Geophysical Determinants of Wind Energy Development in the Far North of Russia

Yu N Gladkiy\textsuperscript{1}, V D Sukhorukov\textsuperscript{1}, L V Larchenko\textsuperscript{1}

\textsuperscript{1}Department of geography, Herzen University, Moika Embankment, 48, Sankt- Petersburg, Russia, 191186

E-mail: Gladky43@rambler.ru

Abstract. The development of the Arctic territories of Russia requires reliable sources of electricity, the nature of which is due to the geographical features of the region. In this regard, new solutions are needed. In addition to small nuclear reactors, wind energy is promising. Geophysical determinants of its development are associated by the authors not only with climate-forming factors, but also with other natural properties of the territory - orographic features, cold, permafrost, etc. It is noted about half of the enormous technical potential of Russian wind energy is concentrated in the Arctic zone. Although almost all Arctic regions have a comparable powerful potential for wind energy, the strategy for the development of wind energy largely depends on the concentration within them of the population, economic objects, transport infrastructure, etc. The contradictory relationship between the geophysical and economic conditions for the development of wind energy is analyzed. It is emphasized that in a number of remote regions of the Far North and the Far East wind energy is not a source of profit, but is designed to perform socially and environmentally important functions.

1. Introduction

Unfortunately, in the energy balance of the country, claiming to be one of the leading energy powers in the world, wind energy still plays a negligible role, and the concept of "Russian wind energy market" is absent altogether in the energy lexicon. In this regard, the Far North, where about half of the enormous technical potential of the Russian wind energy is concentrated – more than 50 terawatt – TWh/hour, is one of the most promising sites in Russia for the creation of highly efficient wind turbines.

Today real projects in this field are associated with the southern regions of Russia - the Krasnodar krai and the Republic of Adygea. It is here one of the state corporations (affiliated with “Rosatom”) plans to build three wind parks with a total capacity of 610 MW by 2020, thanks to a partnership agreement with the Dutch company Lagerwey [1]. Russia believes that this company has a priority in developing the most promising technology for the construction of direct-drive wind turbines (without a gearbox), which is much cheaper to maintain.

The direct connection of the above-mentioned deal with the development of wind power in the Far North is that the partnership with Lagerwey implies not only the organization of production of wind power plants in Russia, but also the transfer of critical technologies necessary for construction. In addition, an important condition of the transaction is the localization in Russia of the production of components for wind turbines at the level of not less than 65%. It was officially announced that in the
next six to seven years about 600 wind turbines with a total capacity of 1.6 GWt were delivered to the Russian market. The creation of the first domestic enterprise (on the basis of the well-known Atommash plant in Volgodonsk), which will be engaged not only in the production, assembly and installation of wind turbines, but also in the formation and management of a chain of suppliers, operation services, will significantly accelerate the use of wind energy in the Northern territories.

The inevitability of large-scale development of wind energy in the Far North of Russia is obvious to many experts, especially after the development of the Arctic has ceased to be a utopian idea and has become an urgent need to stimulate economic growth in Russia. Today, more than 10% of the country's gross domestic product is being created in the Arctic sector, and local natural resources account almost a quarter of the volume of its exports. It is assumed that resource development in parallel will contribute to the strengthening of local and regional business, the creation of new jobs, etc.

At the same time, the appeal to wind energy resources at the first stage will contribute not so much to the resource development of the North as to the improvement of the living standards of the local population in numerous isolated small settlements, including those where specific objects are localized – beacons and other elements of navigation, meteorological stations, reindeer herders' camps, border outposts, etc.

2. Relevance of the issue

The lag of Russia from many countries in the world in the development of wind energy began to change for the better only in recent years. In part, they are related to the fact that, according to estimates of authoritative experts, by 2024 the cost of wind energy in Russia should be equal to the cost of fossil energy [2]. An opinion is expressed on the need to form a unified coordinated approach to the creation of a “Roadmap for the development of the wind energy industry in Russia” with the development of regional programs and specific projects in this area. The search continues for profitable projects, including through the use of various financing models, government subsidies, public-private partnerships, etc.

Geophysical determinants are associated by the authors not only with climate-forming factors. Their manifestation involves a number of properties of the planet itself, ranging from orographic features of the territory and types of local landscapes, to the angular velocity of rotation of the Earth, which has a decisive impact on the circulation of the atmosphere and ocean.

Thus, the object of research is geophysical factors of wind power industry development in the North of Russia. The subject of the study is related to the evaluation of the contradictory interaction of geophysical and economic processes in the development of wind power.

The approach used by the authors provides an assessment of the influence of geophysical factors on the development of wind power in the Far North of Russia, of course, taking into account both the existing technical and socio-economic capabilities of society and the conditions for preserving the fragile natural environment. It is about the correlation of several quantities, among which geophysical one plays a leading role.

The authors took into account the rich experience of authoritative authors in the field of wind energy [2, 3, 4, 5, 6, 7, 8, 9, 10, 11], including the fundamental study of Manwell J., Roger A. & McGowan J. “Wind Energy Explained. Theory, Design and Application”, as well as theoretical developments of domestic authors [12, 13, 14 etc].

3. Results

3.1. Dynamics of the wind regime in high latitudes

The climatic specifics of the extreme north of Europe, Asia and North America, as well as Southern Patagonia (areas of potential development of wind power), are characterized by many common features - a long winter (up to 300 days a year) with snow and strong frosts (35-50° С ), many months
of darkness in the Arctic, etc. But the main thing that interests us is the fact that there is an intensive circulation of air masses, especially in winter and during transition periods - in the fall and spring.

In this case, wind regimes in certain sectors of the Arctic differ significantly, which can influence the strategy of wind power development. As an example it is possible to point out the specific features of the "drainage" climatic regime of Greenland, caused by descending winds to the coast. Such regime is called "catabatic" (from the Greek word katabikos - to descend) and is associated with winds, which, despite the effects of the adiabatic compression during descent, remain colder than the air being displaced. In this case, the density of the surface air is greater than the density of the air located above. As a result, a buoyancy force is created, which helps to accelerate the downward flows. When trying to use the energy of such winds should also take into account the effect of Coriolis force and frictional resistance (especially in coastal valleys and fiords), as well as the ability of catabatic winds to form along the coasts of medium-scale Polar lows.

The low-lying nature of the overwhelming part of the Russian coast of the Arctic Ocean delivers less "puzzles" of this kind, but also there are its difficulties, differentiating on the Arctic and subpolar climatic zones. The first includes the following broad areas of real interest for the wind energy market:

- **Atlantic Arctic region**, represented by the Barents and the Kars Seas, the northern part of the Yamal Peninsula, the Gydan Peninsula, the most part of the Taimyr peninsular, the northern island of Novaya Zemlya, the islands of the North Earth. Dominating here strong winds are caused by development of cyclonic activity on the Arctic Front (in winter the wind speed reaches 9 m/s, and at the entrance to the Strait of Matrochkin Shar – 15 m/s);

- **East-Siberian Arctic region**, stretching from the border with the Atlantic region on the island of Taimyr to the east over the seas of Laptev and East-Siberian to the Chaunskaya Lip, as well as including the Novosibirsk Islands and the strip of land occupied by the tundra and Forest- tundra.

- **Pacific Arctic region**, which falls into the zone of influence of the Pacific Ocean, located over the Chukchi Sea and over the strip of land from the Chaunskaya Lip to Cape Dezhnev.

The Subarctic climatic zone, which lies to the south of the Arctic, is subdivided into three highly distinct areas:

- **the Atlantic subarctic region**, located to the south of the Arctic region of the same name, extending in the east to the lower reaches of the r. Taz and under the influence of wind processes occurring on the Arctic front;

- extensive **Siberian subarctic region**, located between the southern border of forest tundra in the north and the border of the woodlands in the south and stretching from west to east from the Tazovskaya Lip to the Kolyma ridge;

- **Pacific subarctic region** - from Kolyma Ridge to Bering Sea.

On the one hand, all marked climatic areas have a number of beneficial natural and economic moments and, above all, the largest concentration of energy in Russia. Experts point to a higher density of cold air than warm, thanks to which increases the generation of energy (at the same wind speed). The performed calculations indicate that when the air temperature is lowered from +15 to -15° C, the power of the wind turbine increases by 11%. But, at the same time, the drop in atmospheric output from 770 to 730 mm of mercury column reduces the power of wind turbines by 6%. This means that to receive the additional power in unstable weather conditions of the North is quite difficult.

The powerful potential of wind energy possesses practically all Arctic regions, however the strategy of development of wind energy in many respects depends on concentration of population, objects of economy, transport infrastructure, etc.

An important detail related to the stated topic is the climate change predicted by many authors in the Arctic and, in this regard, the search for solutions to the possible problems of wind energy development. These include the melting of permafrost and ice, as well as the reduction of the population in the Arctic regions. The views of foreign experts are based on the negative effects of warming on the economy and ecology, while the majority of Russian authors believe that the change
in the Arctic climate will be advantageous for Russia. Which of these points of view will prove to be more justified in Russia with the available technical and socio-economic possibilities, as well as with the preservation of the natural environment, would show the future.

Wind speed of more than 11 m/s and its gusts up to 20 m/s and more are a serious test for the operation of wind power plants in the Arctic. Under these conditions, it is necessary to slow down the operation of the wind turbine, that carries with considerable technical difficulties (that confirm tests of foreign analogues). On the one hand, the overwhelming majority of facilities located in the Arctic are sparsely populated areas, whose needs for electricity are not large and can be fully provided by small wind turbines. On the other hand, the expanding prospects of Arctic development can put on the agenda the need to produce more powerful aggregates.

This task was successfully coped by scientists of the state research university in Chelyabinsk, which created an automatic control system for the operation of wind turbines in difficult climatic conditions. It consists of mechanical and electrical blocks, programmable microcontroller, as well as a set of sensors to monitor the current state of the main components of the wind turbine. The authors of the proposed system of management assert that the wind installation itself can be operated in any hurricane, and without the control system will fail. At the same time, the entire cost of electromechanical system will be only 2-3% of the cost of the wind plant, and its service life is 35 years [15].

3.2. The role of other geophysical conditions

There is strong evidence that kinetic energy resources in the North's open sea areas are markedly higher than on land. As a result, the generation of energy can exceed the production of energy on land in three or more times - from 2 to 6 w/m². The authors of the study, published in the journal “Proceedings of the National Academy of Sciences” (USA), argue that a Greenland-and-a-half park of wind stations installed in the ocean could fully meet the needs of mankind in electricity [16]. The hypothetical essence of this idea is due to the fact that the influence of the giant wind park on the Atlantic climate remains unclear. But, although their calculations (based on the model "The Community Earth System Model"), have a purely theoretical character, the fact of active transmission over the ocean of kinetic energy from free air to the slow wind streams, which rotate wind turbines at an altitude of 30-120 m, long established and experimentally confirmed.

Naturally, in the conditions of the Far North of Russia, the question of the construction of marine wind parks is not yet on the agenda, as wind energy is necessary, first of all, dispersed villages.

The specific geophysical conditions of the North require many non-standard solutions in the development of wind power. Thus, permafrost presents serious difficulties in the construction of wind turbines. They are well known: it is a drawdown during thawing of frozen, ice-rich bases under the supports of installations, foundations of buildings, embankments of roads, coatings of airfields. Secondly; it is the buckling of piles, foundations, bases of power lines, etc. The main reason for possible destruction is the instability of the properties of the frozen layer. At the same time, Russian science and practice have accumulated a wealth of experience in maintaining the stability of the behavior of frozen soils.

Low temperatures require the use of cold-resistant steel grades for all constrictions (especially with welding); special lubrication for bearings capable of withstanding low temperatures and frost-resistant transmission oil in the gearbox, and special fluid for hydraulic systems of wind turbines. In order to prevent the failure of individual parts and assemblies, it is also required to heat the reducer with external sources, as well as heating the blades of wind turbines to eliminate ice phenomena and frost deposits; insulation of the controller and meteorological sensors to prevent the formation of frost and glaciation, etc.

It should be recognized that the world science and practice in the field of wind power development in the polar latitudes not only has accumulated vast experience, but also went far ahead, compared with Russia. But the first breakthrough achievements of domestic scientists have already appeared. Thus, one of the challenges of geophysical nature in the construction of wind power plants in the Far
North lies in overcoming the difficulties in the process of creating a grounding in permafrost. This problem has to be faced not only in the North, but also in the regions with the spread of sandy and rocky soils. In all these cases, local soils with high resistivity "reject" traditional grounding metal electrodes, which are not able to provide normative spreading of electric current.

With respect to permafrost, sandy and stony soils, characterized by high resistivity (from 300 to 500 Ohm per m) Russian scientists proposed a method of electrolytic grounding (ZANDZ). Its advantages are that its installation: a) does not require special equipment and bulk soil; b) shallow depth (0.7m) eliminates the undesirable effect of "pushing" structures by permafrost; c) there is no accelerated corrosion of the electrodes; d) an innovative idea is used to fill the area freed from frozen soil with a special mixture of mineral salts, which, being diluted with natural water and turning into an electrolyte, seeps into the soil and increases its electrical conductivity; e) finally, the service life of such electrolytic grounding increases to 50 years [17].

3.3. Economic factors against geophysical

There are still a lot of skeptics in the world who doubt the development of wind power engineering not only in the Arctic, but also in other regions. They believe that wind energy is commercially uncompetitive ("green bubble"), has a high proportion of debt financing and develops only thanks to government support [18]. But the rapid dynamics of renewable energy, taking into account the growth of its competitiveness, refutes this point of view. To compare the cost of different sources of electricity, experts often use the LCOE (levelized cost of electricity) indicator, which takes into account all the costs of both investment and operational costs in the full life cycle of a power plant of the corresponding type. According to the company Lazard, which annually produces LCOE estimates for different types of fuel, for the wind this figure has decreased by 66% over the past 7 years, and by as much as 85% for the sun.

However, when calculating the economic efficiency of wind energy, it is important to consider who builds - by the energy company or a legal entity (an enterprise or an individual) independent of it, and which legal entity it belongs to. When the construction is carried out by the power company, the wind power plant operates in parallel with traditional sources, and the total electrical energy (the cost of which is determined mainly by the cost of combustible fuel in thermal power plants) in an impersonal form goes to consumers. Since wind turbines for large power systems often perform energy-saving functions, their economic efficiency will be largely determined by the fuel economy in power plants of the traditional type.

When a wind power plant belongs to an enterprise independent of the power system, it pays for electricity at its cost, and sells excess energy on market terms, independently solving the pricing problem. All this significantly complicates the calculation of economic efficiency. It should be noted that we are talking about the economic efficiency of the use of wind energy within the existing power systems, where it is necessary to seriously analyze their mode of operation in order to identify hourly fuel savings. This task is complicated by the uncertainty of wind conditions that determine the actual energy potential of wind aggregates.

In the conditions of the prolonged transitive period in the development of the Russian market and the dispersed settlement of the inhabitants of the circumpolar state, the low competitiveness of wind energy remains a real state problem. But in the current conditions, this sector of the economy is considered by the expert community within the framework of social and environmental categories rather than economic ones. For numerous isolated small settlements in the North and the Far East, meeting the vital needs of the population is at the forefront. The installation of small-scale wind turbines and hybrid systems (sometimes with diesel generators and batteries) is becoming a social imperative.

The specific natural conditions of many regions of the Far North and the Far East significantly increase the cost of construction of wind power plants, increasing the cost of electricity produced. However, this does not mean that the development of wind power in energy-isolated regions has no prospects at all because of the difficulty of achieving competitiveness in the world market. It is
necessary to look for (create) conditions in which state subsidies and the market will not be a determining factor in the construction of wind power plants. Ultimately, government subsidies are possible if we are talking about important projects with too slow capital turnover, or about the interests of state security.

The introduction of wind energy can also be facilitated by the fact that within the northern territories the prices for electricity and heat generated at power plants and boiler houses based on coal, diesel fuel or fuel oil are significantly higher than in the regions of central Russia.

According to the experience of experts of the International Energy Association (IEA), the harsh natural conditions of the Russian Arctic provide an opportunity to apply special adaptive measures that not only reduce the time of possible construction of wind turbines, but also allow to rationalize their functioning, to carry out preventive work. Thus, the presence of daylight and prolonged sunshine provides an opportunity to work in several shifts in order to drastically reduce the construction time of the wind park - up to 3 summer months. This is favored by the least windy weather in the Arctic during the night hours, while in winter not only the light day is sharply shortened, but the strength of the wind also increases.

On the other hand, there are many specific problems with a pronounced "minus" sign, which prevent the development of wind power in regions with Arctic and Subarctic climate and allow using only a small part of their energy potential. Almost the key problem is the low population density of the territories (the average population density is less than 0.1 people per 1 km2) and, accordingly, low energy consumption in absolute terms. In turn, the latter circumstance is due to the lack of consuming production facilities and the necessary infrastructure - paved roads, high-voltage power lines, etc.

There are difficulties not only with the use of helicopters, but even mobile cranes of high power, transport equipment, etc.

Thus, the priority of the localization of individual wind turbines and wind power parks is a matter of special importance. In the very first reports of the Head of the Program for the introduction of renewable energy IFK (International Finance Corporation, part of the World Bank Group) in Russia P. Willems it was almost only about the developed and relatively densely populated regions [19]. Today, the rhetoric of the reports has changed, and the leadership is already recognized for the isolated energy territories (first of all, the Far East).

4. Conclusions
The above allows you to perform the following main generalizations:
- although average annual wind speeds in Asian Russia are weaker than in the European part of Russia, near the coasts of the northern and especially the Far Eastern seas, the horizontal gradients of the average wind speed increase sharply (up to 9 m / s or more), which is an important prerequisite for the development of wind energy;
- the maximum wind speed in almost all regions of the Far North, with a rich potential of wind energy, falls on the autumn-winter period, when there is the greatest need for electricity and heat;
- the development of wind energy in the Russian North is not yet economically efficient; therefore, the goal of existing plans in this area is not to make a profit, but to fulfill socially necessary functions, including social, environmental, defense, etc;
- the development of wind energy in the Far North of Russia should be viewed in the context of ambitious plans for the resource development of the territory and the commissioning of the Northern Sea Route (in a book published in 2014 by an American expert (employee of the Institute of European, Russian and Eurasian Studies of the Eliot University J. Washington) Laruelle M. “Russia's Arctic Strategies and the Future of the Far North [7] focuses specifically on the link between Russia's economic strategy in the Arctic and energy development).

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