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ENERGY SUPPLY TO ISOLATED AREAS: ATTRACTING INVESTMENT AND DEVELOPING REGIONAL ECONOMY

The study analyses energy supply to isolated areas considering the development of priority areas of the regional economy and assessing the dependence between consumer finances and electricity costs. We examined energy supply problems in the example of the Tuva Republic, the Russian region with vast isolated areas and high prices for energy. We explained the reasons for the increase in electricity costs, including small-scale generation sources based on fossil fuels. The limitations of economically substantiated energy transmission at light loads prevent the connection to a centralised energy supply systems in isolated territories, leading to a decentralised energy supply. Thus, we proposed a methodological toolkit for solving the problem of economic substantiation of the dependence between consumer finances and electricity costs, testing it on the example of the gold mining industry. Our hypothesis relies on technological development opportunities in the field of renewable energy sources to reduce the construction and operation costs of generation facilities. Since the economic feasibility of using renewable energy sources for investors is determined by the dependence of consumer finances on energy generation costs, it is necessary to create energy resource structures depending on different basic conditions. For that purpose, we showed the linear dependence of the profitability of gold mining investment projects on electricity costs. The proposed criteria and methods allow determining the threshold values of the economic efficiency of energy services provided by suppliers and energy produced by self-generating facilities. Based on these results, further research can focus on analysing the impact of electricity costs on the financial parameters of projects to apply innovative energy supply schemes and identifying thresholds of the response of profitability to energy costs reduction for different energy consumption projects.

Keywords: investment projects, electricity costs, generation sources, energy density, decentralised energy supply, renewable energy sources, financial parameters, profitability thresholds, regression functions, analytical linear dependence

For citation: Asaul, A. N., Asaul, M. A., Levin, Yu. A. & Platonov, A. M. (2020). Energy Supply to Isolated Areas in the Context of Attracting Investment and Developing Regional Economy. Ekonomika regiona [Economy of region], 16(3), 884–895, https://doi.org/10.17059/ekon.reg.2020–3-16

Introduction

In Russia, areas relying predominantly on stand-alone power generation systems account for about 65 % of the country's total territory [1]. These areas are inhabited by about 20 million people. The Republic of Tuva is one of such regions, with 68 % of its territory covered by centralized power supply systems. Out of 17 municipal districts in Tuva, 11 have centralized, 3, decentralized and 3, mixed power supply systems [2, p.21].

Tuva is the only region in Siberia where the maximum electrical load is limited by the territory's total power generation capacity. To put it simply, the electric power system in Tuva is inadequate to the region's needs. Only 11.2 % of the electrical load is provided by the region's own power generation sources. A considerable part of the Republic consists of remote areas with decentralized energy generation systems—such areas make up 32 % of the region's territory [3].

The above-described circumstances make our analysis of the feasibility of alternative power solutions suitable for remote areas particularly relevant. In doing so, we are going to focus on the sensitivity of investment projects' financial parameters to the costs of electric energy. The aim of this paper is to find out to what extent financial parameters of investment projects are dependent on energy costs in remote areas and to determine the threshold values of the cost of electricity provided by an energy supplier or generated from one's own sources with different levels of profitability of the enterprise in question.

Although officially Tuva is described as a region with a large number of isolated power generation systems with high energy costs[1]1, we believe that there is insufficient awareness of the impact that the high costs of energy generation have on the realization of investment projects. In some areas of Tuva, the nominal energy capacity per capita does not meet the national standards and varies significantly — from 0.11 W to 4 W per capita. About 82 % of the Republic's territory is mountainous, with alternating mountain ranges and intermontane basins. 2.1 % of the territory is occupied by farmland [2, p.22]. All of the above makes the development of decentralized renewable energy systems a pertinent task for unlocking the region's full potential.

Socio-economic characteristics of Tuva that need to be considered in this respect include its severe continental climate, remoteness of energy consumers, low population density, low capacity of energy generating plants, the lack of large industrial consumers and the agricultural specialization of many of its areas [2, p.23]. Tuva also enjoys a number of strengths such as significant coal reserves (the estimated amount of coal is 11 billion tons) and climatic conditions suitable for using solar power both in power stations with capacity of 5 MW and more and in stand-alone power generators [2, p.25]. To improve the current situation in Tuva's energy sphere, there have been developed and approved the state program 'Energy Efficiency and Energy Development in 2014–2020 (with Amendments as of 21 February 2019)' and the Strategy of Development of the Fuel and Energy Complex of the Republic of Tuva until 2030.

Tuva, Khakassia, Krasnoyarsk and Irkutsk regions are closely connected with each other and together form the economic and geographic space of the Angara-Yenisei macro-region. Economic potential and scale of the investment projects realized in this macro-region are determined by its geo-political significance and resource base, the existing intergovernmental agreements and export contracts as well as the market capacity the neighbouring countries in the Asia Pacific region and North-Eastern Asia [4, p. 286].

The national strategic goals that Tuva is a part of include efficient mineral resource development and enhancement of trade and transport connections with the East. The Strategy of Spatial Development of the Russian Federation until 2025 sets the goal of expanding industrial potential of Tuva and developing its corresponding infrastructure.

The Strategy of Socio-Economic Development of the Angara-Yenisei Macro-Region specifies that stable development of industry and infrastructure are the key to economic growth. These goals require substantial investment and, consequently, a new level of profitability to attract more investors to this macro-region. For economic growth, the region mostly relies on the increasing rates of production of gold, silver, copper, nickel, coal and other mineral resources, processing of mineral raw materials and forest products. The main medium- and long-term goal for the development of the Angara-Yenisei macro-region is to increase the share of the manufacturing sector with a high value-added ratio and to create a modern transport and logistics infrastructure [4, p.287].

A key obstacle to meeting this goal in Tuva is the lack of modern energy infrastructure, which makes energy costs extremely high and creates problems for realization of innovative projects. This problem cannot be solved without state support to enable regional authorities to attract sufficient investment assets for large projects. The development of the infrastructure and resources of the Angara-Yenisei economic region is the aim of the mega-project 'Yeniseiskaya Sibir', which embraces three regions — Krasnoyarsk region, the Republic of Tuva and Khakassia. This project has been given a priority status and included into the Strategy of Spatial Development of the Russian Federation [4, p. 288].

Theoretical framework

The theoretical framework of this study is based on the works of Russian and international scholars dealing with problems of regional economic development and ways to foster competitive advantages of regions (N.L. Zubarevich, G.F. Balakina, A. N. Shvetsov, D. Friedman, etc) [5–10]. In the 1960s and 1970s, Soviet scholars found differences in the degree of the regional effect, stemming from the differences in the structure of energy costs. The latter, in its turn, was seen as dependent on

[1] On Amendments to the List of Regions of the Far North and Similar Areas with Limited Periods of Delivery of Goods (Products). Decree of the Government of the Russian Federation of 6 December 2016 № 1305.

the kind of technology used — energy-intensive or non-energy-intensive. Their findings informed the development of national electrification strategies. Soviet researchers also analyzed the potential of alternative energy sources, although, as far as the industrial applications were concerned, the main emphasis was placed on nuclear energy.

At the same time studies were conducted in the field of economics of renewable energy. These studies evaluated the efficiency of low-capacity power plants such as hydroelectric power plants with the capacity of 150–1,000 kW and solar and wind power stations with the capacity of 50–150 kW. The researchers also investigated the impact of regional (natural, economic, and technical) factors measured by looking at energy costs and their structure. Among other things, they calculated the reduced costs (per unit production costs) for traditional and alternative energy schemes depending on the location of production facilities in different industries and regions [11]. Unfortunately, the results of these theoretical studies did not find wide practical applicability in that period.

Contemporary studies of the current state, trends and driving forces behind the development of alternative energy forms are conducted both by Russian scholars, such as P.P. Bezrukhikh and V.P. Shuisky [12–15], and by international researchers, such as B. Sørensen, J.W. Twidell, and A.D. Weir [16–22]. Their findings lay the foundation for further research dealing with this dynamically developing sphere based on the use of renewable energy sources, in particular in technologically isolated territorial systems. O.A. Surzhikova [23] emphasizes that it is essential for remote and sparsely populated Russian regions to treat the use of renewable energy sources as a priority goal. There are, however, comparatively few studies on the economic aspect of energy supply options to remote areas that would provide critical cost estimates and take into account priorities of regional economic development.

We believe that this research gap impedes further search for efficient solutions to the problems of energy generation in remote areas, including the problems stemming from the use of traditional schemes of energy supply from large power stations, energy shortage and high energy costs due to complex multi-link transport and supply logistics of fuel. All of the above has a negative impact on regional economic development.

Further research is needed into the use of decentralized energy systems in the light of regional industrial development, taking into account landscape characteristics and long-term national interests. Building on the longtime research project that the authors conducted and their extensive dataset on regional economics mandate that we focus on the above-mentioned issues in all their specificity and on their current state in the context of the Republic of Tuva.

Methodology

This study relies on the following approaches and methods: systemic approach, comparative multi-factor analysis used to identify the problems of regional energy consumers; financial and economic calculations of the dependency between the profitability of goldmining investment projects and energy costs; regression analysis, widely used both in Russian and international research.

Analysis

Deficiencies of the infrastructure in Tuva seriously impede the realization of a number of new projects. Inadequate infrastructure also creates difficulties for attracting investors. On the one hand, the vast supply of natural resources and advantages of the Republic's location contribute to the stable development of its economy. On the other hand, the lack of electricity generation capacity and limited capability of interconnection lines, the energy system devoid of backup power supply, and the shortage of large energy consumers in Tuva point to the fact that this region is facing the problem of scarcity of factors of production and significant infrastructural constraints due to the inadequacy of its energy infrastructure, impossibility of creating a centralized energy system and a large number of isolated energy generation systems, characterized by high energy costs.

The cost-plus pricing principle used to set the selling price of electricity is ineffective for local energy providers and for energy consumers alike. The selling price of electricity in Tuva now exceeds the national average although energy is transmitted through the region's own power grids and the amount of energy exceeds that of Tuva by more than 20 times while in Irkutsk region, this figure is higher than in Tuva by more than 100 times. the prices and profits of Tuvan energy companies are growing much more slowly than their expenditures [24]. Energy supply in Tuva is financed by the regional government from the funds for compensation for the shortfall in organizations' revenues.

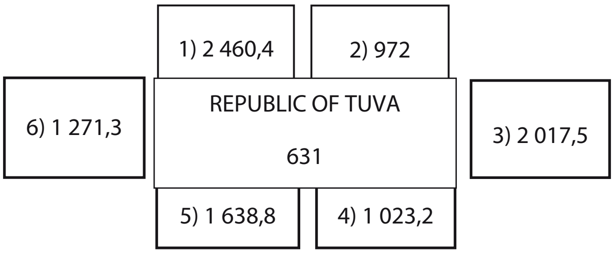

Fig. 1. *Energy environment of the Tuva Republic in kW · hour / capita on average (1 — Irkutsk region; 2 — Republic of Buryatia; 3 — Mongolia; 4 — The Altai Republic; 5 — Republic of Khakassia; 6 — Krasnoyarsk region)*

It should be noted that the cost of services provided through interregional transfer of energy along the federal power grids increases every year, which is detrimental to the profitability of businesses and impedes realization of many long-term investment projects within the framework of the mega-project 'Yeniseiskaya Sibir'. This concerns in particular energy-intensive manufacturing enterprises that do not have their own sources of power generation in such spheres as mineral extraction and manufacturing. Due to high electricity tariffs, many energy-intensive investment projects in these spheres are barely bringing any profit.

The non-regulated prices for energy bought in the wholesale market for the Republic of Tuva has been rising by more than 10 % every year [2, p.22]. The main factor is the low level of energy consumption in Tuva in comparison with other energy companies of the Angara-Yenisei macro-region, despite the fact that the average annual rate of growth of energy consumption in Tuva in the last ten years has been about 4 %. In the neighbouring regions with much higher energy consumption the price is lower by 15–20 %: for example, in Khasassia[2].

Tuva's energy environment is quite favourable (see Fig. 1), especially in what concerns Irkutsk region, Mongolia and Krasnoyarsk region. The two factors — economic (the lack of large industrial energy consumers in the region) and geographical (mountainous relief of Tuva and some of its neighbours in the macro-region) — prevent the establishment of regular power exchange that would be affordable and sufficient in terms of volume. Thus, in the nearest future, isolated power supply systems will remain the optimal solution to the electricity problem in Tuva.

The current situation in the sphere of power supply in Tuva pertains to the economic interests of the whole Angara-Yenisei macro-region and requires economic justification of the energy tariffs, especially in terms of their profit efficiency for industrial consumers in comparison with other regions. Tuva gets over 90 % of its electric power from its neighbor — the Republic of Khakassia. Since many remote regions, which are hard to reach, are not connected to the regional power grid, Tuva has a large number of isolated systems served by diesel engine generators.

Remote areas in Tuva mostly rely on stand-alone power supply systems (diesel power plants). The fuel for these plants is delivered once a year under the 'Northern Supply Haul' program. As these areas can be reached only by water or ferry crossings in summer months, the time when the delivery to these areas is possible is limited.

The cost of diesel supplied to Tuva from Siberian oil refineries has been growing every year. Thus, for Tuva, the complex logistics of fuel delivery to remote areas makes the cost of diesel about 1.5 times higher than for central Russian regions. The high costs of energy production in diesel systems, which are not very efficient and are characterized by increased rates of fuel consumption, pose a problem that so far has remained irresolvable. There are two key factors that determine the increase in the cost of energy from conventional power sources. The first factor results from the constantly rising prices of diesel fuel and the costs of its transportation. The second factor is linked to the decline in net electricity generation as the interest in the development of the region is waning (population decline; decline in production output and so on) while the costs of diesel electricity generation remain practically unchanged. Thus, the Republic sees a steady rise in economically justified energy expenditures.

Such situation not only affects the quality of life in the region but also impedes the development of the real sector, preventing it from making the maximum use of its advantages such as the geographical position near the border, forest and mineral resources (e.g. polymetallic ore deposits).

[2] Electric power consumption per capita //Association 'NP Market Council'. URL: https://www.np-sr. ru/ru/SR_16911.

If the federal government does not launch mechanisms to stimulate consumers' reliance on renewable energy sources (RES), Tuva will not be able to gain competitive edge among other territories of the Angara–Yenisei macro-region.

Tuva's primary competitor is the southern part of Krasnoyarsk region, which is more economically advanced and, unlike Tuva, has a more pronounced specialization, better developed manufacturing industry and resource-based sectors, a comparatively high level of development of infrastructure and human capital [24, 25].

Affordable energy is, of course, not the only factor that can be considered for evaluation of the territory's competitive advantages. Other factors include the region's accessibility by transport, logistics, and so on. The investment necessary for regional development, however, to a great extent depends on the level of energy costs. This problem can be addressed through programs for implementing standard solutions to provide isolated and remote territories with renewable energy sources: these solutions should help reduce the operating costs and ensure a reliable supply of energy [26, 27].

The successful international and national experience of enhancing energy efficiency shows that RES can provide a viable solution to a serious strategic task, which is challenging both technically and socially,—the task of providing a reliable, high-quality source of energy supply for individual consumers and industrial enterprises scattered across the region's territory[3].

The use of RES energy solutions (hydroenergy excluded) in the world has grown fourfold this decade. At the same time the share of RES in the global consumption of energy does not exceed 2 %[4]. 'Although in general, renewables are still more expensive than traditional ones, in some areas these sources are already becoming competitive as they at least reduce, in comparison with traditional sources, the costs of energy if not energy consumption' [28]. In Russia, the costs of RES energy production funded exclusively through market mechanisms are still higher than in centralized power systems. It is possible to cut the costs by providing more substantial state subsidies or through technical modernization, which will result in lower costs of building RES generation infrastructure and lower costs of RES operation and maintenance. In this study, we are going to consider the second scenario in more detail.

It should, however, be admitted that along with the numerous studies of the technical characteristics of RES, there are comparatively few papers dealing with these sources in the context of their economic feasibility. As far as the applications of renewable energy are concerned, populist publications abound. It should be noted that research literature discussing the possibilities of using RES often tends to ignore the financial parameters of the projects where these solutions could be applied.

In the last two decades, certain adjustments have been made to the conceptual and strategic framework of the Russian energy policy[5], although the priorities in this sphere have remained the same, including the use of cost-competitive RES for stand-alone power supply systems with high energy costs[6].

One of the goals specified in Russia's Energy Strategy until 2030 it to increase the use of renewables by more than 9 times; their power, 11 times; and the overall share of RES use, to 4.5 %[7], which is approximately 3 times more than the current level but at least 40 % behind the global long-term renewable energy targets [29]. Such situation—Russia lagging so far behind global leaders—should by no means be treated as acceptable by the country's government. However, the question remains open as to whether consumers will find this option cost-effective, in other words, whether they will find acceptable the costs of electricity generation from renewable energy sources or will be ready to purchase it from a guaranteeing supplier at a retail price. In the following section we are going to discuss the methodological approaches to analysis of the dependence between financial parameters of an investment project and energy costs.

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[3] Power Supply of Isolated Territories in Russia and in the World// Energy Bulletin. № 51. 2017. P. 14–18.

[4] BP Statistical Review of World Energy, June 2019.

[5] The Key Areas of the State Policy in the Sphere of Enhancement of Efficiency of Energy Industry through the Use of Renewable Energy Source until 2020. Executive Order of the Government of the Russian Federation of 8 January 2009 № 1-р // Collected Legal Acts of the Russian Federation. 2009. № 4. Article 515.

[6] On Electric Power. Federal Law № 35-ФЗ. As amended effective of 01.01.2019.

[7] Energy Strategy of Russia for the period until 2030. Adopted by the RF Government Executive Order of 13 November 2009, No. 1715-р.

Results

To analyze the comparative costs and assess the sensitivity of a project's financial parameters to energy costs, we chose the goldmining industry. One of the reasons is that gold mines are usually isolated from centralized power supply. Moreover, the scenario of national economic development prioritizing modernization of the energy and raw materials sector will provide a powerful impetus for the development of Tuva, in particular its goldmining industry.

Goldmining is crucial for the socio-economic situation in Tuva and for creation of gross regional product. It is one of the priority areas for economic development of the region and macro-region (in 2018, 1.45 tons of gold were extracted in Tuva); it forms the taxable base and provides employment for local residents, primarily those inhabiting the municipalities with gold mines. Goldmining is an important source of revenue for governments of all levels, a source of jobs and income for local people and a source of funding for social projects in Tuva[8]. It should be noted that in Sut-Kholsky District of Tuva recently there have been discovered three gold-rich areas, containing from 0.7 to 5.8 grams of gold in a ton of ore, with capacity of 1–3 meters.

Gold mines that can be potentially attractive for investors are usually located in isolated, scarcely populated territories. Since centralized power supply is economically infeasible for goldmining due to low levels of energy consumption and low energy intensity, investors have to look for suitable alternatives to the centralized power grid, such as stand-alone power generation. This requires calculations that would enable the investor to decide whether they are ready to bear the costs or not. The profitability of a goldmining project to a great extent depends on the rational choice of a source of energy.

Table

Analysis of the dependence of financial parameters of an investment project for the development of a gold ore mine on electricity costs [30, p. 32]

Project indicator values		
Cost of electricity, rbs/k·Wh	***NPV*, mln dollars**	***IRR*, %**
2.253	53.6	13.9
2.503	42.0	13.6
2.753	30.3	13.3
3.003	19.0	13.0
3.253	7.7	12.7
5.753	107.0	9.9
6.003	118.7	9.6
6.253	130.5	9.3
6.503	142.2	9.1
6.753	153.9	8.8
7.003	165.7	8.6
7.253	177.4	8.3
7.503	189.2	8.0
7.753	201.0	7.8
8.003	212.9	7.5
8.253	224.7	7.3

To economically justify energy costs in different energy supply schemes for industrial energy consumers, "preproject analysis of an investment goldmining project is necessary to evaluate the sensitivity of its financial parameters to the costs (tariffs) of electrical energy' [30, p. 32] (see the Table).

The sensitivity of financial parameters of a project to energy costs (electricity tariffs) for consumers in isolated territories is used as a criterion. Our hypothesis for forecasting scenarios is built on the assumption that a set of technological measures will be implemented to decrease the costs of construction as well as operational expenses in the energy supply systems based on RES. 'The limiting

[8] Strategy of Socio-Economic Development of the Republic of Tuva until 2030// Ministry of Economic Development of the Russian Federation. URL: economy.gov.ru.

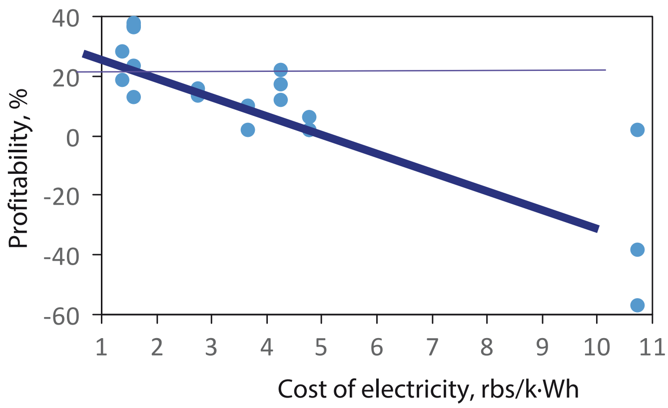

Fig. 2. *Dependence of the profitability of gold mining on electricity costs*

conditions are the net present value — NPV (positive NPV) — and the internal rate of return — IRR' [30, p. 33]. Our calculations have shown the dependence between profitability thresholds of goldmining enterprises and energy costs (Fig.2).

'The calculations we made resulted in a set of points shown in Fig. 2, which enabled us to build a slanting line as a result of approximation (regression)' [30, p. 34]. Thus, we obtained the following approximate analytical linear dependence:

$$y = -0{,}0628x + 0{,}3605, \tag{1}$$

or if profitability is multiplied by 100 %, the following:

$$y = -6{,}28x + 36{,}05. \tag{2}$$

It means that if we take the cost of energy as zero, the level of profitability will be 36.05 %. As the cost of energy increases, for each rouble /kWh profitability will fall by 6.28 %.

Conclusion

The above-described conditions of successful implementation of advanced stand-alone power supply solutions and the proposed approaches to the economic justification of energy consumed by industrial enterprises at the pre-project stage require us to search for those threshold values of electricity costs which would allow us to ensure the desired degree of the project's profitability and to take into account the changes in the economic indicators of energy supply by reducing the operation costs of RES-based energy systems.

By calculating threshold values, the investor will be able to conduct a comparative analysis of the costs of an industrial energy consumer at the preliminary stage of the project. An individual analysis of the impact of electricity costs on financial parameters of the projects involving innovation energy-saving schemes brings to light the thresholds in the sensitivity of profitability to a decrease in energy costs for projects with different levels of energy consumption.

Apart from gold deposits, Tuva also offers opportunities for investment into porphyry copper deposits located in mountain taiga areas as well as in coal mining and coal preparation, construction of mining and processing industrial complexes, wood processing enterprises and other spheres [31, 32]. Some projects in the above-mentioned fields were already realized in 2015–2018 or are still underway, which makes the questions of energy supply more important than ever. The launch of some of the projects implemented in remote territories might be postponed, however, if they turn out to be unprofitable or likely to yield little if any profit. This category of projects includes energy-intensive ones such as projects for construction of industrial enterprises incapable of generating their own electricity and running on secondary resources. Such projects often require state funding to build expensive electric power transmission lines in order to get connected to the centralized power grid. Other projects in this category are less energy consuming but equally important for the region's economy.

Programs based on the use of stand-alone renewable energy systems in combination with incentive schemes for energy consumers can be a viable solution to the complicated question of distributed institutional and economic responsibility for providing reliable and cost-efficient supply of energy for investment projects in remote areas.

Translation

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