable unit price of energy delivered. Analyses of LNG prices should also consider elements dependent on other factors. EUR/USD exchange rate is added to HH indexed LNG bunker delivered to Europe (gas sale price is in EUR, HH is stated in USD). Logistics costs are based on the contract and charter rate for LNG bunker ship, so the cost amount is given in USD. If the parties have concluded a contract for a period longer than two years, logistics costs include the index of consumer prices or they are connected with labour costs, i.e. local indicators.

5. Case Study

5.1 LNG Demand Volume: Economic Analysis

The demand for LNG as marine fuel for ships arriving in Polish ports was determined by a Monte Carlo simulation. This simulation is a process consisting of a very large number of simulations performed for a specific model, accepting that no accurate data of analyzed variables for a future period are available, and that only their past distribution is known. The simulation was based on fuel consumption by the type of propulsion (Table 2). The demand size was determined for steam propulsion as it shows the highest annual fuel consumption.

Table 2. *Fuel consumption by propulsion type*

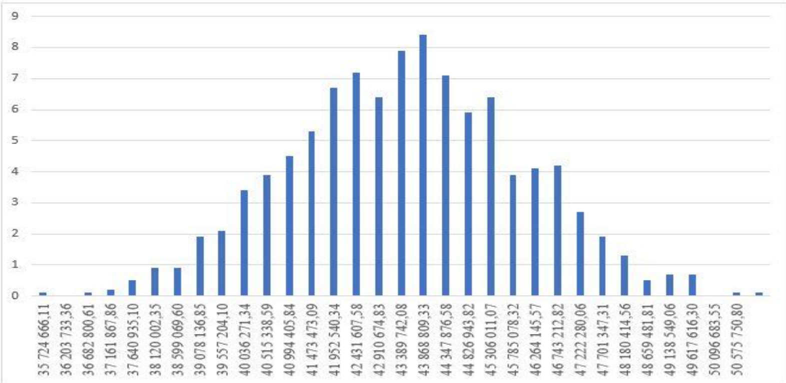
Type of Propulsion	**Fuel Consumption [M^3 / Day]**	**Fuel Consumption [M^3 / Year]**
Steam	398	143 280
DFDE/TFDE	295	106 200
ME-GI	250	90 000
XDF	245	88 200
Steam Re-heat	318	114 480

Source: *Own study.*

Based on the analysis of LNG demand in the years 2018-2015, a simulation was conducted to estimate the probability of LNG volume demand in 2026 for sea-going vessels providing their services in the southern Baltic Sea, calling at 17 Polish ports: Gdańsk, Gdynia, Szczecin, Świnoujście, Police, Darłowo, Elbląg, Frombork, Hel, Kołobrzeg, Krynica Morska, Międzyzdroje, Sopot, Stepnica, Trzebież, Ustka, Władysławowo (Figure 3 and Figure 4).

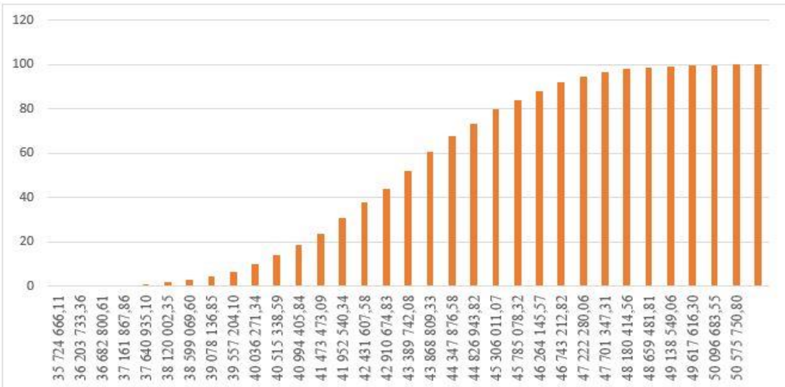
An example chart of relative frequency approximately illustrates the probability of specific demand occurrence in 2026. The chart similar to a normal distribution shows that it is most likely in 2026 that the demand for LNG will be 43 868 809.33 m^3. The probability of such demand level is around 8.5%. The probability of reaching the annual level of 432 389 742.08 m^3 is about 8%.

Figure 3. *The relative frequency [%].*



Source: *Own study.*

Figure 4. *Cumulative frequency*



Source: *Own study.*

The 50 simulations show that the highest demand for LNG for steam propulsion is 44,566,141.49 m3/year with a probability of occurrence of 10.9%. In contrast, the minimum value is 42,427,263.15 m3/year with a probability of occurrence of 7.9%. The difference between the values is about 2 million m3/year. This assumption is most correct, as it is possible to convert the analysed marine fleet to LNG. This results from the higher level of current LNG production in relation to the demand for fuel by the maritime economy, while satisfying other consumers of this fuel.

The results obtained in the conducted simulations support the decision-maker at the investment planning stage in the selection of natural gas for marine transport. The use of LNG as a fuel supplying the distribution zone may become an alternative to other energy sources. However, this type of power supply in the Baltic Sea area is characterized by sensitivity to external conditions, primarily of economic nature. The calculated final sales price of natural gas affects the economic efficiency the most. The relation between expense and cost and the calculated sales prices of natural gas in relation to the prices of other energy carriers which are available on the market makes it possible to use liquefied natural gas as a source of power supply in urban areas. The use of natural gas as a source of energy as an alternative to fuel oil, gives a real possibility to improve the air quality in urbanized areas by lowering the level of CO2 emission.

6. Conclusion

Modern technology contributes to the development of new projects and modifications modifications to existing import terminals to enable efficient distribution of feedstock. Most small regasification plants are built using prefabricated equipment and pre-assembled modules delivered directly to the site, providing a faster project schedule. On top of this, SSLNG is considered a scalable business (production capacity can easily be added to handle increased demand and achieve a synchronized supply chain). SSLNG generates high returns in the medium term. Unlike large LNG projects, the technology allows for lower investment requirements. The commissioning period of the facility is shorter, which reduces the uncertainty of project timing.

SSLNG projects are particularly important for Central and Eastern Europe (they offer solutions to gas supply diversification problems). Poland and Lithuania are examples of successful implementation of alternative solutions by introducing LNG terminal import services. The benefits of LNG deployment resulting in increased diversification of energy sources in the Baltic Sea have led to increased efforts to develop LNG. With the introduction of restrictions on toxic compounds emitted by marine vessels into the atmosphere in strictly controlled areas and other stringent environmental regulations, the availability of LNG distribution networks (as an alternative to meeting regulations) in the Baltic Sea is steadily growing. As the number of LNG-powered ships increases, the demand for infrastructure designed to serve this type of vessels increases. Knowing the amount of demand for LNG in individual ports of the Baltic Sea, it is possible to build import terminals of liquefied natural gas which results in the development of a small scale market in Poland. To sum up:

- The distribution of LNG to sea areas is carried out using road transport.
- SSLNG is a long-term investment, dependent on many variable parameters.

- LNG is an economically viable fuel. Vulnerability of liquid fuel prices to changes caused by changes in oil prices leads to the impossibility of providing a stable price for marine fuels in the long term.
- The price of natural gas is lower than the price of crude oil.
- Additional quantities that need to be considered during the economic analysis are: distribution service costs, regasification costs, LNG transportation costs, margins.
- The economics of establishing an LNG bunkering network is influenced by the bunkering method and the price difference between LNG and desulfurized light diesel.

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