ISSN 2664-9969

UDC 665.612
DOI: 10.15587/2706-5448.2023.283160

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CONSIDERATION OF LIQUEFIED NATURAL GAS AS AN ALTERNATIVE SOURCE OF GAS SUPPLY TO UKRAINE

The object of research is the energy sector of Ukraine, specifically the gas supply system of the national economy. One of the most problematic places is the dependence of the Ukrainian economy on the import of natural gas (NG). Ukraine is rich in various natural resources, in particular, in natural and associated gas. However, own wells for NG extraction are not enough for gas supply to industrial enterprises and the population. Therefore, part of the necessary gas is imported. In the course of the study, methods of alternative supplies were analyzed, namely, liquefied natural gas (LNG), options for its supply with subsequent regasification were analyzed.

The global market for liquefied natural gas (LNG) was studied and it was shown that the production and consumption of LNG is constantly increasing. Since Ukraine is part of Europe, and the main suppliers of LNG for European countries are the USA and Norway, one of the options for gas supply for Ukraine considered the supply of LNG to the territory of Poland by sea transport, its regasification and subsequent transportation to consumers through existing pipelines. The second option is the supply of LNG to the Ukrainian coast of the Black Sea. To do this, it is necessary to study prospective transportation routes, build logistics and terminals for receiving and regasifying LNG. Since the depth of the channels from the Mediterranean to the Black Sea is small, the option of supplying natural gas from Central Asia by pipeline to the Black Sea coast of Georgia, its liquefaction, transportation by sea and regasification is proposed. This option requires significant capital expenditures for the construction of a natural gas liquefaction plant on the territory of Georgia and a regasification complex on the Ukrainian coast or a floating terminal.

In the course of the work, LNG quality criteria used in the world were studied, and it was noted that for the purchase and use of LNG in Ukraine, it is necessary to develop own standards for controlling its composition. Because the technology of providing the consumer with natural gas using LNG is more flexible than pipeline transport. Its implementation will make it possible to provide Ukraine with natural gas in the required quantities and, if necessary, to promptly change the volume of deliveries.

Keywords: *liquefied natural gas, quality of liquefied natural gas, regasification, regasification costs.*

Received date: 25.04.2023
Accepted date: 24.06.2023
Published date: 30.06.2023

How to cite
Diachenko, T., Garanin, Y., Tyshko, D. (2023). Consideration of liquefied natural gas as an alternative source of gas supply to Ukraine. Technology Audit and Production Reserves, 3 (1 (71)), 30–37. doi: https://doi.org/10.15587/2706-5448.2023.283160

1. Introduction

Ukraine is rich in various natural resources [1–6]. However, own operating wells for NG production are not enough to supply gas to industrial enterprises and the population. At present, the lack of gas is compensated by the supply of natural gas received from Europe under the reverse scheme [4–6].

Diversification of gas supply is an urgent task for the Ukrainian economy. One of the options is the supply of LNG with its subsequent regasification. To do this, it is necessary to make a preliminary assessment of the costs of building an LNG gasification complex and develop our own standards for the composition of purchased liquefied gas.

Real steps for alternative gas supply to Ukraine at the state level were made in 2012 [4, 7]. A number of projects were proposed for the construction of an LNG regasification complex on the Black Sea coast. However, the issues of the quality of liquefied gas have not entered the sphere of attention of the government.

The purpose of this study is to study ways of additional gas supply to Ukraine. A preliminary assessment of the cost of supplying and regasifying LNG will help to choose the best alternative gas supply.

2. Materials and Methods

The object of research is the gas supply system of Ukraine. Since there are not enough own LG sources, it is necessary to identify alternative supplies relative to pipeline transport that are acceptable for the Ukrainian economy.

The results were achieved by analyzing the current situation with gas supply, studying alternative gas supply methods, LNG supply routes and preliminary cost estimates for the implementation of these projects.

3. Results and Discussion

LNG is an economical form of storage and transportation of natural gas [8–10]. Unlike pipeline supplies, this method requires significant costs for LNG liquefaction, which are offset by a number of advantages. Compared to pipeline transport, the main advantage is the possibility of recovering up to 40 % of the energy spent on natural gas liquefaction during the regasification process, Fig. 1 [11–13].

The market for liquefied natural gas [8–11] is on the rise today. According to the International Group of Liquefied Natural Gas Importers (GIIGNL) [10], the total annual increase in LNG capacity will be the lowest since 2013, when new export capacities of 0.7 billion cubic meters feet per day were commissioned. Between 2014 and 2022, annual LNG capacity growth ranged from 1.8 billion cubic meters to feet per day in 2021 to a maximum of 5.6 billion cubic meters feet per day in 2018. Four new LNG export projects are expected to start worldwide in 2023 with a total capacity of 1.0 billion cubic feet per day (1 billion cubic feet per day), according to our estimates based on industry press and company press releases.

A significant role in the growth in demand for LNG was played by the energy crisis that broke out in Europe, which was exacerbated by the imposition of sanctions against supplies by pipeline transport from Russia. Thus, the European Union simultaneously increased LNG imports from the USA, African countries and Qatar (Fig. 2) [6, 10, 11].

Australia, Qatar and the United States are the leaders of the modern world LNG export market, each of which has a share of more than 20 %. The leading LNG exporters also include Russia, Malaysia, Nigeria, Trinidad and Tabago, Algeria and Indonesia [6, 10, 11].

As the market for liquefied natural gas expands, the infrastructure for its supply is developing. New LNG receiving terminals are under construction.

Export of LNG from the USA to Europe in 2022 increased by 2.5 times [6, 10, 11]. A sharp increase in exports from 47.8 to 117.4 million cubic meters occurred due to the russian invasion of Ukraine. At the end of 2022, the European Union became the main buyer of liquefied natural gas in the world, ahead of China, Japan and South Korea. In November, the State Department indicated that exports to Europe accounted for 70 percent of all shipments by American companies [10].

Another trend in the European LNG market, in addition to the consolidation of regasification capacities, is the reorientation from large batches to smaller purchases. EU consumers have become open to medium and small traders, and their regasification terminals have changed their configuration and adapted to a variety of options for further deliveries.

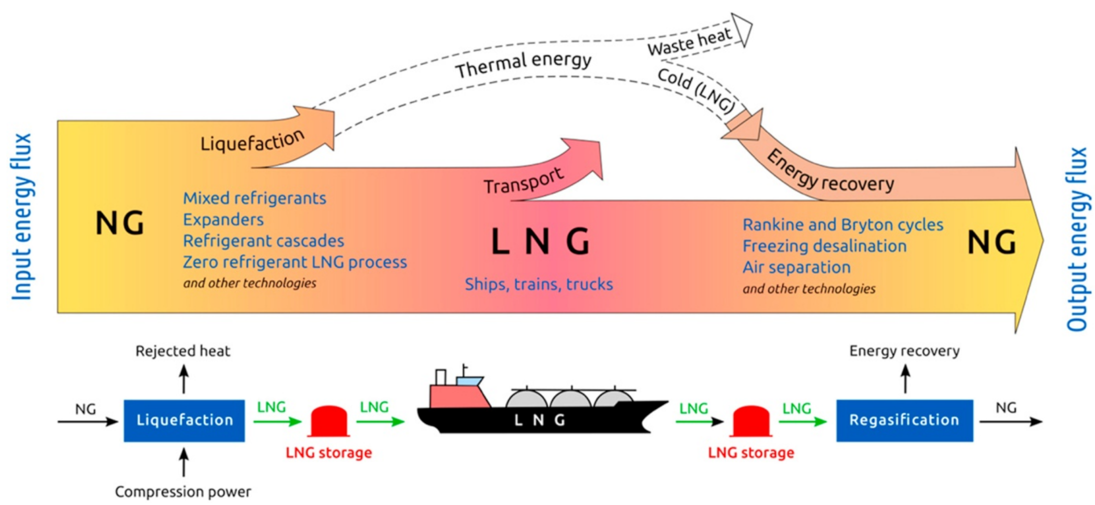

Fig. 1. Structure of production and use of LNG [12]

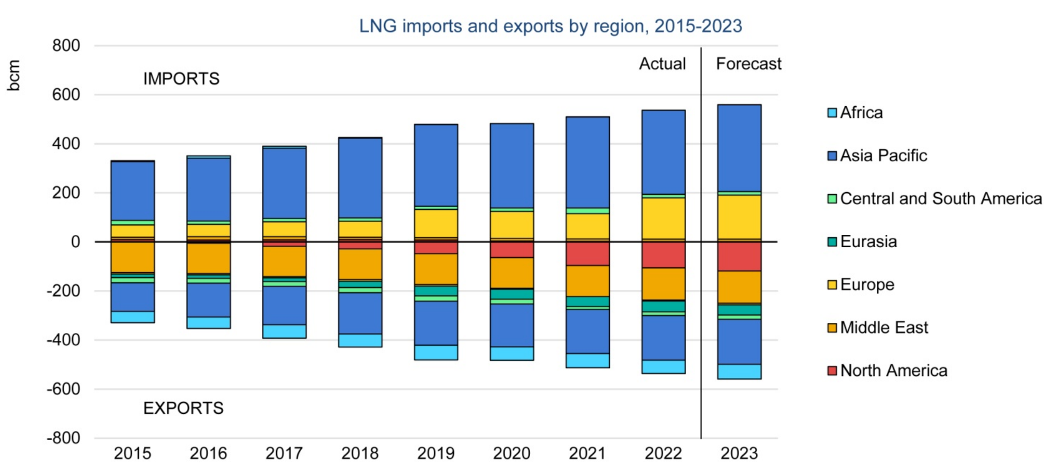

Fig. 2. Import and export of LNG by regions [6]. BCM – billion cubic meters

The oil and gas industry of Ukraine is represented by oil and gas production and processing enterprises [1–4]. The main oil and gas regions of the country are the Dnipro-Donetsk, Carpathian and Black Sea-Crimean regions (Fig. 3), and oil and gas fields of various reserves have been identified in most regions of the country.

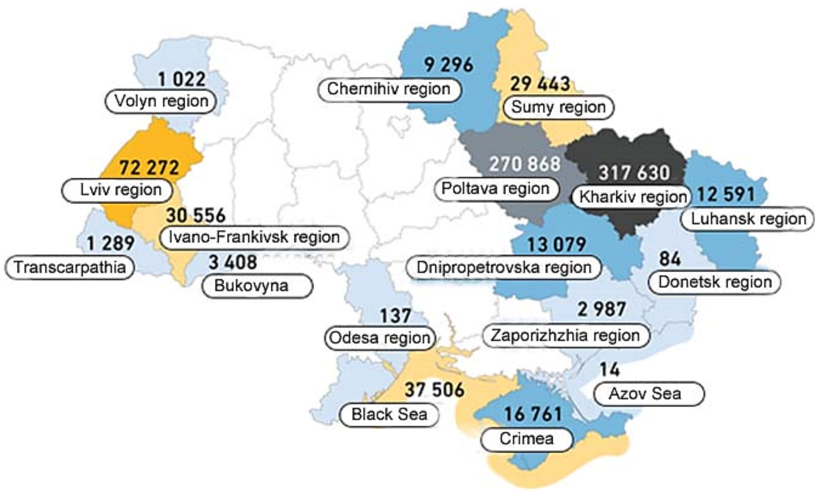

Fig. 3. Distribution of natural gas reserves by administrative regions, million m^3 [1]

According to a number of experts, Ukraine has large promising areas where it is possible to discover hydrocarbon deposits (especially gas) on a global scale [14, 15]. However, the current economic situation in the country does not allow investing in exploration and development of new deposits.

The study of the possibility of supplying gas by supplying LNG to the Black Sea coast shows that in order to organize supplies, it is necessary to evaluate:

– the possibility of supplying raw materials by sea;
– costs for the construction of a receiving terminal for regasification [13];
– if necessary, the cost of building a liquefaction plant [3, 9, 10].

As an example, the option of LNG supplies from Algeria was studied (Fig. 4) [14].

When choosing methane carriers suitable for LNG deliveries, one must take into account the depth of the seas and straits through which the vessel must pass. In our case, the limitation is the depth of the straits leading from the Mediterranean to the Black Sea. The depth of the Bosporus is from 36 to 124 m, the Dardanelles – 55 m.

A ship with a normal draft of 12 meters and a capacity of 250,000 m^3 of LNG was chosen as the vehicle. The duration of one trip from Algeria to Ukraine, taking into account loading and unloading operations, is 5 days. The cost of transporting the work will depend on the volume of supplies.

Real attempts to diversify the supply of natural gas to Ukraine through the supply of liquefied natural gas were made in 2012. The implementation of this direction is possible in the case of the construction of a receiving terminal for the gasification of liquefied natural gas.

In 2012, the head of the State Investment Project, Vladislav Kaskiv, signed a contract with a representative of the Spanish company Gas Natural Fenosa for the construction of a terminal for receiving liquefied gas in Odesa [7, 15, 16]. However, it turned out that the signatory who pretended to be its representative had no authority to conclude agreements.

In 2015, the Ukrainian government signed a memorandum of understanding with the American company Frontera Resources, which planned to build an LNG terminal in the Odessa region to supply it with its own gas produced in Georgia or Azerbaijan (Fig. 5) [17, 18].

A variant is proposed for the supply of natural gas from Central Asia via a pipeline to the Black Sea coast of Georgia, its liquefaction, transportation by sea and regasification. However, this project was not developed either.

The third attempt was made in August 2019, when NSDC Secretary Oleksandr Danilyuk signed a tripartite (Ukraine – USA – Poland) memorandum on cooperation in the energy sector in Poland [19, 20].

Fig. 4. LNG transportation route from Algeria to Ukraine

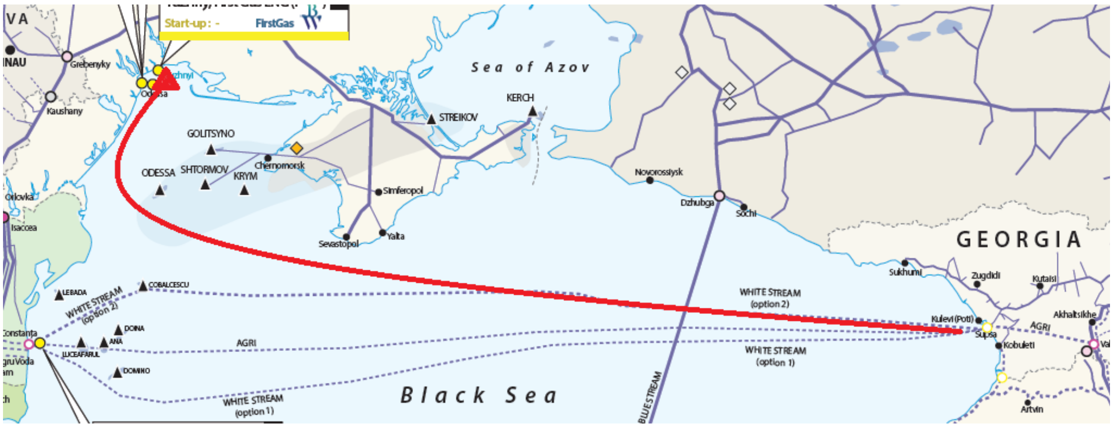

Fig. 5. LNG transportation route from Georgia to Ukraine

It was about creating a gas hub in Ukraine on the basis of Ukrainian underground gas storage facilities, which will be filled with gas supplied from the United States. The US and Ukrainian governments have agreed to supply Ukraine through LNG terminals in Poland with 6–8 billion m^3 of gas per year. It was planned to take 2–3 years to implement this project, since it was necessary to expand the corridor for gas supplies from Poland to Ukraine, which today can ensure the transfer of no more than 2 billion m^3 per year. However, Louisiana Natural Gas Exports, with which memorandums were signed on the purchase of LNG from the United States through a terminal in Poland, abandoned the project.

At present, the problem of diversification has not been solved. This is due to the 2020–2022 pandemic, and the beginning of martial law in Ukraine in February 2022. However, the need for natural gas supplies, both for the population and for industry, has not ceased to be relevant.

To implement alternative gas supply projects, it is necessary to develop a system of standards that determine the quality of incoming gas for Ukrainian consumers.

The supplied liquefied natural gas is often used as a fuel. The requirements for the quality of natural gas have several goals: prevention of corrosion and liquid dropout in pipelines, as well as stable performance of the consumer's burner [21].

Natural gas is a mixture of combustible and non-combustible gases with a predominance of combustible components: hydrocarbons, hydrogen and, to a lesser extent, carbon monoxide. Non-hydrocarbon impurities (mainly nitrogen and carbon dioxide) reduce the specific heat of combustion of gas, so the gas industry has such a concept as gas interchangeability, which is monitored by several parameters.

The main characteristic of gas quality is its calorific value. Its quantitative measure is the gross calorific value (GCV), Fig. 6 [21–24].

Another common characteristic of LNG quality is the Wobbe number [22] – the amount of heat produced by burning 1 m^3 of fuel at atmospheric pressure and a temperature of 15 °C:

$$W = GCV/\rho^{1/2}, \text{ MJ/m}^3,$$

where ρ – the specific density. The physical meaning of this index is that, at the same pressure, gases with the same Wobbe number will give the same energy influx.

The Atlantic Basin countries use regasified LNG with a lower GCV. The largest consumers of such LNG are the US and the UK. Consumers in the Asia-Pacific region prefer to buy LNG with higher GCV. The main LNG producers for these countries are the states of the Middle East.

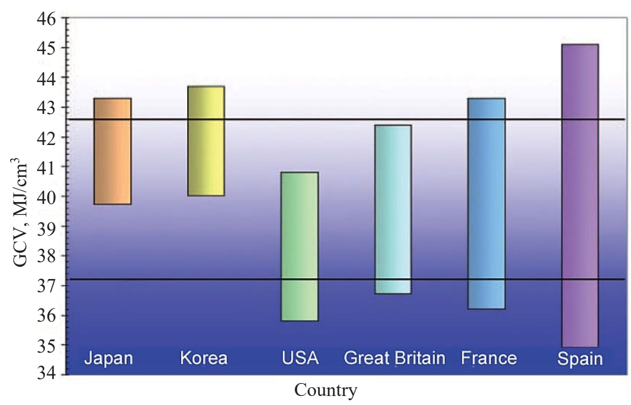

Fig. 6. Permissible ranges of calorific value of liquefied natural gas supplied to various countries [21, 22]

In continental Europe, a different classification of natural gases was originally adopted (Table 1, Fig. 6, 7). The low calorific grade gas (L-gas) came from the Gröningen field (Netherlands), while the high calorific grade (H-gas) was produced in Europe or came from Algeria, russia, Norway, and was also imported as LNG from various countries.

Since the range of calorific value of the latter gases is quite wide, in order to facilitate import and trade, relevant specifications for natural gas have been adopted in European countries with significant ranges for lower calorific value and Wobbe number. Table 1 shows the Wobbe calorific value requirements for the three gas grades H, L and E (intermediate grade) as set out in the European standard EN437.

Fig. 8 shows the allowable ranges of Wobbe numbers of natural gas for those considered in Table 1 grades of natural gases established by the national standards of the main European countries – gas consumers [23].

Table 1

Requirements for the calorific value of LNG by country [22]

Grade of natural gas	Calorific value (Wobbe number), MJ/m^3	
	Min	Max
H	45.7	54.7
L	39.2	44.8
E	40.9	54.7

ISSN 2664-9969

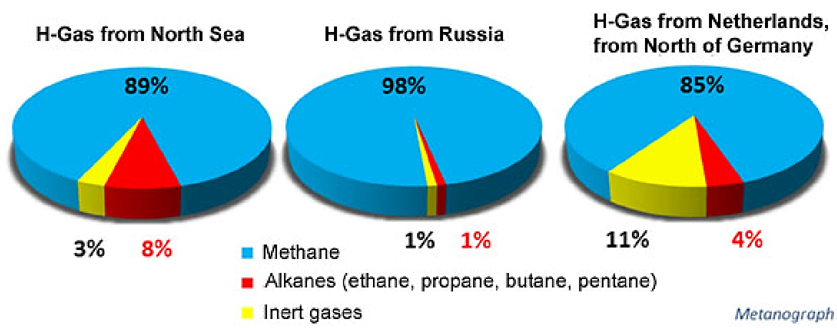

Fig. 7. Composition of natural gas from various suppliers [21]

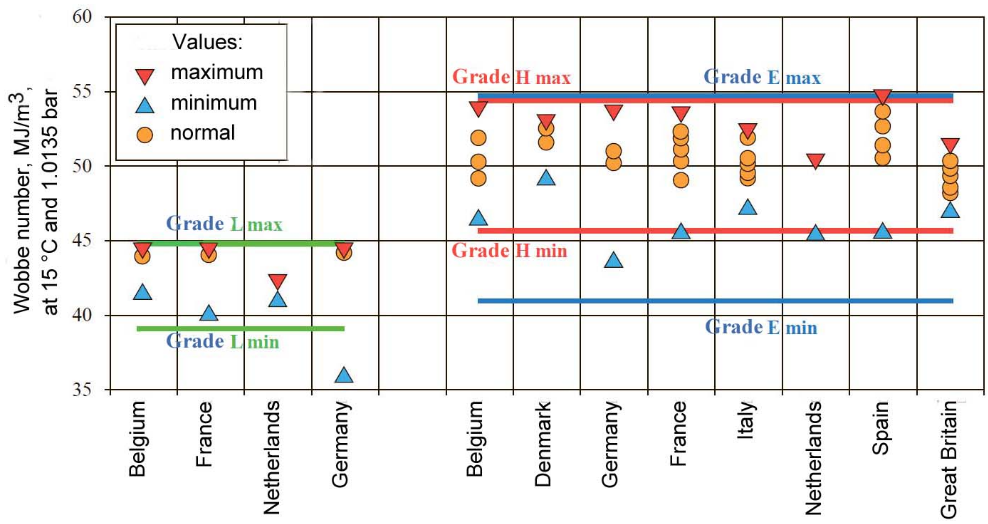

Fig. 8. Permissible ranges of Wobbe numbers of natural gas, established by the national standards of the main European countries for grades of natural gas H, L, E [21]

In the Netherlands, Belgium, France, Luxembourg and partly in Germany, both H- and L-gas are used, but in each of these countries these types of gases are supplied through separate networks.

Natural gas supplied via the GTS in Japan and European countries has a different range of calorific value and detonation resistance (Table 2) [22].

Various methods are used to smooth out fluctuations in the parameters of gas supplied through the GTS during periods of peak consumption, including the addition of liquefied petroleum gas. This leads, firstly, to a decrease in the detonation resistance of the compressed natural gas (CNG) obtained from it, and secondly, to a possible excess of the maximum permissible values of the net calorific value.

In order to import LNG saturated with gas condensate liquid and meet the requirements for supplying gas to the GTS, its calorific value sometimes needs to be reduced. The most common method is to inject an inert gas (e. g. nitrogen) up to the inert limit set for pipeline gas (typically 2 to 3 %).

If it is necessary to reduce the calorific value by 3 % or more, it is necessary to remove C_2 and heavier fractions. If there is a market for gas condensate liquids (GCL) in the area of the LNG receiving terminal, the processes of removal of C_2 and higher are more economically feasible than dilution with nitrogen.

In the UK, the following diagram is used to visualize the interchangeability of gas (Fig. 8). The Wobbe number is located along the y-axis, and the fraction of the sum of propane and nitrogen equivalents is located along the abscissa [24].

As seen in Fig. 9, the variation of the allowed gas parameters is quite large (Acceptable Range area). Energy capacity is from 46.5 to 51 MJ/m^3, and the sum of propane and nitrogen equivalent is from 0 to 45 %.

Keeping the gas within the required limits with a high proportion of nitrogen is obtained due to heavy hydrocarbons, which have a high calorific value. Gas that does not meet these parameters is processed and cleaned to the required level. Gas cleaning geographically takes place in the fields. Gas of already required quality is supplied to the main gas pipelines.

Fig. 10 shows that the limits are quite wide – maybe 15 % of the total propane equivalent and nitrogen, of which nitrogen will be about 4 %. The yellow line marks liquefied natural gas. As it is possible to see, its energy content is much higher than allowed in the UK. Therefore, in order for natural gas to be in the technological range, it is usually diluted with nitrogen in an amount of 2–5 % immediately at the regasification terminal.

To liquefy gas located in places remote from the markets for gas condensate liquids, some CNGs are liquefied together with methane and their content in LNG reaches 14 % (Fig. 9).

Japan, which has been a leader in LNG purchases for decades, prefers to purchase H-gas with higher C_3 and C_4 content in order to increase the CNG content and the energy intensity of the gas produced from LNG. Therefore, a significant portion of market LNG is saturated with natural gas liquids to a much greater extent than is allowed by the technical requirement for compressed natural gas.

Table 2

NG characteristics supplied by the GTS of various countries [21]

Country	Calorific value, MJ/m^3		Detonation resistance, MN
	value allowed by gas standard or gas supply contract	incoming gas value	
Belgium	H: 49.13–56.81	50.9–55.5	75.8±2
	L: 42.7–46.89	43.9–46.6	85.4±2
Czech	–	52.96	98
Denmark	Full range: 48.2–57.9	54.6–55.4	62.6–73.2
	Recommended range: 51.9–55.4		
Finland	48.2–57.7	–	98–98.6
France	H: 43.15–50.56	45.40–50.23	–
	L: 38.0–41.86	39.93–41.86	
Germany	H: (43.2)[1] 46.1–56.5	(43.2) 46.1–56.5	67.7–73.2
	L: (36.0)[1] 37.8–46.8	(36.0) 37.8–46.8	
Japan	13A: 52.7–57.8	–	–
	12A: 49.2–53.8		
Netherlands	43.4–44.4	43.4–44.4	–
	48.3–56.1 (for industrial use)	48.3–56.1 (for industrial use)	
Poland	GZ50: 45–54.0	52.9±0.6	–
	GZ35: 32.5–37.5	35.5±1.2	–
	GZ41.5: 37.5–45.0	Within range	–
	GZ30: 27.0–32.5	Within range	–
	GZ25: 23.0–27.0	Within range	–
	GP[2]: 23.0–27.0	–	–
Spain	48.25–57.81	–	–
Sweden	–	54–55	≈75
Switzerland	47.1–52.3	–	–
Ukraine	41.2–54.3	(41.2–54.3)±5	–

Notes: 1 – only for a limited time in case of an emergency; 2 – provided by the addition of a mixture of «propane-butane-air»; MN – methane number, shows the volume content (%) of methane in its mixture with hydrogen, which begins to detonate at the same compression ratio as the gas being tested

Based on the analysis of the requirements for LNG quality in various countries, it can be concluded that the federal regulation of gas quality in European countries and local regulation (at regasification terminals) in the United States. The main requirement for gas quality is the maximum calorific value. Depending on the receiving terminal, its value varies in a fairly wide range.

An analysis of the standards in force in different countries showed that both North America and Europe have a developed system of standards. In addition, international, European and American organizations are developing common approaches and requirements for the normative indicators of standards for their harmonization with each other. Among the general standards, a prominent place is occupied by those that regulate the requirements in the gas industry, in particular in the field of LNG circulation, since this area is developing rapidly.

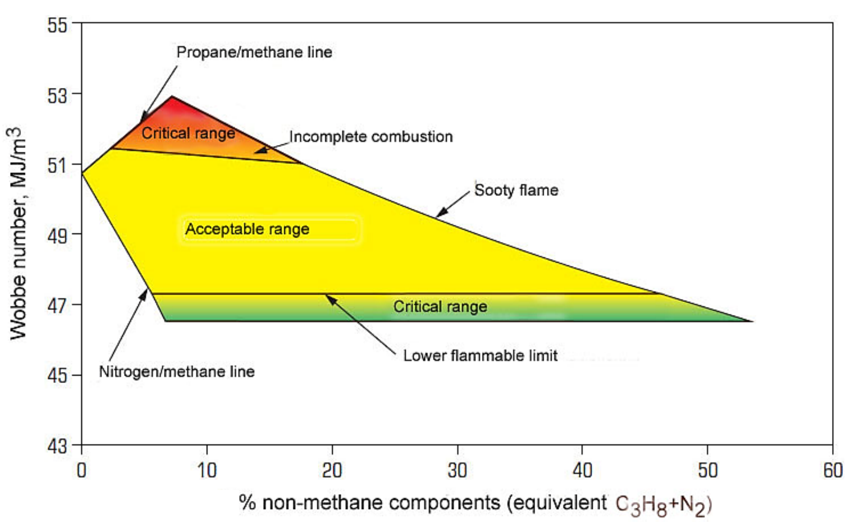

Fig. 9. Natural gas interchangeability diagram [21]

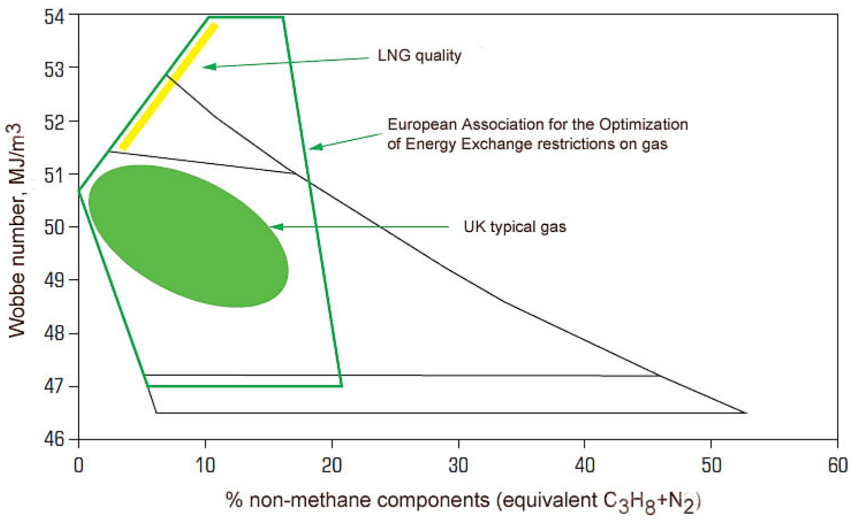

Fig. 10. Typical quality of natural gas consumed in the UK [24]

Standardization of LNG quality requirements is an important success factor. Based on existing standards, the seller can profitably sell its product, and the consumer can receive a product of the appropriate quality or bring its quality to the desired characteristics. To use LNG, Ukraine needs not only to have receiving regasification terminals, but also to develop a system of standards that establish requirements for the quality of natural gas.

This analysis shows options for alternative gas supply to Ukraine through the supply of liquefied natural gas. The research will be useful in choosing an option for implementing an additional, relative to the own sources of gas supply for the Ukrainian national economy.

Work is limited to offshore LNG as the cheapest logistics option. Options for deliveries by rail and road to the western border with the European Union were not considered.

Martial law introduces some adjustments to the choice of the location of the LNG regasification terminal. The most rational design of the terminal in these conditions will be the construction of a floating terminal, taking into account the depths located along the Black Sea coast of Ukraine.

The presented study is just the first step in the study of alternative gas supply options for Ukraine. The next step could be a more detailed study of the proposed projects, taking into account the real capital costs of operating costs.

4. Conclusion

The option of LNG supplies to the Black Sea coast was considered. Promising transportation routes were studied, and a variant was proposed for delivering natural gas from Central Asia via a pipeline to the Black Sea coast of Georgia. The implementation of this project will require significant capital expenditures for the construction of a pipeline and a plant for liquefying natural gas, as well as a regasification complex on the Ukrainian Black Sea coast.

It is shown that an urgent task for producers and consumers of LNG is the development of general criteria for assessing the quality of this product. The most common criteria are the calorific value of LNG and its variation, the Wobbe number. To implement alternative gas supply projects in Ukraine, it is necessary to develop its own system of standards that determine the quality of incoming liquefied gas.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The research was performed without financial support.

Data availability

The manuscript has no associated data.

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