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ASSESSMENT OF WIND ENERGY POTENTIAL IN THE CHECHEN REPUBLIC

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Abstract

The authors sought to examine the wind conditions in the Chechen Republic to assess the wind resource available in the territory. Most of the territory turns out to be an area with an average level of wind energy. However, the wind conditions here feature an uneven wind distribution across the territory and wind strength varying in different periods throughout the year. The wind potential of the territory is influenced by a set of physical and geographical conditions, the most important of which are geographical position, terrain, planetary circulation of the atmosphere, etc. The strongest winds commonly blow over open terrains and wherever orographic factors increase pressure gradients and lead to convergence of air flows, with annually averaged wind speeds to reach 5–6 m/s or over. Gross, technical and economic potentials were assessed in line with wind parameters distributed for the heights of modern wind turbines with a capacity of 750–1000 kW. The use of wind energy is promising in certain regions of the republic, where the wind speed is quite high (more than 5–6 m/s at an altitude of 10 m and higher above ground level) and in these areas wind energy can be most effectively used.

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Keywords: Air flows, circulation of the atmosphere, orographic factors, pressure gradients, wind energy, wind speeds

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1. Introduction

According to experts, the technical potential of wind energy in Russia is estimated to be over 6,000 billion kWh/year and the economic potential is approximately 31 billion kWh/year. Russia is one of the richest countries in this respect. The longest coastline on Earth, an abundance of flat, treeless spaces, large water areas of inland rivers, lakes and seas – all these are the most favorable places for wind farms.

Wind energy is proceeding apace in Russia, with new capacities to be commissioned exceeding 500 MW. On average, in recent years, the growth rate has made up 100% per year, being one of the highest rates in the world (Dokuchayeva et al., 2024; Tang & Yang, 2024). According to research by the Russian Association of the Wind Industry (RAWI) in Russia, the share of the wind energy sector in the total capacity has increased up to 0.08% (European Commission, 2020). To date, over 15 large wind farms have been built in Russia, accounting for about 95% of the total capacity. In addition to the large projects listed above, about 1,600 small wind turbines with a capacity of 0.1 to 30 kW are also installed in Russia (Kerimov & Debiev, 2019).

On the territory of Russia, the wind speed almost the entire coast long, as well as in the Far East and in the Krasnodar Territory, is 6 m/s and more, which corresponds to approximately 3–5 thousand hours of using the nameplate capacity of the wind turbine per year. It is also necessary to have in mind climate change that will inevitably entail modifications in wind energy potential (Lipich & Balahura, 2024; Regnerová et al., 2024; Shumilina & Antsiferova, 2024). Thus, according to “Materials for a Strategic Forecast of Climate Change in the Russian Federation for the Period up to 2030 and their Impact on Economic Sectors” prepared by Roshydromet by 2030 in the North Caucasus, including the Chechen Republic, wind loads will rise by 1.2 times. Given that by 2020 the cost of solar and wind generation became less than fossil energy generation, the growth of wind energy received an additional impetus (Makarov et al., 2019).

2. Problem Statement

The territory of the Chechen Republic is a part of the country with an average level of wind energy. Wind conditions are characterized by an uneven wind distribution across the territory and wind strength varying in different periods throughout the year. The wind potential of the Chechen Republic is influenced by a set of physical and geographical conditions, with the most important to be geographical position, terrain, planetary circulation of the atmosphere, etc. (Kerimov et al., 2010).

As long as anticyclones move from the north or west near the northern slopes of the Greater Caucasus, which retard the movement of air masses, separate centers of high pressure are formed. These orographic anticyclones can occur at any time throughout the year, but their effect is most noticeable in winter. In summer, they cause partly sunny, dry weather, in winter – precipitation for 1–2 days (Ahmad et al., 2024; Singh et al., 2024; Waite, 2024). As long as anticyclones move from the northeast, independent high-pressure cores are not formed over the North Caucasus, since in the southwestern periphery of the anticyclone, southeastern air masses blow along the mountains, which prevents the air from accumulating near the northern slopes of mountain ranges. In summer, these streams bring dry hot air from Central Asia.

3. Research Questions

A regional feature of wind activity is a secondary cyclogenesis over the Eastern Ciscaucasia. Secondary cyclones form here due to a disturbing impact of the Greater Caucasus on mid-tropospheric air currents, mainly during the cold season, governing cloudy weather with drizzles and low cloud cover that often turns into fog.

When the southern cyclones move in the territory of the Eastern Ciscaucasia, mainly during the cold season, southern winds blow, often strong and foehn. The Greater Caucasus systems located in the south impede the penetration of warm air from the south, although, cold air masses freely travel from the north and, meeting the mountains, stay here for a long time. The most common type of local winds are mountain-valley winds, caused by temperature contrasts in some parts of valleys or hollows and slopes. Mountain-valley winds are characterized by a daily change in direction. In summer, the mountain-valley circulation is most pronounced and reaches its maximum.

4. Purpose of the Study

A wide variety of landforms also affects the frequency of calmness distribution. In closed basins and under mountain slopes, the frequency of calm is highest – 44-58%; in foothill and mountainous areas – up to 30%. The average annual wind speed varies within a fairly wide range – from 0.8 to 6.0 m/s. The annual cycle of wind speed depends on the annual cycle of atmospheric circulation. However, as in the distribution of wind directions, orography greatly contributes to wind speeds. The strongest winds blow in high mountain areas in open landforms and wherever orographic factors increase pressure gradients, leading to convergence of air flows.

5. Research Methods

The average annual wind speed in these regions reaches 5–6 m/s, it is slightly lower and amounts to 3-4 m/s on open plains and in wide valleys, in the foothills – up to 3 m/s, in closed basins and in low-lying southern regions it does not exceed 1–2 m/s (Kerimov et al., 2010). In the annual cycle, the highest wind speed is most commonly recorded in spring or winter when cyclonic activity is more intensive, the lowest – in summer and autumn. As shown by observations, a wind speed of 1–5 m/s (70–90%) is most frequent in most areas. Wind speeds over 10 m/s are rare with frequencies not exceeding 10%. In some landforms at high altitudes and in bottleneck valleys, the number of days with strong winds blowing reaches 20-30 or more per month.

All things considered, westers and easters, and to a greater extent – westers, dominate in the Tersko-Kumskaya plain, the Tersko-Sunzhenskaya Upland, the Chechen plain, in the eastern mountainous part of the republic. The prevalence of westerly winds over easterly is typical of the summer months.

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6. Findings

Weather data on average wind speeds commonly correspond to the particular landscape and relief conditions nearby a weather station and should be determined at a particular altitude above ground. Therefore, calculations were performed to bring the data on long-term wind speed to comparable conditions for open and flat terrain (Bezrukikh, 2008).

6.1. Terrain openness class

Average wind speeds ($\overline{\upsilon}$) correspond to particular relief and landscape conditions nearby a weather station and to a certain altitude above ground (vane height). It is customary to lead $\overline{\upsilon}$ to comparable conditions for open and flat terrain. For these purposes, the classification used by the Russian meteorological service was used to describe the characteristics of the terrain in the areas of weather stations. The relationship between corrected average speed ($\overline{\upsilon}$ c) and measured average speed ($\overline{\upsilon}$ m) at the vane height is determined as follows:

$$\overline{\upsilon}_c = \frac{K_o}{K_{act}} \overline{\upsilon}_m, \tag{1}$$

where K_o is the openness coefficient according to Milewski's typology; Kact is the actual openness coefficient at the vane height.

6.2. Ratio of average wind speed to heights

Instruments for measuring wind speed are normally located at meteorological stations at heights of 7–10 m. The axes of modern wind turbines are located at heights of up to 100 m. With a steady wind streamline, the higher above the Earth's surface the greater the wind speed. In this regard, it becomes necessary to establish a vertical profile of wind speeds (Jaip, 2003). In general, the wind speed at the height of the wind wheel axis h_{WT} is estimated through the wind speed at the height of a weather vane h_V as follows:

$$\overline{\upsilon}_{WT} = \left(\frac{h_{WT}}{h_V} \right)^m \overline{\upsilon}_V \tag{2}$$

The parameter depends on both the season and the average speed. Subsequent calculations relied on the average statistical relationship between the parameter m and the wind speed $\overline{\upsilon}$, based on long-term weather observations.

6.3. Relationship between time of day and average wind speed

The relationship between speed changes during the day was averaged throughout the course of a certain month according to long-term observations. This relationship is often called daily averaged variation of wind speed. This characteristic is important for assessing the wind energy potential of the

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area, as well as for its effective use by aligning the schedule of wind energy supply with the schedule of energy loads.

In general, monthly averaged rates are highest in the cold season and coincide with the seasonal peak of electricity consumption. Based on the data, wind speeds most drastically change in the summer, while the speed in the daytime is 1–2 m/s higher than at night.

6.4. Wind speed distribution

With a steady wind flow, the higher above the Earth's surface the greater the wind speed. Modern wind turbines (W_T) use wind streamlines at heights of up to 100 meters. The efficiency of using wind streamlines should be assessed with duly respect to wind speed changes along the vertical axis.

The distribution of a random variable includes the distribution of the wind speed F_i, which is defined as a likelihood of the wind speed to fall in the *i*-th or higher interval of speeds.

Wind speeds are estimated by the two-parameter Weibull distribution, most applicable in such calculations, which is described by the following formulas (Kim & Yum, 2008):

$$F(\upsilon) = e^{-\left(\frac{\upsilon}{c}\right)^k}; \tag{3}$$

$$f(\upsilon) = \frac{k}{c} \cdot \left(\frac{\upsilon}{c}\right)^{k-1} \cdot e^{-\left(\frac{\upsilon}{c}\right)^k}, \tag{4}$$

where c is the scale parameter of the distribution on the velocity axis (m/s); k is the slope distribution parameter.

6.5. Maximum wind speed

This is the principal characteristic affecting the stability of a wind turbine (Sayigh, 2012). Weather stations record $\upsilon_{\max}$ possible once in a given number of years, for example 1-5-10-20 years. The value $\upsilon_{\max}$ depends on the height the wind speed is measured, naturally varying at the height of the weather vane and at the height of the wind turbine hub.

Wind velocity was determined as follows:

$$q = S \cdot p \cdot \upsilon_{\max}^2 \tag{5}$$

where p is the wind power density.

Nominal air density p_0 = 1.226 kg/m^3 at a temperature T = 15 °C (288 °K) and a pressure B=760 mm Hg, i.e. at sea level. Given these values, the pressure is calculated using the following formula:

$$P = p_0 \frac{288B}{760T} \tag{6}$$

With no turbulence, the volume of air passing per unit time through a cross-section with an area S has kinetic energy. Hence, the power (as energy per unit of time) is defined as follows:

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$$P_0 = \frac{M\upsilon^2}{2} \tag{7}$$

where M is the mass of air in the volume of a cylinder with a base area S and a length equal to the velocity υ.

Including the air density p, the instantaneous power is equal to:

$$P_0 = \frac{Sp\upsilon^3}{2} \tag{8}$$

6.6. Average power density

The average power density ($\overline{P}_{pd}$) for a period of time (1 year), with the distribution of speed over intervals for this period, based on the formula (6), is found from the following expression:

$$\overline{P}_{pd} = \frac{1}{2}\rho\sum_{i=1}^{n}\upsilon_i^3 t_i \text{ (kW/m}^2\text{)} \tag{9}$$

6.7. Gross (theoretical) potential

This is a part of the average long-term total wind energy in the region, which is available for use in the region for one year. To determine W_G, the entire target area was divided into climatic zones within which geographic, natural and climatic conditions are homogeneous.

Specific gross potential W_{SG} (kWh/year) of wind energy in the zone was defined by the value of the average power density $\overline{P}_{pd}$ of the wind stream:

$$\overline{W}_{pd} = \overline{P}_{pd}\frac{T}{20} \tag{10}$$

where T=8,760 h/year.

The gross potential of the zone is defined as:

$$W_G = W_G \cdot S \tag{11}$$

where S is the area of the zone (m^2).

For the target area, the total gross potential made up 1,406.0 billion kWh/year

6.8. Technical potential

Assessments of wind energy technical potential in the region is the overall electrical energy that can be derived in the region given a current level of technology development and environmental compliance. The technical potential depends on the parameters of a wind turbine, the average annual wind speed at the height of a gondola, the area of a zone and can be determined for average conditions using the following formula:

$$W_T = W_B \cdot C_P \cdot \eta_g \cdot \eta_r \cdot \frac{S_T}{S} \tag{12}$$

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where C_P is the coefficient of wind power utilization, which depends on the wind speed according to the Joukowsky-Betz limit from a minimum value of 0.05 to a maximum value of 0.593. The reached maximum value is 0.40-0.45. In most cases, it is taken equal to 0.2.

η_g is the WT generator efficiency.

η_r is the WT gearbox efficiency.

S_T is the area of a zone or region where, subject to technical and environmental restrictions, it is possible to locate a wind turbine. It can vary from 10 to 30% of the entire area of the zone (region). In this case, it is taken equal to 15%.

For regional studies, the ratio between the technical and gross wind energy potential of the region is taken as 2% of the gross wind energy potential used in the region:

$$W_T=0.02W_G \tag{13}$$

Consequently, the technical potential for using wind energy is W_T≈29.0 billion kWh/year.

6.9. Economic potential

This is the amount of annual economic value-added electric energy in the region extracted from the use of wind turbines. Based on national and foreign data, it is believed that the economic potential of the use of wind energy is on average 0.5% of the technical potential of the region and, accordingly, for the territory of the Chechen Republic it amounted to ≈0.15 billion kWh/year.

7. Conclusion

Since the early 21st century, wind power has been developing at a high rate, sometimes even more rapidly than conventional capacities are commissioned in many regions of Russia. With the amendments to the federal law "On the Electric Power Industry" pertaining to the support of renewable energy, there appeared to be some more incentives for the construction of power plants based on renewable energy sources, resulting in the reduced risks in the field of energy security associated with cross-border challenges and threats. The endeavors to improve the regulatory framework in Russia generally have ceased to hinder the integration of technologies for the use of renewable energy sources, including wind.

Based on the calculations of the parameters of wind energy, the following conclusions can be drawn:

i. Despite being a part of the country with an average level of wind energy, the territory of the Chechen Republic has a significant wind energy resource that can be utilized.
ii. The use of wind energy is promising in certain regions of the republic, where the wind speed is high enough (more than 5–6 m/s at a height of 10 m and higher above ground level) and in these areas it is possible to effectively use wind turbines to generate electricity.
iii. Due to specific locations of Russian Hydrometcenter weather stations, there is not enough information to be used in wind energy and it is not detailed, therefore, the calculations performed indicate just a general situation. To clarify and determine some characteristic features of the wind conditions, additional research is needed.

It seems more promising to locate wind turbines on the Terek and Sunzha ridges, practically crossing the entire central part of the territory in the sub-latitudinal direction. The hypsometric marks of the ridges vary from +700 m in the west of the territory and gradually decrease to +300 m in the east. The watershed part of the ridges is treeless, free of buildings. The territory is mainly used for sheep breeding and has a developed transport network.

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