Assessment of the wind energy potential of the territory of southern Russia

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Abstract. The research was carried out in order to identify promising territories for the creation and operation of economically justified and environmentally friendly wind power plants in the south of Russia. The annual duration of winds with operating speeds in most of the studied area is 50-60 % of all winds, and only at the southernmost end of the territory the duration of winds with operating speeds decreases to 20-40 %. The predominant wind directions (52 %) in the Stavropol Territory are east and west. In the Rostov region, these directions dominate for 51% of the time of the year, in the Krasnodar region, 56 %. The prevailing wind direction in Kalmykia and the Astrakhan region is less pronounced. Here the east and west directions make up 30 %, southeast and northwest – 35 %. In the Volgograd region, all paired wind directions are equally probable and amount to 20-28 % in time. In almost 75-80 % of the territory, the specific power of the wind flow is 125-500 W / m².

1. Introduction
Modern production and use of traditional energy resources, the functioning and development of the fuel and energy complex in the world have a negative impact on the reproduction of natural resources and on the environment [1]. Therefore, the search for savings in energy consumption and alternative resource-saving options for solving modern energy problems is very important [2-4]. The most promising direction of using the energy resource potential of economic complexes is wind energy. The energy potential of wind energy is quite high [5-7].

For Russia, the most interesting ones are autonomous wind power plants (WPP) [8, 9]. But now the widespread use of autonomous wind turbines is constrained by technical difficulties and other limiting factors. The mass distribution of wind turbines is possible as the cost of scientific and technical solutions becomes cheaper, their efficiency and reliability increase. If it is possible to significantly reduce the cost of generating electricity from wind turbines, then this type of energy will have a great future [10].

2. Materials and methods
Wind speed is the main factor that determines the amount of energy generated by wind turbines [11, 12]. Wind turbines generate electrical energy when the wind speed exceeds a certain threshold. Therefore, for the design of wind turbines, it is necessary to assess the wind energy potential of the territory. The aim of the research is to identify promising territories (in terms of wind energy use) for the creation and operation of environmentally friendly and economically viable wind power
complexes in southern Russia. The tasks of the research included: taking into account the duration of
winds with operating speeds of different directions in spatial and temporal dynamics on the territory of
southern Russia; regionalization of the territory according to the specific power of the wind flow in
winter (<75, 75-125, 125-250, 250-500, 500-1000 and 1000-1500 W / m²).

The materials for research were data from ground-based observations, meteorological stations and
literature sources [13-15].

To calculate the specific energy of the wind flow, the following expression was used:

\[ N_e = \frac{1}{2} \rho \int_{u_{max}}^{u} f(u) du, \]

where \( f(u) \) is the differential frequency of the wind speed by gradation; \( \rho \) – air density, kg / m³; \( u \) – wind speed by gradation, m / s.

3. Results and Discussion

The most promising ones in terms of wind energy in winter are the coastal regions of the northern
seas. Here the specific wind power reaches 1000-1500 W / m² (9% of the area). High wind energy
is noted on the coast and in the areas of the Black and Azov Seas, in the foothills of the North Caucasus,
where the specific wind power reaches 500-1000 W / m² (12% of the territory) (Figure 1).

\[ 1 - <75, 2 - 75-125, 3 - 125-250, 4 - 250-500, 5 - 500-1000, 6 - 1000-1500 \text{ W/m}^2 \]

**Figure 1.** Zoning of the territory according to the specific power (Ne) of the wind flow in winter.

On almost 75-80 % of the territory of the south of Russia, the specific power of the wind flow is
125-500 W / m². Here, three characteristic directions of changes in the specific wind power were
revealed: the Millerovo - Morozovsk - Gniloaksaysk line, the Novorossiysk - Armavir - Achikulak
line, and the Novorossiysk - Krasnodar - Krasnogvardeyskaya - Elista line. In the first direction, the
wind power (by the cube of the weighted average wind speed) varies in the range of 291-217 W/m², in the second – 465-217 W/m², in the third – 465-597 W/m².

An important indicator of wind activity is the duration of the period of action of winds with operating speeds for wind turbines. The annual duration of winds with operating speeds in most of the studied area is 50-60 % of all (starting from 4 m/s) winds, and only at the southernmost tip of the territory the duration of winds with operating speeds decreases to 20-40 %, Figure 2.

![Figure 2. The frequency of occurrence of winds with operating speeds (%) in the south of Russia.](image)

Spatial differentiation of the frequency of winds with operating speeds is explained by the nature of the formation of anticyclones and cyclones. Most often, stable anticyclones are formed with a center in the south of the Urals, and cyclones are formed with a center over the Black Sea. At the periphery of these formations, increased wind speeds occur. Large relief elements also play a significant role in differentiating wind frequency. Air masses meet obstacles on their way, concentrate and change direction. In the area of concentration of air currents, wind speeds increase.

The dynamic influence of the Caucasus ridges and local obstacles on the air transport character is observed near the city of Kislovodsk. Subsequently, airflows change direction from east to southeast and penetrate into the Kuban depression (Armavir corridor). On the western outskirts of the Krasnodar Territory, wind speeds are determined by the transfer of air masses from the western directions. Due to the nature of the air currents, the highest wind speeds in the Krasnodar and Stavropol Territories are observed in the area of Anapa, Armavir, Nevinnomyssk, Izobilny. High wind speeds are in the area of
the cities of Tikhoretsk, Krasnodar, Ust-Labinsk, Stavropol, Aleksandrovskaya. Increased wind speeds are noted in the Millerovo and Morozovsk areas of the Rostov region.

It is of practical interest to take into account the duration of winds with operating speeds of different directions. Analysis of meteorological information showed that in the Stavropol Territory, the predominant (52 %) wind directions are east and west. Southeast and northwest directions make up 14 %, east - southeast and west - northwest – 25 %, west - southwest and east - northeast – 25 %. These wind directions add up to 46 %.

In the Rostov region, east and west winds in time occupy 51 %. Southeast and north-west wind directions make up 12 %, east - south - east and west - north - west wind directions make up 19 %, west - south - west and east - north - east winds make up 8 %. In total, they reach 39 %. The rest of the wind directions account for 10 %.

On the territory of Kalmykia, the winds of the eastern and western directions in time average are 35 %. The share of east - southeast and west - northwest winds accounts for 22 %. The share of west - south - west and east - north - east accounts for 5 %. In total, these winds are 27 %. Other areas account for 8 %.

In the Krasnodar Territory, east - west winds are 56 % in duration. Winds along the line west - south - west and east - northeast are 23 % in duration. On the line southwest - northeast the winds have a frequency of 7 %. On the line east - southeast and west - northwest, the winds have a frequency of 9 %. On the southeast - northwest line, the frequency of winds is 4 %. In total, the frequency of occurrence of winds in these directions is 43 %. Winds from other directions account for no more than 1 %.

In the Volgograd region, north - south winds have a frequency of 20 %, north - west - southeast, west - east and south - west - northeast, respectively, 27 %, 28 % and 25 %.

The values of the frequency of occurrence of winds (%) with operating speeds for individual administrative units from the 1st to the 4th quarter are presented in table 1.

**Table 1.** The values of the frequency of occurrence of winds (%) with operating speeds for individual administrative units

| Region           | quarters |           |           |           |
|------------------|----------|-----------|-----------|-----------|
|                  | I        | II        | III       | IV        |
| Volgograd region | 55-70    | 40-60     | 40-50     | 50-65     |
| Rostov region    | 50-70    | 45-60     | 45-50     | 55-65     |
| Astrakhan region | 60       | 55        | 45-50     | 50-55     |
| Republic of Kalmykia | 55-65 | 50-60     | 40-60     | 45-60     |
| Stavropol region | 30-50    | 35-50     | 30-40     | 20-50     |
| Krasnodar region | 45-80    | 40-70     | 30-70     | 35-75     |

The described wind speed regime and its specific power apply to open flat terrain. To take into account the influence of topographic conditions, it is necessary to correct the data by the coefficients given in table 2.

**Table 2.** The values of the coefficients taking into account the change in the speed (K₁) and the specific power of the wind (K₂) in connection with topographic conditions

| Topographic conditions | K₁ | K₂ |
|------------------------|----|----|
| open area              | 1.0| 1.0|
| closed area            | 0.8| 0.5|
| seaside                | 1.1| 1.3|
| open sea               | 1.2| 1.7|
| hills and mountains    | 1.5| 3.8|
Coefficients for open areas are taken as a unit. The closed area is characterized by low coefficients $K_1$ and $K_2$. Sea coast, open sea, hills and mountains are characterized by increased coefficients $K_1$ and $K_2$.

4. Conclusion
The territory of the south of Russia is promising for the development of wind energy. Here, on almost 75-80% of the area, the specific power of the wind flow is 125-500 W/m$^2$. This wind regime occurs here, 50-65% of the time in relation to all winds. On the territory under consideration, there are three characteristic directions of the regular change in the specific wind power. In the first direction (Millerovo - Morozovsk - Gniloakaysk), the wind power per cube of the weighted average wind speed varies within 291-217 W/m$^2$, in the second (Novorossiysk - Armavir - Achikulak) – 465-217 W/m$^2$, in the third (Novorossiysk - Krasnodar - Krasnogvardeyskaya - Elista) – 465-597 W/m$^2$.

The average annual frequency of winds with operating speeds in most of the south of Russia is 50-65%. The predominant wind directions (52%) in the Stavropol Territory are east and west. In the Rostov region, these directions dominate for 51% of the time of the year, in the Krasnodar region – 56%. The prevailing wind direction in Kalmykia and the Astrakhan region is less pronounced. Here the east and west directions make up 30%, southeast and northwest – 35%. In the Volgograd region, all paired wind directions are equally probable and amount to 20-28% in time.

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