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Management of liquefied natural gas distribution based on the logistic infrastructure of European and African countries

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***Abstract*—The Russian full-scale invasion of Ukraine in 2022 prompted European countries to implement economic sanctions against Russia to address the ongoing conflict. In response, Russia resorted to manipulating gas deliveries to Europe, leading to changed contracts, gas flow limitations, and artificial restrictions. Given the importance of reliable energy partners, European countries started urgently developing a plan of action to reduce Russian gas consumption. The existing network of export and import LNG terminals could offer a viable solution for partially replacing Russian gas. This paper focuses on a case study that explores the optimal transportation solution for LNG gas in the Mediterranean Sea region, utilising the existing infrastructure of Europe and Africa. The study formulates the problem as a linear programming transportation task, seeking to minimize costs and maximize efficiency, considering port capacities, gas demands of individual countries, and distances between transportation points. Additionally, the paper considers the scalability of the proposed optimisation task to accommodate changing energy demands and supply patterns.**

Keywords — LNG gas, gas replacement, transportation problem, Mediterranean Sea region, European and African infrastructure, gas management, optimization task

I. Introduction

From the beginning of the Russian full-scale invasion (from 24 February 2022) to Ukraine, European countries initiated economic sanctions on the Russian Federation to stop the war conflict. Responding to this step Russia started manipulating the delivery of gas to Europe. Among those manipulations are changed contracts, limitations of the gas flows, fake restrictions etc. Considering the situation, we can assume that the situation will remain complicated during the conflict and for a long period after it.

Before the full-scale war conflict European countries consumed approximately a lot of Russian gas, which accounted for slightly less than one-third of total gas consumption. Accordingly, as an instant measure to replace Russian energy resources European countries switched to the much more expensive gas from LNG (Liquefied Natural Gas) [1]. As a result, that caused a decrease in Russian gas consumption to the level of 13%, however, the prices became volatile simultaneously.

It goes without saying that business is building on reliable partners. Because of the full-scale conflict in Ukraine become continuous and the background for the successive negotiations with Russia neglected European countries must confirm an urgent plan of action. Partially Russian gas can be replaced using the existing network of export and import LNG terminals. However, such a way of gas transportation requires some limitations and restrictions. Among them ports' import and export capacity, countries' gas needs, distance between the transportation points, cost of cargo etc. Accordingly, in this paper, we consider the case study on the best transportation solution for LGN gas in the Mediterranean Sea region using the existing infrastructure of Europe and Africa. This optimisation task can be qualified as the linear programming transportation problem. In addition, the scalability of the reflected in the paper optimisation task is also considered.

II. Assessment of the Gas Supply in EUROPE and LNG Potential

In Europe, an essential network known as ENTSOG (European Network of Transmission System Operators for Gas) has been established to cater for the diverse needs of consumers in the realm of gas supply. This organization plays a pivotal role in ensuring the efficient and reliable transmission of gas across the continent. One of the primary responsibilities of ENTSOG is to develop the TYNDP (Ten-Year Network Development Plan) that encompasses various scenarios of gas infrastructure development, consumption trends, and other relevant factors [2].

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The TYNDP plan serves as a roadmap for the expansion and enhancement of gas transmission infrastructure over the coming decade. By forecasting future demands and evaluating potential challenges, it helps ensure the security and stability of the gas supply network while also promoting sustainability and environmental responsibility. However, the TYNDP plan established in 2022 has faced a considerable obstacle as it did not consider the unforeseen circumstances of the war year 2023. The outbreak of conflicts and geopolitical shifts significantly impacted the gas market and led to unpredictable changes in consumption patterns, supply routes, and infrastructure needs. Further, we consider basic facts on what the TYNDP was relying on.

Prior to the Russian full-scale invasion of Ukraine, Europe relied on several sources for its gas supply. Russia was the largest supplier, other major suppliers included Norway, Algeria, and Qatar [3]. In fact, European consumption of Russian gas before the war conflict (in Q1 2022) was around 27% [4].

LNG gas played an important role in the existing gas supply. LNG is natural gas that has been liquefied and transported by ship. It is a flexible source of gas and can be imported from a variety of countries.

The TYNDP 2022 ENTSOG plan highlighted the need to expand the role of LNG gas in the European gas supply. This was due to several factors, including the increasing demand for gas in Europe, the need to diversify away from Russian gas, and the potential for LNG to play a role in decarbonizing the European economy [3].

The full-scale war in Ukraine has changed the situation significantly. The EU has imposed sanctions on Russia, which has led to a reduction in Russian gas exports to Europe. This has increased the need for LNG imports and has also led to higher gas prices.

Considering the LNG potential market share LNG supply has increased significantly from around 10 % from 2015 to 2018 to around 21 % in 2019 and is expected to play an increasingly important role in Europe [3].

In terms of efficiency, LNG gas has higher energy density compared to traditional fuels translates into reduced transportation costs and greenhouse gas emissions per unit of energy delivered. Its versatility in transportation modes, including pipelines, ships, and trucks, enhances supply chain flexibility, contributing to more resilient energy infrastructure. Additionally, the growing availability of LNG infrastructure and the economies of scale achieved through its distribution networks make it a cost-effective alternative to conventional energy sources, thereby stimulating economic growth and energy security.

III. Methodology and Data for Research

A. Data characteristics used in the paper

The Mediterranean Sea region has emerged as a critical hub for the transportation and distribution of LNG. The existing infrastructure in this area plays a significant role in meeting the energy demands of European countries and beyond. In this chapter we provide a comprehensive description of the current export and import LNG infrastructure in the Mediterranean Sea, highlighting key export and import terminals, and their significance in the context of the energy landscape. In addition, we consider the gas demand of the countries in the region.

For computing the existing export/import capacity we provide the comparative analysis of the LNG points. To do that we recalculate the data provided by Gas Infrastructure Europe [5] with the methodologies used by [6], [7] the Cetiner Engineering Corporation and British Petroleum respectively. These organisations are recognized for running energy businesses and doing engineering and consulting services. The transferred capacity allows us to equal values, compare the capacity and build optimal paths further. Both companies are at the same time considering the equality for the 1 billion cubic meters per annum (bcma) for the 700-735 million tons of LNG gas. Accordingly, in this paper, we consider this value as the minimum that the companies suggest for the transformation. Further in this chapter, we consider and describe the characteristics of three LNG export terminals located in the Mediterranean Sea region.

Located near the coastal town of Arzew in Algeria, the Arzew LNG export terminal is a significant player in the Mediterranean Sea's LNG infrastructure. Operated by Sonatrach, Algeria's state-owned energy company [8], the terminal has been operating since the early 1970s and has undergone expansions to meet the growing demand for LNG in international markets. The Arzew terminal has multiple liquefaction trains, each capable of producing large quantities of LNG. The facility's combined production capacity is approximately 28,0 bcma (calculated by the authors), making it the largest LNG export terminal in the Mediterranean Sea region.

Damietta LNG terminal, located on Egypt's Mediterranean coast, is one of the region's significant export facilities. It began operations in 2004 by the Spanish Egyptian Gas Company SAE (SEGAS) [9]. The terminal has a capacity of approximately 6,8 bcma (calculated by the authors) and serves as a supply source for European markets.

Idku LNG Terminal is also located in Egypt and operated by the Egyptian Natural Gas Holding Company (EGAS). It began its operations in 2005 and has a capacity of about 9,8 bcma (calculated by authors). The terminal has been instrumental in enhancing the availability of LNG for Europe and other international markets.

The Skikda and Marsa-el-Brega LNG export terminals, located in Algeria and Libya respectively, were significant contributors to the global LNG trade. However, due to technical challenges and geopolitical instability, both terminals ceased operations. Their closures impacted the Mediterranean LNG landscape and emphasized the importance of diversifying energy supply strategies for enhanced resilience and energy security. The Skikda LNG export terminal ceased operations due to an explosion in 2004 with further decommission. In the case of the Marsa-el-Brega LNG export terminal, its closure was a result of the civil unrest and political upheaval in Libya, which

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disrupted operations and made it unsafe to continue LNG production and export activities [5].

Europe's LNG import terminals serve as crucial hubs for receiving, storing, and distributing LNG to various parts of the continent. These terminals enable flexibility in the energy market by allowing the import of LNG from diverse sources worldwide. There are many more existing terminals in contrast to the export terminals. Their characteristics are provided further in the tab.I.

TABLE I. DESCRIPTION OF THE EXISTING LNG TERMINALS LOCATED IN THE MEDITERRANEAN SEA REGION

№	Country	Name of terminal	Location	Import capacity, bcma
1	Portugal	Sines LNG Terminal	Sines	7,6
2	Spain	Huelva LNG Terminal	Huelva	11,8
3	Spain	Mugardos LNG Terminal	Mugardos A Coruna	3,6
4	Spain	Bilbao LNG terminal	Bilbao	7,0
5	Spain	Cartagena LNG Terminal	Cartagena	11,8
6	Spain	Sagunto LNG terminal	Sagunto	8,8
7	Spain	Barcelona LNG Terminal	Barcelona	17,1
8	France	Fos-Tonkin LNG Terminal; Fos Cavaou LNG Terminal	Fos Tonkin Fos Cavaou	10,0
9	Italy	Panigaglia LNG terminal	Panigaglia	3,4
10	Italy	OLT Offshore LNG Toscana FSRU	Livorno	3,6
11	Italy	Rovigo LNG terminal	Rovigo	9,0
12	Malta	Malta Delimara LNG terminal (Armada LNG Mediterrana)	Marsaxlokk	0,7
13	Croatia	Krk LNG Terminal (LNG Croatia)	Krk Island	2,6
14	Greece	Revithoussa LNG Terminal	Revithoussa	7,0

To enhance the precision of our task, we conducted an essential step by obtaining distances between all the export and import LNG terminals, as mentioned in our research, utilizing the advanced NETPAS tool [10]. This diligent effort allowed us to gain valuable insights into the geographical separation between these vital terminals, enabling a comprehensive analysis of their interconnectivity.

Following the data acquisition process, we constructed a matrix encompassing these distances. The matrix of distances represents a fundamental component of our research and serves as a pivotal reference for our subsequent analyses. In tab.II, we provide a concise yet informative overview of this distance matrix, facilitating a clear understanding of the spatial relationships among the various LNG terminals involved in our study.

Lastly in the experiment, we use the countries' gas demand values of the pre-war 2021 year. In the paper, we compare the total need for gas with the supply possibilities and consider the overall country gas consumption as the additional limitation while building a mathematical model for the transportation model.

TABLE II. MATRIX OF THE DISTANCES BETWEEN LOCATIONS WITH EXPORT/IMPORT LNG TERMINALS IN NAUTICAL MILES

Export LNG terminals	Import LNG terminals					
	Sines	Huelva	Mugardos A Coruna	…	…	Revithoussa
Arzew	545	398	940	…	…	1 257
Idku	2 101	1 954	2 497	…	…	527
Damietta	2 167	2 020	2 562	…	…	571

The data pertaining to the gas requirements and demands of the respective countries are meticulously detailed and presented in tab.III [11].

TABLE III. EUROPEAN COUNTRIES GAS NEEDS IN 2021

Country	Gas need, bcma
Portugal	5,7
Spain	33,8
France	41,6
Italy	76,1
Malta	0,4
Croatia	2,9
Greece	6,5

B. General approach to solving the transportation problem

Linear programming transportation problem, a fundamental optimization technique, has evolved significantly over the years and finds wide-ranging applications in various fields today. Originally formulated during World War II to address resource allocation challenges, it has since developed into a powerful tool for solving complex real-world problems efficiently and effectively [12].

Over the years, researchers and practitioners have made significant advances in solving the transportation problem efficiently. Today, the emergence of computer technology and the availability of powerful optimization software have revolutionized the way transportation problems are solved. These modern solvers use advanced algorithms to efficiently find optimal solutions for large and complex transportation networks, making the technique highly applicable in today's data-driven world.

The linear programming transportation problem nowadays has found widespread applications in diverse fields, addressing complex logistical and resource allocation challenges. Some of the contemporary applications include but are not limited to:

1. Supply chain management where the transportation problem is extensively used in optimizing supply chain logistics, determining the most cost-effective way to transport goods from suppliers to customers, warehouses, or retail outlets.

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2. Transportation and distribution in shipping companies and logistics providers to optimize freight distribution routes and minimize transportation costs.

3. Energy and utility companies use linear programming transportation problems for optimizing the distribution of electricity, gas, or water from different sources to various demand centres, considering constraints on capacities and demands.

At its core, the transportation problem aims to minimize the total cost of transporting goods from a set of supply sources to a set of demand destinations, subject to supply and demand constraints. The problem is mathematically formulated as a linear optimization model, involving linear equations and inequalities. Considering the basic formulation, the problem has the following description [13]:

$$\sum_{j=1}^{n} x_{ij} = a_i,\ i = 1, 2, 3, \ldots, m \ (1)$$

$$\sum_{i=1}^{m} x_{ij} = b_i,\ j = 1, 2, 3, \ldots, n \ (2)$$

$$\sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \rightarrow \min \ (3)$$

Accordingly, in this paper, our primary objective is to apply the mentioned solution to the transportation problem to identify and optimize the best routes for LNG gas transportation, considering the geographical locations of export and import terminals, and their capacity.

C. *Review of similar methods, used in the other research papers*

The optimization of LNG logistics and distribution is a highly topical subject in today's energy landscape. As the global demand for natural gas continues to rise, efficient transportation and distribution methods are crucial for meeting this growing need. Additionally, the geopolitical factors and the desire to reduce dependency on Russian gas in Europe have further elevated the importance of LNG as an alternative and reliable energy source. Embracing LNG as a viable and strategic option for diversifying energy supplies will undoubtedly make its optimization even more relevant and popular in the years to come.

In the paper [14] the authors present a mathematical model for optimizing the LNG supply chain. The model is based on mixed-integer linear programming (MILP) formulation and considers a variety of factors, including the cost of LNG, the demand for LNG, and the capacity of the LNG infrastructure. The authors use the model to evaluate different scenarios for the LNG supply chain and identify the most efficient way to operate the chain. The paper's findings have important implications for the LNG industry. The authors show that there are significant opportunities for optimisation in the LNG supply chain. By optimising the chain, the industry can reduce costs and improve efficiency. The paper's findings are also relevant to other industries that rely on the transportation of commodities.

Later these authors developed their research and published a paper [15] that evaluated different scenarios for the small-scale LNG supply chain and identified the most efficient way to operate the chain. They find that there are significant opportunities for optimisation in the small-scale LNG supply chain. By optimising the chain, the industry can reduce costs and improve efficiency. For Their investigations, they used the same MILP model.

Authors [16] provide an overview of the LNG supply chain and the industry's challenges in terms of sustainability. They then review four quantitative models that have been developed to address these challenges. The models are classified as economic, environmental, social, and multi-criteria.

In the paper [17] the authors evaluate different scenarios for the LNG delivery planning problem and identify the most efficient way to operate the system. They find that there are significant opportunities for optimisation in the LNG delivery planning problem. By optimising the system, industry can reduce costs and improve efficiency. The paper uses a mathematical model to optimize the LNG delivery planning problem.

To conclude this section the transportation task of LNG gas has garnered significant attention in the literature, and research findings continue to evolve. Numerous papers have explored this subject, often employing mathematical or logical models to address various aspects of the LNG supply chain. These findings not only hold crucial implications for the LNG sector but also bear relevance to other industries reliant on commodity transportation, emphasizing the importance of continuous development in the field of LNG logistics and distribution.

Research connected to any of the energy markets [18] will be highly beneficial if it leverages comprehensive and reliable data along with innovative and novel approaches, as this combination can lead to deeper insights, more accurate predictions, and effective solutions for the challenges facing the energy industry [19].

In this paper, we aim to make a contribution to the development of the topic by utilizing advanced methods of linear programming to optimize the LNG logistics and distribution process. By employing these sophisticated techniques, we seek to uncover novel insights and solutions that can further enhance the efficiency, sustainability, and cost-effectiveness of the LNG supply chain.

D. *Experiment details used in this paper*

The core algorithm guiding our research, as illustrated in fig.1. The algorithm systematically guided the steps of data preprocessing, mathematical modelling, and achieving balance, ensuring a coherent and rigorous methodology.

Initially, we constructed a comprehensive and accurate basic dataset using the data presented in the previous sections of the paper, ensuring a reliable foundation for our analysis.

Subsequently, we formulated a mathematical model that incorporated the various limitations and constraints inherent in the LNG supply chain. The model aimed to optimize the transportation routes and allocate resources efficiently.

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Our model was initially unbalanced due to a significant disparity between the supply capacity and demand. To rectify this imbalance, we introduced a balancing supplier to the model, harmonizing the supply and demand sides. This enabled us to develop a feasible mathematical representation of the LNG transportation scenario.

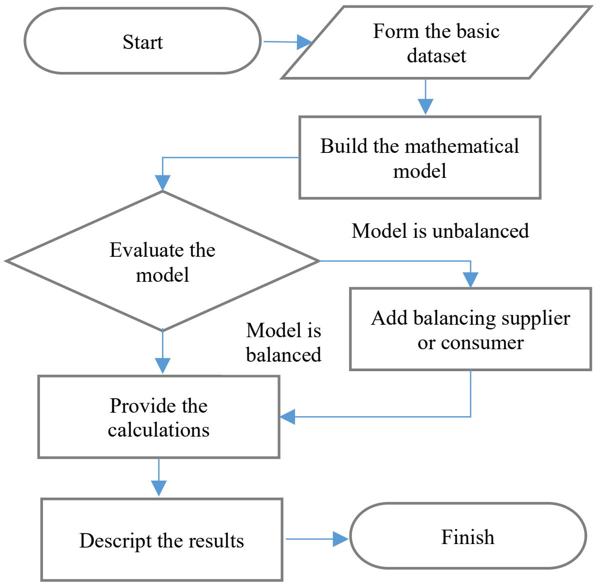

Fig. 1. Algorithm of providing the research in this paper

To execute the computations and obtain the optimized solutions, we leveraged the Microsoft Excel Solver Tool [20], which proved to be highly suitable for handling the complexity of such calculations. This tool facilitated precise and efficient computations, contributing to the generation of reliable results. In the empirical results section, we present a detailed account of the outcomes obtained through our algorithm and mathematical model.

IV. Empirical Results and Scalability

The presented empirical findings demonstrate the effectiveness of our optimization approach, which can have implications for enhancing the efficiency and reliability of LNG gas transportation worldwide, while also catering to the evolving energy demands of the region. In this section, we present the empirical results obtained from the application of our proposed optimization methodology to the LNG logistics and distribution process. The obtained solution for the optimisation task is reflected graphically in fig.2. The map is built using the OpenStreetMap following the Copyright and Licence [21], and all the numbers provided are given in bcma.

The empirical results of our paper reveal the optimized supply chains for the transportation of LNG gas, ensuring efficient utilization of terminal capacities and minimal distances covered. From Arzew, gas is transported to Cartagena, Sagunto, and Barcelona, effectively maximizing the capacity of two terminals in Cartagena and Sagunto while partially utilizing the terminal in Barcelona. For Damietta, the best approach involves transporting all available gas to the closest terminal, Revithoussa.

Idku presents more complex logistics, necessitating gas transportation to Rovigo, Marsaxlokk (Malta Delimara terminal), Krk Island, and Revithoussa. This arrangement optimally utilizes the capacities of Delimara, Krk Island, and Revithoussa terminals. Additionally, incorporating Delimara in the supply chain contributes to partially covering Malta's gas needs, making it a valuable addition.

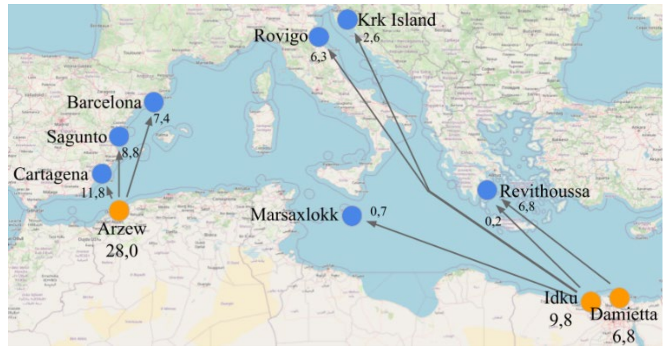

Fig. 2. Distribution scheme for optimal LNG gas delivery

Despite the apparent simplicity of the task, scalability considerations prompt us to extend the optimization to include planned import LNG terminals in the region (in Greece Dioriga Gas FSRU, Alexandroupolis LNG terminal, Thrace LNG, Argo FSRU; in Italy FSRU 1 – SNAM, FSRU 2 – SNAM, Porto Empedocle (Sicilia) LNG terminal; in Cyprus Vasiliko LNG terminal etc.) [5] and export terminals worldwide. This expanded scope encompasses terminals from the USA, Africa, and other regions, further complicating the task but yielding more advanced and comprehensive results.

Indeed, despite the optimization achieved in our supply chain models, it is important to acknowledge that the total LNG supply may only cover partial needs in some countries. While our approach maximizes efficiency and distribution, the overall demand for LNG gas may surpass the available capacity.

As we analyse the results, we recognize that addressing this limitation would require considering the countries' overall needs as an essential factor when planning future LNG infrastructure expansion. With the increase in export points and the development of new terminals worldwide, it becomes possible to mitigate this challenge and accommodate the growing energy demands of countries more effectively.

Lastly, the empirical results presented in this study, it is crucial to acknowledge that while our findings provide valuable insights into the management of LNG gas distribution, the practical implementation of these solutions can be influenced by a multitude of external factors. Investments, regulatory frameworks, and the ever-evolving landscape of geopolitical dynamics all play pivotal roles in determining the feasibility and success of these strategies in real-world applications. Thus, while our research offers a foundation for decision-makers, it is imperative that stakeholders remain attuned to these influencing factors.

V. Conclusions

In conclusion, this paper has presented an optimization approach for the transportation of LNG gas in the Mediterranean Sea region. The proposed approach was based on a linear programming model that considered the various limitations and constraints inherent in the LNG supply chain. The model was able to optimize the transportation routes and allocate resources efficiently, resulting in a significant reduction in transportation costs and an improvement in the overall efficiency of the LNG supply chain.

The empirical results of the paper demonstrated the effectiveness of the proposed optimization approach. The results showed that the optimized supply chains for the transportation of LNG gas ensured efficient utilization of terminal capacities and minimal distances covered. The results also showed that the proposed approach could be scaled to include planned import LNG terminals in the region and export terminals worldwide.

The paper also discussed the limitations of the proposed optimization approach. One limitation is that the total LNG supply may only cover partial needs in some countries. While the proposed approach maximizes efficiency and distribution, the overall demand for LNG gas may surpass the available capacity. Another limitation is that the proposed approach does not consider the environmental impact of LNG transportation.

Despite these limitations, the proposed optimization approach provides a valuable tool for improving the efficiency and reliability of LNG gas transportation in the Mediterranean Sea region. The approach can be used to plan future LNG infrastructure expansion and to mitigate the challenges associated with meeting the growing energy demands of countries in the region.

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