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Article

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September 20–23, 2019, Okinawa, Japan

Economic assessment of heat and power generation from small-scale liquefied natural gas in Russia

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Abstract

Small-scale production of liquefied natural gas (SS LNG) is a promising, but little-known direction of the gas industry development, which is aimed at meeting the needs for environmentally friendly decentralized energy supply of nearby regions. In this study, an economic efficiency of four energy generation options, based on SS LNG, with nominal capacities from 0.3 to 3 MW was assessed. Total cost of heat and electricity at different delivery distances was determined. A number of regression models were developed to determine the key technical and economic characteristics of energy plants. The results showed that only 9 out of 85 Russian regions have sufficiently high tariffs for heat and electricity for effective SS LNG energy generation. It was also found that the average cost increase depending of delivery distance is 1.23 %/km for electricity and 2.51 %/km for heat.

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Keywords: Small-scale LNG; Economic efficiency; Heat and power generation; Energy tariffs; Russian regions

1. Introduction

Natural gas, with high probability, is going to be the main fuel of the 21st century, which will replace oil. Even today, natural gas is more preferable than many other energy resources because of its technical, economic and environmental characteristics.

From the technical-economic point of view, the narrowest link of natural gas supply chain is a delivery. The major part of the world's gas is delivered by pipeline, which has a number of drawbacks, especially in current unstable political environment. Firstly, the length of pipeline could be tens or hundreds of kilometers, which should be regularly maintained and protected. Secondly, in the case of international gas supplies, the construction of pipeline requires coordination with the transit countries. Thirdly, pipelines are absolutely inflexible in changing the direction of supply. In case of closing one of them, pipeline will be a source of financial losses. All these reasons have

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determined the relevance of more flexible technological schemes development, including the production of liquefied natural gas (LNG).

LNG technological chain (TC) allows to solve the problems of pipeline flexibility, however, it requires the construction of additional gasification facilities at the initial point and regasification at the point of consumption or nearby from it. Depending on the volume, there are large — (LS; more than 3000 tons LNG per day), medium — (MS; up to 3000 tons per day) and small-scale (SS; less than 500 tons per day) LNG production [1]. As a rule, scientific literature deals with LS and MS production [2], as more important for global development from economic and political points of view. SS LNG is more related to meeting the needs of consumers within the country as well as in nearby regions.

In General, SS LNG has the same advantages as LS production. It avoids the need of the pipeline construction, allows to create a flexible system of delivery, to use various combinations of transport depending on the region. Moreover, according to Mokhatab et al. [3], the payback period of SS plants is significantly lower than that of LS, due to lower average capital costs (500 against 1500 USD/t), as well as a shorter average construction period (3 against 5 years).

There are several alternative options for SS LNG projects implementation (Fig. 1A). In Fig. 1A: SRSDR LNG — system for receiving, storage, distribution and regasification of LNG; GVRCS — gas vehicle refueling compressor station.

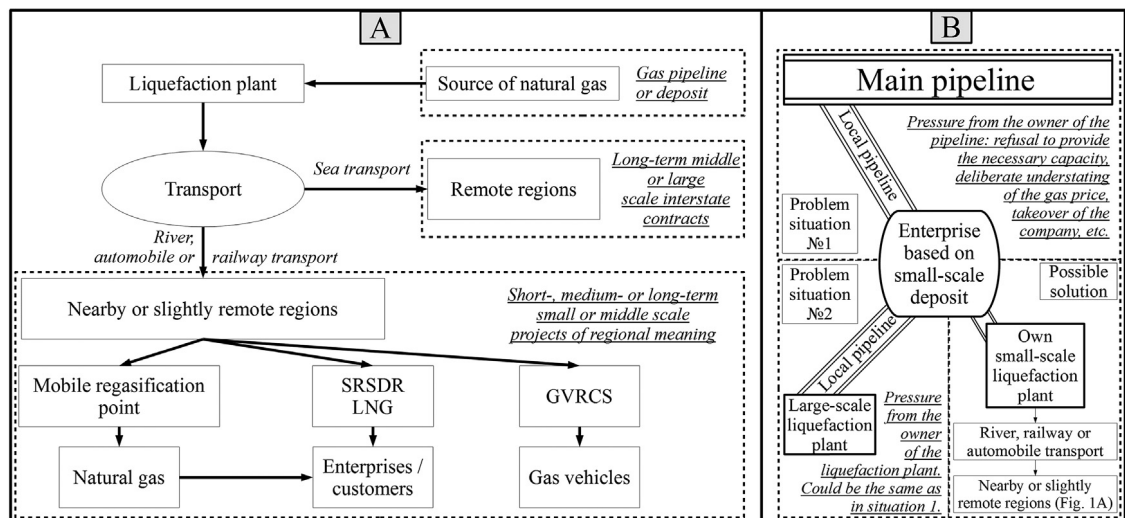


Fig. 1. Alternatives for SS LNG projects (A) and LNG as a possible way for small extractive enterprises (B).

The relevance of this study is determined by an acute shortage of cheap and environmentally friendly energy in many Russian regions. According to the Russian Federal State Statistics Survey, there are about 8000 small settlements (Fig. 2), more than half of which are not planned to be gasified through a gas pipelines due to excessive capital expenditures.

There are two key questions behind this article. Firstly, what are the prospects of energy generation from SS LNG in Russia at the moment? Secondly, what types of small-scale energy plants can be cost-effective at current tariffs for heat and electricity? Thus, the aim of this study is an economic assessment of heat and power generation from SS LNG with using equipment, which is available in the domestic market of Russia. The following parts of the article are organized as follows. The methodology (Section 2) is divided into 3 parts. Section 2.1 includes the analysis of literature. Section 2.2 provides a brief description of the research background. Section 2.3 describes the design of the study and proposed economic model for assessment. Section 3 shows the results of the study. Section 4 — conclusions.

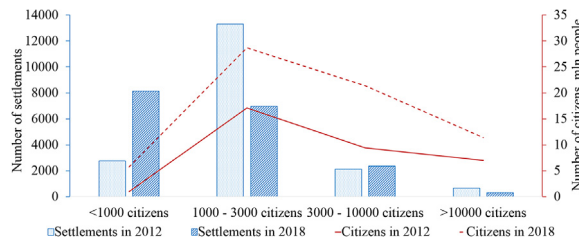


Fig. 2. Alternatives for SS LNG projects.

2. Methodology

2.1. Literature review

In the world scientific literature, studies on the economic aspects of SS LNG production are in few tens. Boolean search in the [sciencedirect.com](https://www.sciencedirect.com) database with « “small scale LNG” or “small-scale LNG” » request in “Find articles with these terms” field gives 116 articles since 1983, most of which are focused on technical aspects of liquefaction and regasification processes [2]. Nevertheless, Fig. 3 shows that there is increasing interest in this topic, which can be attributed to raising relevance of decentralized energy supply issues. The issues of SS LNG development in the national journals of Russia are also rarely raised. As a rule, this topic is discussed in the framework of the Russian energy industry comprehensive analysis.

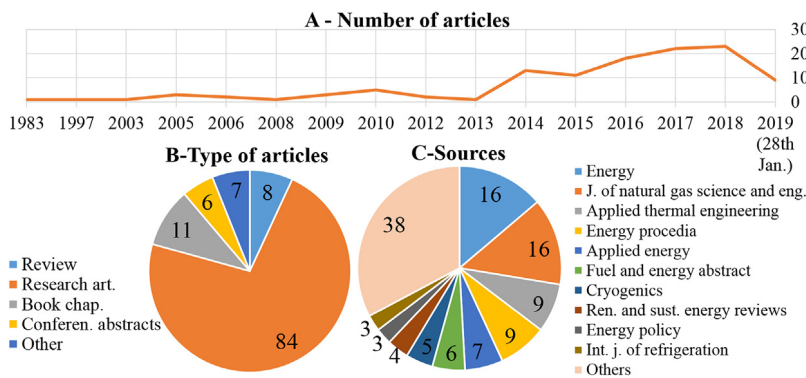


Fig. 3. Distribution of “small-scale LNG” articles by years (A), types (B) and sources (C).

In most studies, a gas pipeline is considered as a source of natural gas for the production of SS LNG, next to which it is possible to build a liquefaction plant. In rare cases, if SS supply chain includes marine delivery, a liquefaction terminal can be considered as an initial point. For example, the mathematical model for the optimization of the LNG supply chain is proposed in Bittante et al. [4]. This model is limited by marine transport and does not take into account pre- and after-shipping logistics. Another option, which was mentioned in a number of Russian-language studies, is a production of LNG on the base of small-scale gas fields to improve their economic efficiency (see Fig. 1B); however, no practical recommendations or evaluations have been proposed yet.

Transportation of SS LNG is usually associated with onshore infrastructure [5]. For example, automobile transportation of LNG is considered in Kim et al. [6]. Authors also proposed a promising idea to combine LNG and liquid nitrogen supply chains to increase overall economic efficiency. Some works, like Bittante et al. [4], consider marine delivery for SS LNG because of specific geographical locations of producers and consumers [7]. As an alternative, in Jokinen et al. [8] a model for optimization of delivery costs for combination of off- and onshore transport along a coastline was proposed.

LNG regasification and energy production are generally explored with combined heat and power (CHP) or Tri-generation technological cycles. For example, study Kanbur et al. [9,10] describes a system for LNG’s cold

utilization in the small-scale application with evaluation its thermodynamics, environmental and thermoeconomic characteristics. The relevance of Tri-generation schemes development is quite obvious, although their practical application in developing countries is difficult due to the lack of necessary technologies and economic conditions. In Kanbur et al. [11] a cryogenic CO₂ capture system for small-scale applications was proposed. Despite the initial stage of such technologies development, it will allow to classify some kind of LNG power generation systems as climate change mitigation technology in the nearest future. Given the increasing role of natural gas in the energy sector, this is essential both for individual countries and for the world as a whole [12].

Based on the literature analysis, the following conclusions were made. Firstly, innovative results and suggestions obtained from the most of studies cannot be applied in Russian practice due to deterioration of country's position in the geopolitical arena and introduction of sanctions to the import of several technologies. In this regard, it is necessary to rely on those technologies that are being tested or are already operating in the SS LNG infrastructure of Russia, or are available in the Russian market of equipment.

Secondly, there is a kind of incompleteness in the assessment of LNG supply chains. Typically, separate studies focus either on liquefaction, or on transportation, or on regasification. Issues related to the delivery of natural gas to liquefaction facilities, use of natural gas after regasification as well as assessment of integrated economic efficiency of full supply chains are practically not considered. In this regard, there are gaps in knowledge about technical, economic and environmental potential of SS LNG. In this regard, the framework of this study includes the stages of regasification, heat and power generation, and delivery to the consumer.

2.2. Research background

In the previous study [13], a detailed assessment of the LNG production and transportation costs was carried out, as well as a comparison with pipeline gas. It was found that the cost of SS LNG transportation can be significantly lower than that of pipeline gas, provided that the distance is more than 930 km, and the number of delivery directions is not less than 5 (Fig. 4). However, when considering gas supply projects for individual locations, LNG is less attractive due to relatively high operational expenses. Estimated price of LNG (for 5 supply direction at 930 km distance) was taken as a basis for the analysis carried out in this article.

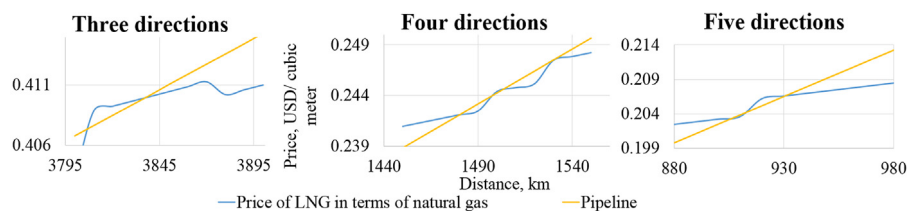


Fig. 4. Comparison of transportation costs of SS LNG and pipeline gas.

2.3. Design of the study

Within this study, a comparative assessment of four technological chains (TC) “LNG storage – Regasification - Energy generation - Energy delivery” (Fig. 5) was carried out: generation of thermal energy (A), power generation only (B), separated generation of thermal and electrical energy (C) and cogeneration (D). The comparison was carried out within equivalent nominal capacities. In addition, the TC “C” was considered in three variants, differing in the ratio of nominal electric (25%/50%/75%) and thermal (75%/50%/25%) capacities.

The price of LNG for the basic variant of the assessment (242.36 USD/ton) was taken from the results of the previous study [13]. The cost of USD is assumed to be 66 RUB (according to Central Bank of the Russian Federation on the 08th of March 2019). LNG is stored in tanks. Regasification is carried out by ambient air vaporizers. The amount of natural gas in 1 ton of LNG is assumed to be 1333 m³ [13].

The list of equipment for the considered TC is quite limited in Russia, and prices and specifications vary significantly from different manufacturers. In this regard, financial proposals for the construction of small-scale heat and power plants from the websites of various energy and service companies were explored. Such proposals

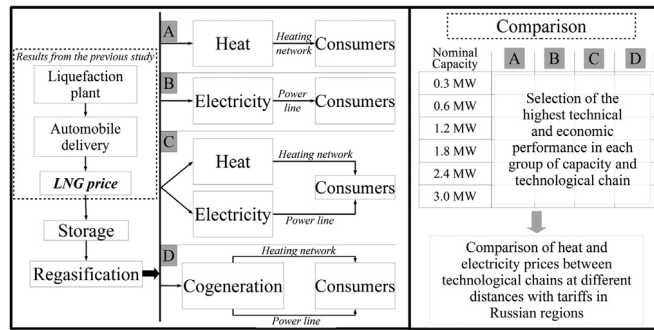


Fig. 5. Technological chains under assessment.

include cost and basic characteristics of necessary equipment (generators, boilers, turbines, tanks, vaporizers, heat recovery systems, switchgears), auxiliary systems, cost of construction (including the construction of foundation), installation and management.

The main criterion for the selection of proposals — appropriateness for energy supply system of small rural settlements (0.3–3 MW with less than 1000 people). Construction of regression models (Fig. 6) was based on the following samples: 15 heat recovery systems (0.15–1.75 MW); 6 LNG storages (14–48 tons of LNG); 9 ambient air vaporizers (121–402 m³/h); 17 heat plants (0.25–3 MW); 30 electricity plants (0.25–2.9 MW).

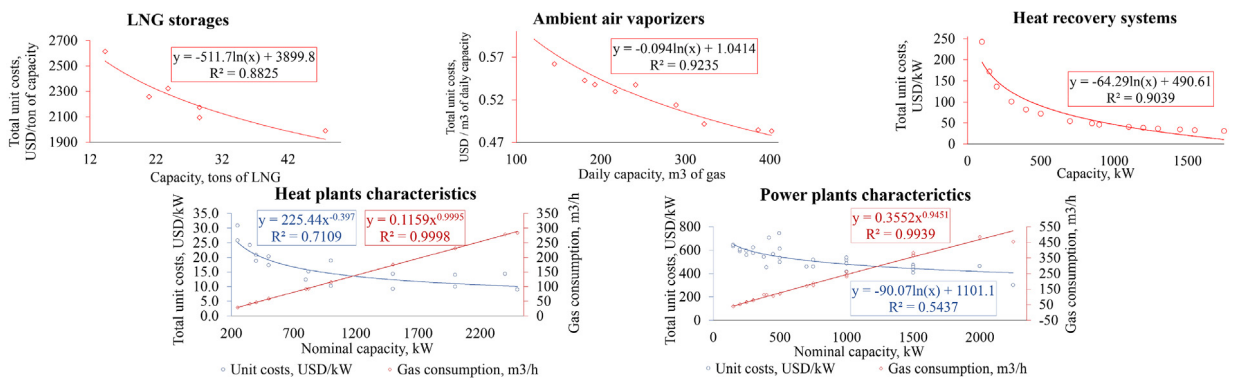


Fig. 6. Regression relationships for basic characteristics and total unit costs of necessary equipment.

The depreciation period of energy systems varies in literature from 20–25 [9,10,14] to 10 years [15]. Taking into account relatively low level of Russian energy technologies development, as well as difficult environmental conditions in the Central and Eastern part of the country, we assume that depreciation period of energy system is 15 years. The operating time of the equipment is 7500 h per year [16]. The operating expenses of the plant (formula 1) depend on the number of personnel, material costs and maintenance, LNG costs, and unpredicted expenses ($k = 10\%$).

$$OPEX_P = P_G + (N \cdot S + M) \cdot (1 + k) \tag{1}$$

where P_G — the cost of purchased LNG, USD/ton; N — the number of employees to maintain the equipment; S — annual salary of employees, USD/year; M — material expenses and maintenance, USD/year.

In this study, we assume that standalone energy system is created for one or few small rural settlements (up to 1000 people, see Fig. 2), without any specific energy-intensive facilities on their territory. Per capita electricity consumption may vary slightly around the national average values — 2.5–3 kWh/day (According to the Russian Federal State Statistics Survey). The cost of construction and maintenance of in-house energy communications is carried out by the owners.

It should also be noted that in cogeneration TC, 25% of the operating expenses for storage and regasification, as well as the price of purchased LNG, are attributed to the cost of heat, and the remaining 75% to the cost of electricity.

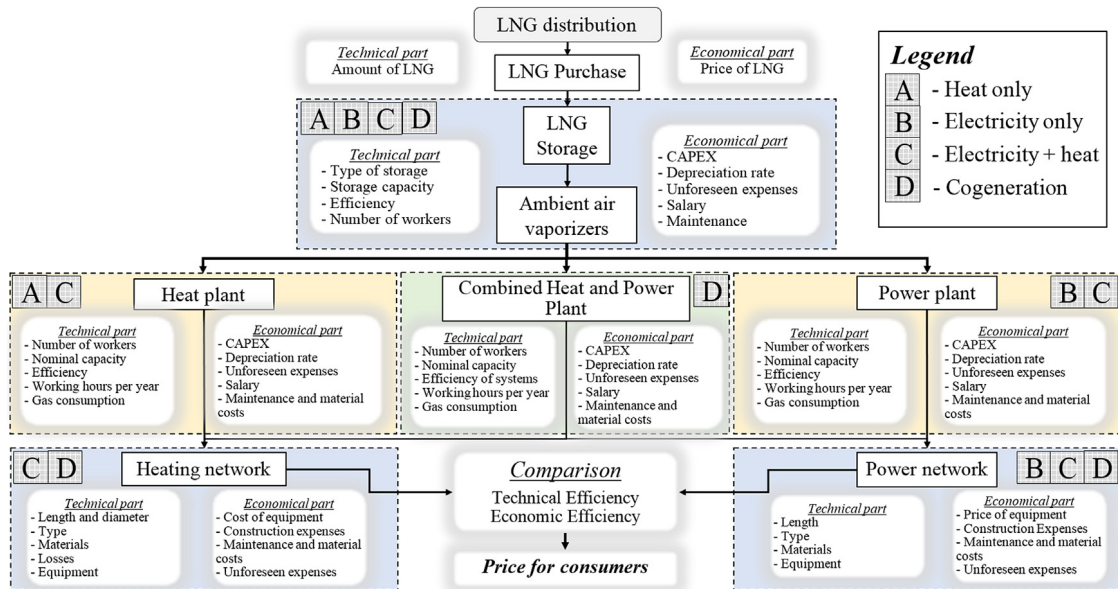


Fig. 7. Technological chains under assessment.

The expenditures for power lines construction is equal to 12,880 USD/km, depreciation period — 10 years, maintenance — 901.5 USD/km-year (according to Russian Federal Grid Company “JSC Russian Grids” website). The expenditures for the construction of heating networks are calculated according to formula 2. The total losses of heat pipeline transport are about 4%/km, the depreciation period is 10 years [17,18]. Operating expenses depend on diameter of a pipeline, as well as delivery distance. Comparison of equipment was carried out on the basis of technical (formula 3) and economic (formula 4) efficiency indicators. Graphical interpretation of the proposed technical-economic model is shown in Fig. 7.

$$CAPEX_{HN} = E_p + E_m + E_i + CAPEX_{CS} + E_c \quad (2)$$

where E_p — specific expenditures for horizontal drilling and pipe laying, USD/km; E_m — total costs for metal rolling, USD/km; E_i — total costs for pipe insulation, USD/km; $CAPEX_{CS}$ — total expenditures for compressor stations, USD; E_c — expenses for commissioning, USD.

$$E_t = \sum C/G \quad (3)$$

where C — volume of generated energy, Gcal; G — volume of gas consumption, m³.

$$E_e = (P_e \cdot C_e + P_h \cdot C_h)/Ex \quad (4)$$

where P_e — price of electricity, USD/kWh; C_e — volume of power generation, kWh; P_h — price of heat, USD/Gcal; C_h — volume of heat generation, Gcal; Ex — total expenses (is the sum of CAPEX divided by depreciation period and OPEX), USD.

3. Results

3.1. Economic efficiency of heat and power generation

Due to the lack of a unified database of tariffs for heat and electricity in the Russian regions, data from open official and unofficial sources (2017–2018 years) were collected for the analysis (Fig. 8).

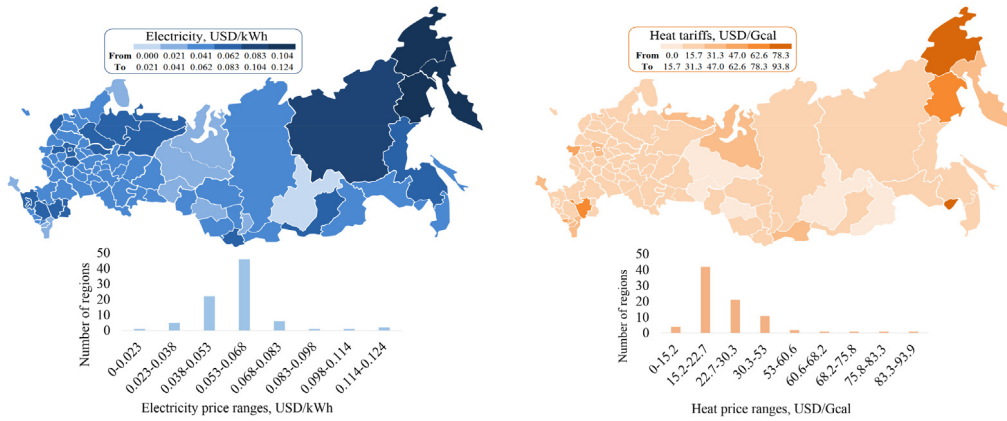


Fig. 8. Tariffs for electricity (left) and heat (right) in Russian regions.

There is a significant spread in energy prices within the territory of the country, which is determined by socio-economic conditions of a particular region, as well as by the complexity of energy resources delivery to the North-East. The minimum cost of heat is 12.5 USD/Gcal, electricity — 0.015 USD/kWh (both in Irkutsk region). Maximum values are 94 USD/Gcal (Jewish Autonomous region) and 0.124 USD/kWh (Chukotka Autonomous Area and Kamchatka territory). Despite the significant spread, tariffs for electricity in most regions are from 0.038 to 0.068 USD/kWh and for heat from 15.2 to 30.3 USD/Gcal (Fig. 8).

The average heat price in Russia is 26.65 USD/Gcal, electricity — 0.0578 USD/kWh. The median values are 21.94 USD/Gcal and 0.0565 USD/kWh. Given that the difference between the median and average values in relation to the total price spread is 6.3% (for heat) and 1.7% (for electricity), we can agree that the state control system of energy tariffs for the population is quite effective in most regions. Median values were taken as a basis for assessing the economic efficiency of TCs (Table 1).

Table 1. Economic efficiency (Ee) of technological chains.

Capacity	B1	GT1	C1	S1	S2	S3
300	0.747	0.431	0.561	0.513	0.464	0.592
1200	0.754	0.441	0.588	0.526	0.476	0.605
2100	0.757	0.444	0.597	0.53	0.479	0.609
3000	0.758	0.445	0.602	0.532	0.481	0.612

The Table shows a comparison of the selected TCs. Separated production of heat and electricity was considered in three variants, which differ in the ratio of nominal capacities. The first option — an equivalent capacity of boiler and gas turbine (“separated (50/50)” — S1), the second — the capacity of gas turbine is 3 times higher than boiler (“separated (25/75)” — S2), the third — the capacity of boiler is 3 times higher than gas turbine (“separated (75/25)” — S3). TCs with boilers (B1) and gas turbines (GT1), theoretically, are variants of separated energy production, in which electric power or thermal capacity is zero, respectively. Cogeneration (C1) is closest to the S1 case but with less gas consumption.

With using median values of heat and electricity prices, all generation options were ineffective, since E_e is less than 1. However, this cannot be an indication that such TCs are inefficient at all. Based on the available values of heat and electricity tariffs in the regions of Russia, those were selected where more than two technological chains (Fig. 9) are cost-effective (average efficiency for all capacity values).

B1 and S3 TCs are economically viable in all selected regions, in contrast to GT1 case. S2 case is effective only in three regions, although the value of the performance indicator is almost equal to 1, which means closeness of income and expenditures. C1 and S1 cases show mixed results. It was found that three factors have the greatest impact on economic efficiency: the price of electricity, the price of heat and the price of LNG. Fig. 10 shows the dependence of TCs’ economic efficiency on changes in prices for heat and electricity.

Region	Heat, USD/Gcal	Power, USD/kWh	Average economic efficiency					
			B1	GT1	C1	S1	S2	S3
Jewish Autonomous region	94	0.057	3.23	0.45	1.12	1.23	0.77	1.95
Chukotka Autonomous Area	82	0.124	2.82	0.98	1.55	1.49	1.19	1.96
Magadan region	74.8	0.11	2.57	0.87	1.39	1.34	1.06	1.78
Republic of Kalmykia	63.6	0.066	2.18	0.52	0.97	0.99	0.71	1.41
Bryansk region	58.4	0.052	2.01	0.41	0.82	0.86	0.6	1.27
North Ossetia-Alania	54.6	0.059	1.88	0.46	0.85	0.86	0.63	1.22
Saint-Petersburg	41.3	0.066	1.42	0.52	0.81	0.77	0.62	1.01
Nenets Autonomous district	41	0.074	1.41	0.58	0.87	0.81	0.68	1.02
Kamchatka territory	40.1	0.124	1.38	0.98	1.24	1.08	1.02	1.18

Fig. 9. Economic efficiency of TCs in Russian regions.

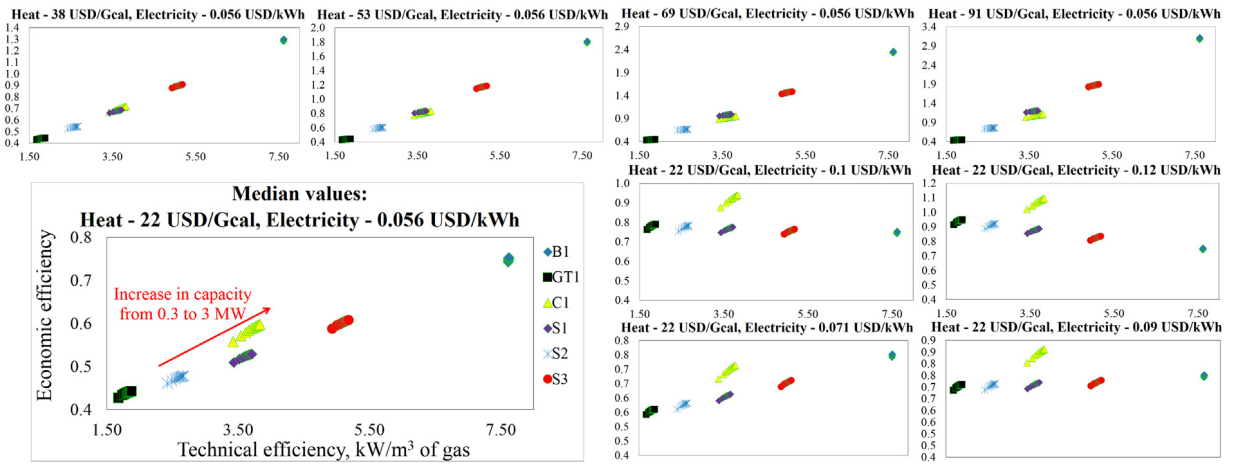


Fig. 10. Dependence of the TCs' economic efficiency on the price of heat (on the top) and electricity (in the bottom).

Price ranges selected for Fig. 10 are connected with the current energy tariffs in the Russian regions (Fig. 8). When the price of heat changes, B1 becomes effective at the price of 29.1 USD/Gcal, and S3 at 43.18 USD/Gcal. C1 and S1 are at the bottom of the efficiency range ($E_e \geq 1$) from 69 to 91 USD/Gcal. The effectiveness of other TCs does not depend, or depends slightly, on changes in tariffs for heat. The changes in electricity prices significantly affected only the C1 option, which is due to the peculiarity of the costs distribution for this TC (see study design section). It becomes cost effective at a price of 0.11 USD/kWh. Other TCs are ineffective in the considered range of prices. In contrast to heat and electricity prices, the decline in LNG price has a positive impact on the economic efficiency of all TCs (Fig. 11).

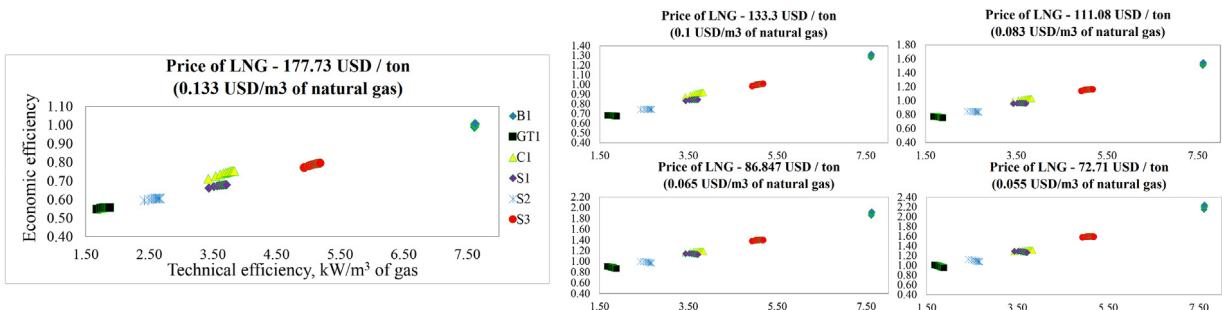


Fig. 11. Dependence of the TCs' economic efficiency on the price of LNG.

In the basic variant (Fig. 10), the LNG price was 242.36 USD/ton. B1 case could be effective, when LNG price is equal or lower than 177.73 USD/ton. At the price of 133.3 USD/ton S3 case becomes effective, and C1 and S1 cases at 111.08 USD/ton and below. Other TCs require price reduction below 86.85 USD/ton, which is equal to 0.065 USD/m³ of natural gas. According to previous estimates [13], such prices are unattainable, since they are significantly lower than the cost of LNG immediately after the liquefaction process (186 USD/ton).

3.2. Heat and electricity costs depending on delivery distance

The results of the evaluation showed that the delivery distance has little effect on the cost of heat (Fig. 12) and electricity. S2 case has the maximum cost of heat, regardless of the distance and nominal capacity. C1 case at low power is comparable to S2 case. However, when comparing TCs with a nominal capacity of 1.2 MW and above, C1 heat cost becomes significantly lower and more preferable than in S1 case.

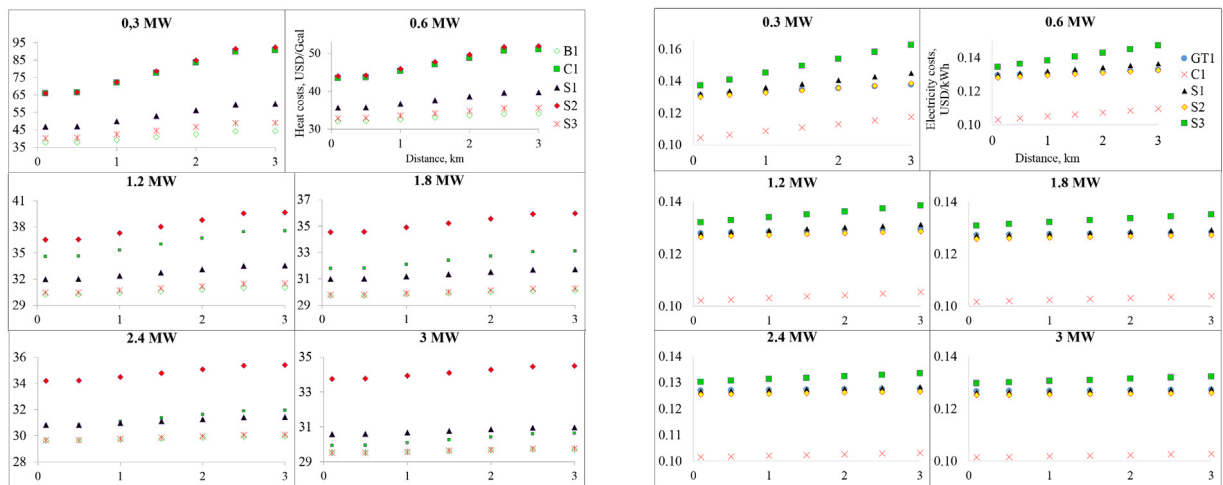


Fig. 12. Dependence of total heat costs (left) and electricity costs (right) on delivery distance.

S3 has the maximum cost of electricity (Fig. 12) in all observed cases. In General, the increase in the delivery distance has little effect on the relative effectiveness of TCs. S1, S2 and G1 cases are comparable in costs values. The cost of electricity in the C1 case is 1.5–3 US cents lower with any options of nominal capacity and delivery distance.

Delivery distance has the greatest impact on C1, S2 and S3 TCs (Fig. 13) at 0.3 MW nominal capacity. The maximum average increase in heat costs is observed in C1 (11.3%/km) and S2 (12.08%/km) TCs. The maximum average increase in the costs for power generation is observed in C1 (4.03%/km) and S3 (5.89%/km) TCs. With respect to C1, it should be noted that the share of transport costs in the cost of heat and electricity depends significantly on the way of expenses distribution (see study design section). Despite this, even if the cost structure will be changed, the growth rate of at least one type of energy will be one of the highest among the considered options. With the increase in capacity, the average growth rate of unit costs is significantly reduced and, in all cases, become lower than 1%/km.

As a result, the possibility of using considered TCs in the Russian regions (Fig. 9) was evaluated at different energy delivery distances (Fig. 14). As mentioned above, the delivery distance has a slight impact on the efficiency of most TCs. However, the cost of electricity and heat in S2 case already after the minimum delivery distance (0.5 km) become lower than the tariffs in Kamchatka territory. Other changes related to the Kamchatka territory are observed with C1 case. With a delivery distance of more than 0.5 km, thermal energy becomes more expensive than the current tariff. Other considered options did not show visible changes with increasing in delivery distance.

4. Conclusions

SS LNG is a promising part of the gas industry, which has a significant growth or research studies in recent years (from 1–2 per year in 2012–2013 to 22–23 in 2017–2018). The relevance of SS LNG is determined mainly by the

TC	Capacity	Average heat costs growth rate, %/km	Average electricity costs growth rate, %/km	TC	Capacity	Average heat costs growth rate, %/km	Average electricity costs growth rate, %/km	TC	Capacity	Average heat costs growth rate, %/km	Average electricity costs growth rate, %/km
B1	300	5.57	-	C1	300	11.3	4.03	S2	300	12.08	2.14
	600	2.05	-		600	5.49	2.08		600	5.86	1.1
	1200	0.86	-		1200	2.77	1.06		1200	2.85	0.56
	1800	0.4	-		1800	1.38	0.71		1800	1.38	0.38
	2400	0.34	-		2400	1.22	0.54		2400	1.19	0.28
	3000	0.21	-		3000	0.79	0.43		3000	0.76	0.23
GT1	300	-	1.6	S1	300	3.64	3.13	S3	300	6.84	5.89
	600	-	0.82		600	1.63	1.62		600	2.65	3.09
	1200	-	0.42		1200	0.76	0.83		1200	1.14	1.6
	1800	-	0.28		1800	0.66	0.56		1800	0.53	1.08
	2400	-	0.21		2400	0.41	0.42		2400	0.45	0.82
	3000	-	0.17		3000	0.41	0.34		3000	0.28	0.66

Fig. 13. Average growth rate of electricity and heat costs per 1 km (in 0–3 km range).

Region	BT1				GT1				C1				S1				S2				S3			
	0.5	1	1.5	3	0.5	1	1.5	3	0.5	1	1.5	3	0.5	1	1.5	3	0.5	1	1.5	3	0.5	1	1.5	3
Jewish Aut. region																								
Chukotka Aut. Area																								
Magadan region																								
Republic of Kalmykia																								
Bryansk region																								
North Ossetia-Alania																								
Saint-Petersburg																								
Nenets Aut. district																								
Kamchatka territory																								

Fig. 14. Acceptability of technological chains with different energy supply distances, km. Green — electricity and heat are cheaper than existing tariffs; yellow — electricity or heat is cheaper than existing tariffs; red — at these distances electricity and heat become more expensive than existing tariffs; blue — could not be effective according to Fig. 9 . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

need to meet the needs for environmentally friendly decentralized energy supply systems for small and medium-sized settlements, as well as individual enterprises. In addition, there is a hypothesis in a number of studies that SS LNG can improve the efficiency of small hydrocarbon deposits, however, there are no estimates and practical proposals to date (Fig. 1B).

To some extent, it is the result of relatively low number of studies in this field, in comparison with other areas of energy research. Existing studies are mainly focused on examining individual stages of SS LNG technological chains. This paper presents an economic assessment of the “Storage - Regasification - Energy Generation - Energy delivery” stages, which is related to the previous study on the evaluation of “LNG production - Automobile Delivery” stages (Fig. 4). Six energy generation options were chosen for the assessment: only heat generation (boiler), only electricity generation (gas turbine), cogeneration and separated generation with 3 cases of the nominal capacity distribution (Fig. 5).

It was found that:

1. The most effective from a technical and economic points of view is the production of heat by boilers. Regardless of the nominal capacity of the compared units, economic efficiency of boilers is 1.2–1.7 times higher than other options (Table 1). The least efficient option is a simple power generation by a gas turbine.

2. Only 9 out of 85 regions of Russia can be cost-attractive for more than one of the considered TCs, due to high tariffs for heat and electricity (Fig. 9). In most regions prices for electricity are between 0.38 and 0.68 USD/kWh and for heat are between 15.2 and 30.3 USD/Gcal. It is explained by the strict state control policy of energy tariffs for the population.

3. Changes in heat and electricity tariffs, as well as LNG prices, have the greatest impact on economic efficiency of the considered TCs. Sensitivity analysis (Fig. 10) showed that all TCs, except GT1 (no heat) and S2 (heat capacity — 25% of total) are cost-effective at maximum heat tariffs, which are observed in Russian regions. The growth of

electricity tariff influence significantly only on C1 case, which becomes effective at 0.11 USD/kWh. Reduction of LNG costs has a positive effect on all TCs (Fig. 11); however, their economic efficiency reaches acceptable values at a price below 186 USD/ton, which is unattainable.

4. Energy delivery distance has little effect on the growth of total unit costs (Figs. 12 and 13). The high influence is observed in C1 case (0.3 MW): for heat — 11.3%/km, for electricity — 4.03%/km. The maximum increase in heat costs is observed in S2 case (0.3 MW) — 12.08%/km, and electricity costs in S3 case — 5.89%/km. The average growth rate of electricity costs with increasing range from 0.5 to 3 km is 1.23%/km, of heat — 2.51%/km.

5. Prospects for the development of SS LNG in the Russian regions are extremely limited with existing tariffs for heat and electricity (Fig. 14). Basically, heat generation is efficient, while power generation significantly reduces economic efficiency of all considered TCs. To date, in Russia, only the presence of state support could increase the attractiveness of SS LNG supply chains, due to relatively low rate of energy tariffs and low economic efficiency of liquefaction technologies.

Despite the fact that this article discusses several options for energy generation, it is based only on one technology of LNG production, as well as delivery only by trailers [13]. Geographical location of regions also should be taken into account. For example, there is a lack of necessary road infrastructure for LNG automobile delivery in Chukotka Autonomous Area and Kamchatka territory. In this regard, further research will focus on expanding the list of alternative technologies under consideration and on increasing flexibility of the economic model for full SS LNG supply chains evaluation.

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