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Feasibility Study of Renewable Energy Deployment Scenarios in Remote Arctic Communities

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ABSTRACT

The paper aims to analyze the economic efficiency of investments in renewable energy in remote areas of the Russian Arctic. Despite the proximity to oil and gas wells, the development of renewable energy sources (RES) is most promising in these locations. The paper presents a feasibility study of two investment options based on RES with a calculation of electricity costs which ensure an expected return to potential investors. The estimation is given in comparison to the existing electricity rates in some communities of the Russian Arctic. The investigation revealed that the investment in RES is feasible but requires a proper technical and financial estimation. The estimation of undiscounted future cash flows may not be sufficient in case of long-term investments; high initial capital investments in RES are not always covered by lower operating costs. As a conclusion, the investment option of the wind-power plant with the system of accumulation and use of energy in the form of hydrogen, bound in a liquid organic carrier is less financially attractive due to high capital investments in comparison with the variant of wind-diesel deployment. The given calculations can provide an economic feasibility approach in finding the best option for RES deployment in remote Arctic areas.

Keywords: Renewable Energy, Wind Turbine, Hydrogen Energy Carriers, Diesel Generation, The Russian Arctic
JEL Classification: Q4

1. INTRODUCTION

There is a large amount of undeveloped resources (hydrocarbons, valuable metals, etc.) in the Arctic and the potential of development of trade and transport network, military and digital infrastructure is of great importance. Therefore, many leading countries, like Russia, the US, Canada, Norway, Denmark put a strategic focus on the scientific, technological and industrial development of the region.

The Nenets, Yamalo-Nenets, Chukotka okrugs, and Murmansk Oblast completely relate to the terrestrial areas of the Arctic zone of Russia, in addition to the islands in the Arctic Ocean; partially terrestrial are – Krasnoyarsk Territory, Arkhangelsk Region, the Republic of Sakha (Yakutia). The current population of the Arctic zone of the Russian Federation is about 2.5 million according to statistics (The Demographic Yearbook of Russia, Rosstat 2017).

Russia plans to develop maritime trade, military routes and infrastructure, to continue mining activity and to work on many other projects in the Russian Arctic. Along with it, such scientific and technological projects as Yamal LNG, the "Prirazlomnaya platform" have already been implemented and some other strategic projects of the Russian companies PJSC Gazprom, PJSC Gazprom Neft, PJSC Novatek, PJSC Rosneft are being implemented.

Besides the extraction of hydrocarbons, the mining industry develops extraction of nickel, titan, zinc, cobalt, platinum group metals, gold and silver in the Russian Arctic. Here we can mention the Norilsk mining district, fields in Chukotka Autonomous okrug and on the Kola Peninsula. Implementation of such projects demands well-developed infrastructure and established distribution logistic schemes, there is a need for additional ports, terminals, railroads and bridges. Only then defense tasks and optimal location of production are to be considered. Development of the Arctic region requires innovative approaches to the development of new technologies in special materials, building foundations, designs and constructions, ecology, intelligent control systems; navigation and shipbuilding. The autonomy of the implemented projects, when the system being created combines energy supply, water treatment and waste processing, is of great relevance for the Arctic territories.

Large-scale development of the Arctic zone faces a set of threats and risks. Among them, protection of the interests of indigenous minorities of the North, addressing issues of food security, creating a highly skilled workforce, developing innovative technologies aimed at maintaining environmental safety, reducing the energy intensity of mining projects. The challenges and opportunities in the development of the Arctic zone are described in detail and widely discussed in scientific literature.

Söderholm investigates the issues of sustainable development and environmental regulation in the mining industry (Söderholm et al., 2015). According to the author, mining projects should be estimated in terms of their impact on the environment, and the environmental regulation is to be designed and implemented to achieve positive environmental outcomes. Various issues of the sustainable development at the implementation of investment projects in oil, gas and mining sectors in the Arctic are raised by many other authors (Tysiachniouk et al., 2018; Tysiachniouk et al., 2018; Nong et al., 2018; Konyshev et al., 2018; Ulyanova and Danchenkov, 2016).

Environmental aspects of the mining industry in the Arctic zones of Sweden, Finland and Russia are considered in (Oksanen et al., 2015). In addition to ecological balance, some authors (Suopajärvi et al., 2016) study the social sustainability of mining in the northern communities of Europe and Northwest Russia. Koivurova’s (Koivurova et al., 2015) research emphasizes the real threat to the traditional livelihoods of indigenous northern peoples and examines how the rights of the communities are protected against adverse impacts of mining activities.

Thus, a common thread running through all scientific and technical projects in the Arctic is the emphasis on sustainable development and the need to maintain the ecological balance, which leaves its imprint on the technologies to be used. The Arctic is a region whose condition affects global socio-economic development, and a violation of the stability of the ecosystem of the Arctic zone can lead to climate change. That is why experts note the importance of such a strategic direction as the development of the Arctic using renewable resources for the materials, food and energy supply (Masloboev, 2017; Morgunova et al., 2017).

It is necessary to focus on the risks and threats in the energy sector of the Arctic zone. The “Strategy of development of the Arctic zone of the Russian Federation and national security for the period until 2020” identifies the following problematic areas of the development of the Russian Arctic:

- Remoteness from industrial regions and high dependence on imported fossil fuels;
- Obsolescence of fixed assets in the energy sector;
- Poor energy and transport infrastructure, imbalance of the energy system;
- High energy intensity;
- High costs of electricity.

The listed risks are ultimately accounted in high electricity prices. In some communities of Yamalo-Nenets Autonomous District, electricity rates vary from 20 to 35 rubles/kWh, Table 1 - data from the official site of Yamalkommunenergo JSC.

As Table 1 shows, the prices for the household consumers and other categories of consumers differ by 10–17 times, which indicates subsidizing retail prices for the population at the expense of industry and the regional budget. While prices for the household consumers in the Yamalo-Nenets Autonomous District are kept low, in some communities of the Republic of Sakha (Yakutia) they reach 100–200 rubles/kWh, regardless of the category of consumers, Table 2 (official data from the website of Sakhaenergo JSC).

Without a reliable, systematically organized energy supply, the carrying out of such a strategic task as the development of the Arctic zone territories is not possible. The available electric power is necessary for the realization of all variety of large and small projects in severe climatic conditions. At the same time, the power supply of remote and isolated consumers through the traditional approach of building the electrical grids connected to large power plants may not be economically feasible. As alternative sources of local autonomous energy supply in the remote Arctic territories one can consider: Wind, solar, wind-solar stations; tidal and thermal stations, biomass energy facilities, and traditional sources in a new form (for example, liquefied natural gas (LNG), synthesis gas, low-power nuclear power plants and others).

Table 1: Electricity prices in selected Yamalo-Nenets communities in 2017, rubles/kWh

Community	General electricity tariff		electricity tariffs for the population	
	1½-year	2½-year	1½-year	2½-year
Nadymsky District	30.92	27.874	1.81	1.88
Mushi	26.029	24.326		
Gorki	30.794	25.851		
Ovgort	34.281	32.778		
Gyda	28.853	27.07		
Aksarka	20.943	20.222		
Beloyarska				
Katrovozh,				
Shchuchye				
Payuta				
Cape Kamenny	24.662	21.99		
Novy Port				
Panayevsk				
Salemal				
Seyaha				
Yar-Sale				
Krasnoselkup	27.388	26.588		

Table 2: Tariffs for electricity in selected communities of the Republic of Sakha (Yakutia) in 2017

Community	1½-year	2½-year
Verhnyaya-amga	174.34	174.34
Troitsk	226.93	226.93
Desku	115.48	115.48
Machakh	104.68	104.68
Barylas	102.79	102.79
Osohtoh	121.39	121.39
Alysardah	131.9	131.9

At the same time, the ecosystem of the Arctic can suffer even from the smallest human influence. Therefore, keeping in mind the need to maintain the environmental balance while implementing key projects, an urgent solution is the use of renewable energy sources (RES). The share of RES in the energy balance of the Arctic is one of the indicators characterizing the socio-economic development of the territory, therefore, in accordance with the "Action Plan for the implementation of the development strategy of the Arctic zone of the Russian Federation and ensuring national security for the period until 2020," it is envisaged to implement projects using alternative sources in the framework of investment programs of enterprises.

A variety of renewable sources can be used for energy supply (for heating and cooling) on the territories of the Arctic zone: Wind, tides, oceanic biomass. In addition to these sources, pellets can be promising. According to the paper (Soloviev et al., 2017), the efficient and ecological energy supply is possible with the integrated use of resources of the Arctic territories. To support this thesis, we can mention the successful experience of energy supply of Antarctica with the help of a complex of various RES, described in the paper (Tin et al., 2010). The joint use of solar panels and wind turbines with simultaneous improvement in energy efficiency in the severest climatic conditions of Antarctica leads to wise energy consumption, less dependence on imported fuel, cost reduction and minimization of environmental damage. The paper (Gabderakhmanova et al., 2015; Gabderakhmanova et al., 2016; Popel et al., 2015) also considers RES in the isolated territories of the Russian Arctic, as a result, the authors offer some hybrid power systems consisting of diesel generators, solar and wind installations.

Berdin et al., 2017 analyses the current situation with renewables in the isolated power supply systems of the Arctic zone. The paper provides some practical cases of hybrid systems implementation in remote communities of the White Sea coast, where the tariffs for the consumers have been reduced by 2–5 times. The paper summarizes the Russian experience of using RES in the Arctic. The cases using renewables in remote Arctic regions of the Far East and the Far North are analyzed in the paper (Boute, 2016; Goryunov and Nazarova, 2015; Kulakov et al., 2016; Nazarova et al., 2017). The absence of RES or difficulties of their usage are recorded in the Taimyr and Chukotka Autonomous Districts. In addition to some solar-diesel facilities, 21 payment terminals supplied by RES are installed in four remote communities in the Murmansk region; in the Arkhangelsk region, some road lighting is powered by wind and solar energy. Pilot RES projects are realized in the Nenets (Amderma settlement) and Yamalo-Nenets (Labytnangi) autonomous regions. The projects for the construction of solar power systems are being actively implemented in the Republic of Sakha (Yakutia), where there is also a pilot project of the wind farm in the village of Tiksi. RES quite successfully develops in the Kamchatka Territory, here we can find 3 wind farms and geothermal stations.

In addition to the use of wind and solar energy, a promising direction of renewable energy supply in the Arctic zones is the energy of tides, the resource estimate of which is given in the study (Myslenkov et al., 2018).

Thus, some experience has been gained in the implementation of autonomous power systems, but both the electricity consumer living in the Arctic and the potential investor should be aware of the estimated future costs of electricity, based on the chosen option for energy supply.

2. METHODOLOGY OF THE RESEARCH

We propose two options of energy supply for electricity costs optimization in the isolated remote communities of the Russian Arctic. The calculation and the economic analysis is based on existing tariffs in the chosen communities.

The methodological approach of the study is based on the assessment of economic efficiency set out in the "Methodological Recommendations for the Assessment of the Effectiveness of Investment Projects (Second Edition)" approved by the Ministry of Economics of the Russian Federation, the Ministry of Finance of the Russian Federation, the State Committee of the Russian Federation for Building Architectural and Housing Policy (№ 477 of 21.06.1999) and based on the modeling of discounted cash flows. There is no need to use undiscounted costs per 1 kW as we focus on the ability to generate returns to investors in the future considering the time factor.

As the reference conditions, we assume that the average capacity of the autonomous power system is 100 kW, and peak loads will not exceed 200 kW on some days.

As a current option, we take the energy supply from diesel generator systems and apply existing diesel energy supply rates (Tables 1 and 2), which can be up to 226 rubles/kWh in some Arctic communities.

The following two options are proposed as alternatives.

The first option considers a wind-diesel generator-battery hybrid power system (WDBHPS) installation. In the main time, the generation of electricity including peak loads is carried out at the expense of diesel units (DU) with a total power of 300 kW (3 DU of 100 kW each). The estimated load of the DU is 75%. Additional generation of electricity up to 50 kW (25% of the time) is carried out through wind turbine with a total capacity of 150 kW (3 wind power systems of 50 kW). Peak loads are compensated by means of accumulator power storage batteries and power capacity reserves.

The second option considers a wind energy supply system with storage of electrical energy in hydrogen chemically bound form as liquid organic hydrogen carrier (LOHC). The main source of energy in this option is a wind turbine with a total capacity of 600 kW (6 wind power plants of 100 kW), which work 50% of the time. Part of energy is delivered to the consumer, the rest – to the charging of the batteries and accumulation in the liquid organic carrier of such amount of hydrogen which will allow providing the consumers with energy during the remaining 50% of the time. Peak loads, as well as loads in the absence of wind, are compensated by the batteries and secondary generation of electricity from hydrogen by burning it in solid oxide fuel cells.

3. THE RESULTS OF RESEARCH

As part of this study, we have assessed possible electricity rates in case of RES technologies. The objective of the study was the cost-effectiveness analysis of the considered energy supply options in comparison to the current electricity rates in some remote Arctic communities.

Following assumptions were made for our research cases:

1. The discount rate is 10%;
2. The calculation horizon is 20 years based on the life of the main equipment;
3. In constant prices, without taking inflation into consideration;
4. Annual operating costs include fuel costs, payroll, maintenance and repair;
5. The total payroll is based on the average wage values in the communities of the Arctic including contributions to extra budgetary funds of 927 thousand rubles per year;
6. Property tax is 2.2%;
7. Income tax is 20%;
8. The rate of depreciation is 5%.

The total capital expenditure under option 1 is 28.3 million rubles, while under option 2–167.6 million rubles. The largest share of capital investments in option 1 is allocated to wind turbines (66.4%), whereas in option 2, in addition to wind turbines (44.9%), a significant share of capital expenditures is spent on the purchase of an electrolytic cell (27.2%) and a fuel cell (13.6%). The comparison of capital investments structure of both options is presented in Table 3.

The annual operating expenses for option 1 are estimated at 33.7 million rubles, while for option 2–11.8 million rubles. The annual operating expenses of option 1 are 3 times higher than those of option 2, which is explained by the absence of costs for imported diesel fuel. Nevertheless, a significant portion of the annual costs goes to maintenance and repair, which is due to the short life of the fuel cell (3 years). The comparison of the structure of operating expenses for options 1 and 2 is given in Table 4.

Specific discounted costs for 1 kWh and the electricity tariff were calculated with the assumption of IRR from 10% to 15% in order to choose the optimal variant of the power supply (Table 5).

4. DISCUSSION

Our calculations show that the introduction of innovative power generation technologies will make it possible to reduce existing tariffs by 2–4 times (on the example of the Republic of Sakha (Yakutia), Table 2). While in some communities of the Republic of Sakha (Yakutia), tariffs range from 103 to 227 rubles/kWh, the tariffs for the proposed RES options does not exceed 52 rubles/kWh.

Nevertheless, the analysis of calculation results, a wind-diesel unit (option 1) and a wind turbine with a system for storing and using energy in the form of hydrogen bound to a liquid organic carrier (option 2) shows the priority of the first option. If we compare undiscounted costs (including taxes on property and profit) per 1 kWh in both options, we can note that option 2 is 37% cheaper. The explanation can be in lower operating costs, which do not include the expensive imported fuel. But as it was mentioned above the future undiscounted cash flows do not account for the time value of money and do not ensure the achievement of target profitability.

The calculation with the discounting approach shows a greater dependence on the rate of return which the potential investor wants to get. When the system works to reach the break-even point (IRR = 10% with a discount rate of 10%, NPV = 0) option 2 may be more favorable than option 1. If the investor wants to get a yield of 12–15%, the tariff for option 2 grows to 45–52 rubles/kW * h in comparison with 43–45 rubles/kW * h under option 1, which is caused by the larger volume of initial capital investments. The benefit derived from savings in its operating costs can be minimized by the decrease in the time value of money in the future.

5. CONCLUSIONS

The results of the study are as follows:

- The main challenges in development and energy supply of the Arctic are highlighted,

Table 3: Capital investment structure of options 1 and 2

Units	Option 1 WDG BH	Option 2 WES LOHC
Wind power installation (incl. delivery costs)	66.38%	44.89%
Electrolytic cell		27.21%
Li-ion battery, including control system	7.95%	1.34%
Automated control system and powerhouse	6.03%	1.02%
Fuel cell		13.60%
The system of accumulation, storage, transportation and use of energy in the form of hydrogen, bound in a liquid organic carrier, including the cost of catalysts		11.93%
Diesel unit (incl. delivery costs)	19.64%	

Table 4: The structure of operating costs, options 1 and 2

Cost item name	Option 1	Option 2
Fuel costs	87.4%	0.0%
Maintenance costs	5.8%	51.6%
Staff costs	2.8%	15.7%
Cost of major repairs and refurbishments	4.0%	32.7%

Table 5: Economic comparison of energy supply options for settlements in the Arctic zone, million rubles

Indicators	Option 1	Option 2
Capital investments, without VAT	28.3	167.6
Annual operating costs (without depreciation, property tax and income tax)	33.7	11.8
Including fuel costs	87.4%	0.00
Specific undiscounted costs per 1 kW * h	40.72	29.54
Tariff (IRR 10%)	42.68	41.11
Tariff (IRR 12%)	43.38	45.25
Tariff (IRR 15%)	44.49	51.90

- Investment options based on RES in remote Arctic communities are analyzed;
- The economic efficiency of the considered energy supply options has been assessed in comparison with the current existing tariffs in the communities with the aim to reduce the costs of energy supply;
- Tariffs/costs were calculated for two RES investment options (wind-diesel plant and wind-power plant with a system of accumulation and use of energy in the form of hydrogen bound into a liquid organic carrier).

The research reveals that RES deployment is economically feasible in some remote territories of the Arctic, depending on the current costs of electricity. A special attention should be paid to reducing initial capital investments.

The given calculations can be used as a potential guide and criteria for the selection of an appropriate model of RES in the isolated Arctic territories of Russia and other countries. They can also be used for a user-aware electricity price optimization. The analysis and the data can provide the potential investor with the specificity and opportunities of renewable energy development in the Arctic, with the cost structure of the proposed RES investment options and their comparison with the current tariffs in the region. The future of RES development in the Arctic requires further research of dependence on the existing logistic schemes and of the capacity development of RES.

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