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Autonomous power supply to remote consumers: state of the art and adaptability of measures

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Abstract. The forecast predicts that by 2040 electric energy consumption will have increased more than twofold. Even today, providing electricity to remote areas is characterized by the absence or shortage of supply. The construction of power lines for a small number of consumers in remote areas is costly and, therefore, not economically viable. Partially, the energy supply of remote areas is provided by diesel power stations. However, the high cost of fuel combined with its transportation results in a high price on electric power and diesel power stations negatively impact our environment. Meanwhile, the modernization of active or the construction of new generators based on the usage of renewable energy sources, especially wind, significantly reduces the cost of electricity generation and presents a holistic solution for many remote or isolated areas. This effect may become more visible via innovative tools for the management of development and operation of energy supply facilities for remote areas that do not have access to a centralized energy grid.

Key words: remote areas, isolated areas, centralized energy system, cost of energy consumed, natural environment, renewable energy sources.

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Научная статья

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Автономное электроснабжение удаленных потребителей: современное состояние и адаптивность мер

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Аннотация. В соответствии с прогнозом, к 2040 году потребление электроэнергии увеличится более чем в два раза. Даже сегодня обеспечение электроэнергией отдаленных районов характеризуется отсутствием или нехваткой электроснабжения. Строительство линий электропередачи для небольшого числа потребителей в отдаленных районах затратно и, следовательно, экономически нецелесообразно. Частично энергоснабжение отдаленных районов обеспечивается дизельными электростанциями. Однако высокая стоимость топлива в сочетании с его транспортировкой приводит к высокой цене на электроэнергию, а дизельные электростанции негативно влияют на нашу окружающую среду. Между тем, модернизация действующих или строительство новых генераторов, основанных на использовании возобновляемых источников энергии, особенно ветра, значительно снижает стоимость производства электроэнергии и представляет собой комплексное решение для многих отдаленных или изолированных территорий. Этот эффект может стать более заметным благодаря инновационным инструментам управления развитием и эксплуатацией объектов энергоснабжения отдаленных территорий, не имеющих доступа к централизованной энергосистеме.

Ключевые слова: отдаленные районы, изолированные территории, централизованная энергосистема,

стоимость потребляемой энергии, природная среда, возобновляемые источники энергии.

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Introduction

A lack of electric power supply from a centralized energy grid for remote and isolated areas with low population densities requires new solutions to this issue, considering the capacity to pay, business activity growth, and environmental safety. The electricity generated through renewable energy sources has demonstrated its competitiveness with traditional energy sources. It is expected that in 30 years, the share of renewable electricity will constitute 2/3 of the global electric power generation, replacing fossil fuels electric energy [Investory topyat za... 2019]. The cost of energy generated through hydrocarbons with their depletion will increase, whereas thanks to the improvement of construction materials, the technologies of their production and application will decrease the cost of renewable energy sources, opening new opportunities for their application in remote areas. It is also known that electricity generation through fossil fuels emitting carbon is predominant in many parts of the world due to the inaccessibility of low carbon and renewable energy sources [Hirth 2016]. At the same time, there is a growing awareness of the importance of the preservation of natural resources. The bottom line is not the only goal of modern progressive firms. Along with it, they have the goal of the preservation of the global environment. If we ignore environmental issues now, we will pay for this in the future [Wunderlich 2018]. Also, costs on renewable energy production and application may be reduced thanks to the effective management of the production and application of power supply plants, development of partnerships between participants, and thanks to innovative technological and managerial decisions. Costs may be reduced thanks to the popularity of wind as a choice in the structure of renewable energy sources. By measurement of effectiveness among solar, hydro, nuclear, thermal, and geothermal energy sources, wind energy occupies the first place by the large margin [Wang 2013], and it can be used in places where it is financially viable. Thus,

the large-scale introduction of relatively cheap and clean energy on the competitive market with the help of replacing one energy source with others or their reasonable combination and the reduction of technological and managerial costs will bring momentum to the economic growth of remote areas, and the improvement of the environment and social climate of residents.

Literature review

Providing energy to isolated and remote areas constitutes a problem in many parts of the world. The global electricity consumption is undergoing significant quantitative and structural changes. Despite various forecasts, now electricity consumption is decreasing, and its structure is changing. In 2019, the growth of the global electricity consumption was only 0.7% in comparison with the average figure, 3% a year between 2000 and 2018, whereas the share of wind and solar energy quickly and steadily grows, and it has already reached 8.5% [Wiatros-Motyka 2023], considering the energy infrastructure development of remote areas. A number of states reached a remarkable share of wind and solar sources in their energy production (table 1). Table 1 contains the list of some successful countries at renewable energy development, including Germany, Portugal, Spain, the UK, and New Zealand. The countries of this group have the average share of wind and solar sources equalling 26.2%. The other group, that includes Belgium, Chili, Romania, Turkey, Sweden, and the Netherlands, has the average that lags 1.8 times compared to the former group equalling 14.8%. The success of the first group and the failures of the second one can be explained by different potentials of opportunities for tackling the issue of renewable energy sources development and the capacity to use this potential. In table 2, we observe the states with the highest demand on investments into renewable energy sources [Great expectations... 2018]. They do not always match with the list of states that have the highest share of wind and solar energy in overall energy production.

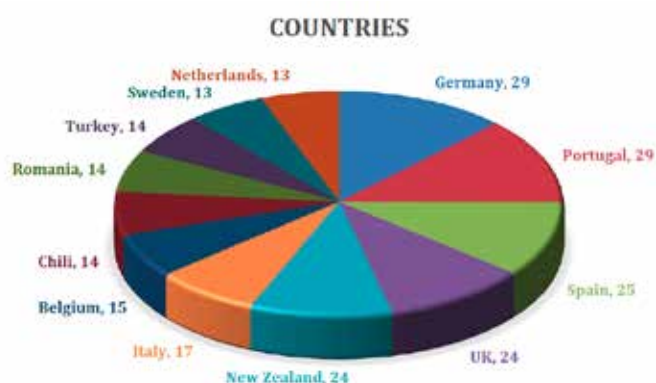


Figure 1. The share of wind and solar sources in electricity generation, 2019
Source: [Great expectations... 2018]



Figure 2. Countries with the highest activity in the investment market regarding renewable energy sources, 2018
Source: [Great expectations... 2018]

The creation of infrastructure in remote and isolated areas is a world level task, as a significant number of people in remote areas do not have access to the centralized energy grid. Approximately 500–600 million Africans do not have access to electricity. In Russia, more than 20 million people live in 30,880 localities in the North, Siberia, and the Far East region located in areas with decentralized energy supply, constituting 13,7% of the entire population of Russia. The issue of providing electricity to isolated areas without the access to centralized energy grid is also relevant in the arctic part of Canada, New Zealand, and some US regions, particularly Alaska and Hawaii. The problem is also sound in China, although to solve it, the Chinese authorities invest substantial money in the development of energy infrastructure. Typically, remote and isolated areas have unfavorable climates, shortages of local fuel, and low level of infrastructure development.

The issue of energy supply is addressed using several approaches depending on external and

internal circumstances. In some countries that lack the necessary infrastructure, or their climates are exceedingly cold, fossil fuels are used for electricity generation. In some states, electricity generators for renewable energy sources are mostly used. The most popular now is the third approach when states follow the hybrid option that is a combination of two previous approaches. The choice of an approach to providing energy to remote consumers has to be decided at the stage of the construction design, and in the process of following the management of a project, its creation, and application. Commercial part of this process plays a crucial role and is defined considering the potential profit for an investor, reach and longevity of the maximum characteristics of application, reliability, durability, environmental part, and social conditions of the local population. Electricity generation facilities are rarely renovated in such areas and have low energy efficiency and insufficient reliability. There are also high risks of equipment breakdown due to extreme weather conditions [Energosnabzheniye izolirovannykh territoriy 2017]. In such areas, the period of power outages lasts 12 to 15 hours a day.

Results

In 2019, the share of renewable energy in the global energy mix increased to 27%, in line with a trend that began and has been developing in the 2000s. This increase is due to new capacity mainly from wind and solar power plants, as the share of hydro in the global energy mix has been at 15% since 2000 and has not changed significantly.

Modern energy development in remote and closed areas is well developed in countries with a high share of solar and wind energy in electricity production. For instance, in the EU member states 35% of the energy balance comes from renewable energy sources, followed by China with 27%, India with 21%, the US, Russia, and Japan with about 18% [Wiatros-Motyka 2023]. They have a highly-skilled workforce, experienced in working with communities and local businesses, with excellent knowledge of modern energy technology, and adaptive regulations and standards.

A new and sustainable trend driving the development of renewable energy in remote areas is the reduction of production costs, which have fallen faster than any other energy source since 2010 i.e., solar by 85% and wind by 49%. As a result, renewable electricity storage costs have fallen (are

expected to fall by...) by 85% [Investory topyat za... 2019]. Climate change programmes in the EU, China, India, USA, Russia, Japan, Australia, Turkey, Iran, and Nigeria have contributed to this decline.

The renewables market is one of the fastest-growing areas of the power sector and is attracting more private investment. Each area, remote and isolated from central sources of energy, has its growth drivers. This makes development uneven across the world as all areas, in developed and developing countries, have different opportunities. A strategy of private investment by oil and gas companies in renewable energy projects in areas where these companies have a presence has proven to be in demand and mutually beneficial [World Investment Report 2023].

Renewable energy in remote and inaccessible areas has proven to be a tool to provide energy security for communities and to meet the Kyoto Protocol emission limits on the use of solid fuels. This problem has a long history. As early as 1995, the UN countries began to seek consensus on climate change mitigation, which remains relevant today [Rocha 2018]. It is worth noting that the cost of transmitting electricity from wind power can be higher than from coal or nuclear power since the distance between production and consumption of renewable energy can be much greater compared to the traditional way of generating it. For wind and solar power, the length of transmission lines must be optimised to minimise maintenance costs and reduce the likelihood of fires. At the same time, the equipment used to generate renewable energy requires the same level of control as in a conventional power plant, which entails additional infrastructure costs. If these costs are factored into the design and upgrades, they pay for themselves and do not increase the cost of renewable energy. The results of China, India, Russia, USA, and Japan present distinctive features of providing renewable energy to remote and inaccessible areas that require separate consideration

China

China occupies the first place in the world in terms of installed wind power plants. The country is the absolute champion in both production of renewable energy equipment and installation of solar and wind power plants. This is no coincidence as it is the biggest polluter due to its intensive economic development, including remote and enclosed areas.

This country has a pronounced conflict between ecology and economy. China is home to 18% of the world's population, yet it burns 28% of the planet's fuel [Den'gi iz vozdukha... 2019]. In order not to affect climate change on a global scale, the consumption of fossil fuels has to end and renewable energy sources have to be used in different sectors of the economy [Renewable 2020]. Besides, the wind is a free, renewable, and clean source of energy, as far as the environment is concerned. Plants which convert wind into electricity can be constructed on agricultural land and used in harmony with nature [Nazir 2019].

Because of the current situation, the Chinese authorities have decided to intensify the development of renewable energy sources. In 2019, the government set a goal of increasing the total share of renewable energy in the country's energy mix to 30% by 2030. Now, in China, supplying remote and closed areas with clean and renewable energy is one of the priorities of a major government program to support the economy with a total investment of \$586 billion. Approximately 25% of this amount is allocated to renewable energy projects, energy efficiency, and environmental improvements. Wind and solar are key sources of energy for supplying remote and enclosed areas. The government actively supports Wind power, and is developing it at an accelerated pace [Lema 2007]. In 2018, wind-generated electricity constituted 5.2% of China's total electricity output. Already in 2019, China accounted for around 30% of the world's renewable energy sources, compared with just 10% in the USA.

India

According to 2018 data, India became the fourth country in the world in terms of installed wind power capacity [Dipen 2020]. To solve the problem of providing power to remote and isolated areas in India, just one of the many, a large local power company, Tata Power, has outlined a plan to build 10,000 autonomous microgrids (Microgrids) by 2026, which could serve 5 million households (25 million people) who are without sustainable access to electricity [Tata Power and... 2019]. The active and rapid development of wind power in India was preceded by government decisions and legislation. These have helped bring down the cost of wind power to a record low of 3.4 US cents per kilowatt-hour [Dipen 2020].

India is generally reorienting its investment

course towards prioritizing the development of renewable energy sources. In 2020, it aims to double the total amount of electricity generated from renewable energy sources, including remote and isolated areas. India, through auctions, has set record low prices for electricity generated from wind and solar photovoltaics, which account for about 90% of new capacity. This number is high because the Indian authorities have planned to increase alternative energy generation to 175 GW by 2022 (the current figure is 58.3 GW). Experts advising the Indian government on these matters believe that this goal is achievable. The untapped renewable energy potential in remote and isolated areas contributes to this, as well as the fact that the country's total solar potential exceeds 750 GW, and the potential capacity of wind installations exceeds 1,000 GW. An important factor that drives the development of renewable energy in remote areas is the need to move away from fossil fuel-polluting and climate-damaging power plants. Besides, India, like other countries, is consuming natural resources rapidly, which poses serious problems for future generations [Jia 2018].

Russia

In Russia, due to its vast area and the distance from power generation facilities to consumers several thousand kilometers away, solving the issues of full supply of the remote areas with a harsh climate can only be done by using a unified energy system operating on the basis of renewable energy sources. The development of renewable energy sources in remote areas of Russia is taking place as part of a major program of upgrading power generation capacities. About 65% of the entire territory of the Russian Federation is situated in the zone of isolated (autonomous) energy supply. With the development of the Arctic, the state's new strategic task has become to develop alternative energy in remote northern territories. Due to renewable energy sources in remote northern areas of the country, both the cost of delivery and harmful emissions to the atmosphere are being reduced, energy and social problems of the population are being solved, and business activity in northern territories is increasing.

In the north of Yakutia, there is a large testing area in the scientific and educational center "Sever", which is used for studying the eastern area of the Arctic, and for solving the problems of energy distribution to remote settlements [V Arktike

poyavitsya... 2020]. It is implemented within the framework of the integrated development plan of "Tiksi" until 2025. The tasks of the testing area are, researching alternative energy sources, energy conservation, biotechnological processing of bio-raw materials from the Arctic, as well as design and construction of buildings and structures adapted to Arctic conditions. In the framework of the Siberian branch of the Russian Academy of Sciences and International center for scientific research in the Arctic, based on the resources of the Academy of Sciences of the Republic of Sakha (Yakutia), it is planned to study the natural environment of remote areas in the Eastern Arctic, which is affecting the power supply of remote settlements with alternative sources of energy. The creation of the testing area will contribute to the development of the economy of the remote Arctic territory, investment in local businesses, and the maintenance of an alternative energy supply system for the population, with the help of a tourist and recreational cluster of the Arctic.

At the same time, remote villages of Chukotka are switching to alternative energy sources. Currently, the Chukotka Autonomous District produces 60% of its own energy from the generated quantity. The Anadyr wind farm, the largest one in the Russian Arctic, is successfully operating and supplying electricity to the entire Anadyr territory. In the localities of Beringovskiy and Ust-Belaya, two wind farms with a capacity of 450 kilowatts each were built. Solar panels with the highest solar activity are being installed in remote settlements of the Anadyr district. The projected capacity of the power plant in Kanchalan will be 400 kilowatts, in Snizhne — 180, and in Markovo — 800 [Udalennyye sela Chukotki... 2020]. In 2021, it is planned to modernize a significant number of wind power plants.

USA

Wind energy is developing well in the United States. Its growth in recent years is due to an increase in demand for this energy resource [Sugimoto 2018]. Wind farms are becoming more technologically sophisticated. The development of adequate technologies for generating and transmitting electricity to remote consumers will reduce the cost of energy as much as possible, up to 2-3 cents / kW, especially in areas with a high average annual wind speed [Ratner 2012]. The US is also integrating offshore wind power into the electricity grid, helping to reduce costs [Simão 2017]. In the United States,

when solving the problems of developing renewable energy sources, both in remote and closed areas, and in general, they rely on tax incentives and state support for the further development of innovative technologies. The US Department of Energy regularly provides research grants in the field of alternative energy. As an example, in 2020, a major grant from the US Department of Energy to the tune of \$158 million, was allocated for research in the field of creating innovative energy storage systems [Vasiliev 2020]. The tax benefits apply not only to research institutions, but also to businesses related to energy storage. Unlike many other countries, where solar and wind dominate among the sources of renewable electricity, in the United States, a significant part of the production of environmentally friendly electricity belongs to hydroelectric power plants. In the United States, many generating companies are convinced that in the future, the electricity they produce from renewable energy sources will have an advantage over traditional energy.

An important feature in support of renewable energy sources in the United States is the promotion of the development of high-capacity energy storage facilities, which allows the electricity providers to smooth out fluctuations in the volume of its production depending on the weather and time of day. At the same time, the US refusal to implement the Paris Climate Agreement is a clear example of how, as a result of the actions of the state, very profitable opportunities can turn into a loss for investors, since they pay special attention to the current laws and regulations, perceiving them as the main obstacles to investment activities for the development of renewable energy sources in remote areas from centralized energy networks.

Conclusion

The demand for renewable energy sources in remote and closed areas is steadily growing, and where it is implemented, the use of this type of energy allows it to almost completely meet the three main requirements of consumers: affordable cost, sufficient stability of energy supply, and high environmental friendliness. The provision in large areas, remote from centralized energy supply systems, contributes to their socio-economic development. Its strategic role in the development of new production capacities, formation of optimal models for economic development, and the preservation of ecological balance on the planet, is

increasing.

The high importance of solving the problem of energy supply to the world's population determines various measures of state support in the field of autonomous energy supply to remote and isolated territories. International cooperation has a significant practical application, both in the field of energy development of remote areas with the help of renewable sources, and in the field of creating components and mechanisms for their electrical supply.

All successful solutions for the energy supply to remote and isolated areas are based on local specifics. Activities related to the development of renewable energy sources fit into the framework of the general policy of the state, are linked to other similar programs, and have their own sequence. It is also significant that, regardless of the political model of the country, be it liberal, conservative, or social, the solution of energy supply issues in remote and isolated territories is always linked to state funding. It is carried out either at the initial stage, supported by budget funding, or on a permanent budget basis. Private financing and public-private interaction are widely used. This is due to the fact that the structure of the potential for investing in renewable energy sources in remote and isolated areas is changing around the world. Oil and gas companies invest in them, depending on in which regions they are located. Investing in modern technological solutions and energy infrastructure in remote and closed areas is a new global trend, increasing the contribution of oil and gas companies to green energy, reducing emissions produced by hydrocarbon power plants, and contributing to the implementation of the terms of the Paris Agreement.

Under a favorable scenario for the global economy, by 2050, renewable energy sources in remote and closed areas will be able to meet about a third of the world's electricity demand, combined with additional electrification. To achieve these goals, it is necessary to: increase the capacity of generating electricity from wind energy on land and at sea by four and ten times compared to existing production.

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