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Wind energy potential in the southeastern part of Western Siberia

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Abstract. For the study of the wind regime, the data of meteorological monthly data were used for the period from 1966 to 2016 for 124 meteorological stations in the southeast of Western Siberia. The paper presents the basic characteristics of wind speed, estimates the wind energy potential, constructed a map-scheme of the distribution of the average velocities in the territory under consideration, and the regions are classified according to the accepted classification for wind energy purposes. Analysis of distribution shows that most of the territory refers to unpromising and unpromising areas. Only in the south–west of Novosibirsk and the west of the Altai Krai are areas that are promising for low–power wind turbines. Several stations are allocated (Blagoveschenka, Rodino, Rubcovsk), where small and high power wind turbines can be used. In the Republic of Altai, the Kara–Turek station is allocated, where it is also possible to use low and high power wind turbines. It should be noted that this distribution is caused by a noticeable decrease in average wind speeds over the period under review. The results of the assessment of wind energy potential have practical application in the design and use of energy supply systems using renewable resources. Wind energy resources can be used in the future planning of economic development of the given territory.

1. Introduction

During the development of industry in energy supply projects, energy sources were mainly based on various types of fossil fuels. Intensive use of minerals as fuel ultimately put on the agenda two problems – pollution of the environment to critical values and the threat of depletion of mineral resources. These global problems force us to look for alternative sources of energy. In this capacity, nuclear power engineering can be considered (but it meets increasing objections due to the huge danger and the problem of radioactive waste disposal) and the so called clean energy sources, which include installations using wind energy. Wind energy was used already in ancient times, but the low energy density, depending on weather conditions, the imperfection of its transformation into more convenient forms of energy, limited the widespread use of this natural source. The present development of science and technology has led to the emergence of new and improved facilities for the conversion of wind energy into other forms of energy, including the most convenient form – electrical energy.

These plants are called aerogenerators or wind-driven power plants (WDPP). They are used in a variety of places: individual residential construction, farms etc. Combined with other sources of energy, wind-driven power plants can bring significant savings. The effectiveness of the practical use of wind energy is largely dependent on how closely by project designs were considered regularities and specific data on wind speed in the place of proposed plant operation. It is important to have an understanding about the features of the distribution of the characteristics of the wind regime in time and territory to solve the problem of estimating the wind energy potential and its possible contribution to resource conservation.



It is necessary to take into account the fact that local conditions such as the presence of water bodies, features of terrain and underlying surface have a large influence on the wind regime.

2. Data and methods

The data of 124 meteorological stations from 1966 to 2016 were used to estimate the wind conditions and wind energy potential of wind south-east of West Siberia (Tomsk region, Novosibirsk region, Kemerovo region, Altai Krai, Altai Republic).

For calculation of statistical characteristics of average monthly values of speed of a wind the Statistica 6.0 program was used. For map development of distribution of average speed of a wind across the territory the Geostatistical Analyst module of the ArcGIS 10.2 program was used. It provides geostatistics tools for the analysis and mapping of continuously distributed data and creation of surfaces on their basis.

Energy (E) contained in a moving air flow is determined by the following relation [1,2]:

$$E = 0.000481 V^3 D^2 \xi \eta \quad (1)$$

V – is velocity of the wind, D – diameter of the wind turbine, ξ – the nominal rate of wind; η – thermal-electric conversion efficiency.

Numerous studies have shown that the practical efficiency of the turbine-generator system reaches about 30–40%.

The authors [3] have used a formula that takes into account the average wind speed V_c and its variation coefficient C_v to calculate the average specific capacity of the wind flow (wind power potential at $1 \text{ m}^2 - \text{Wm}^{-2}$) N_c :

$$N_c \approx 0.613 V_c^3 (1 + 3 C_v^2 - 0.9 C_v^3 + 2.9 C_v^4) \quad (2)$$

This formula defines the theoretical (potential) value of wind energy and is the upper limit of stocks of wind resources, since it ignores the conversion loss. Wind energy resources in practice and in theory are divided into two types: potential and technical. Potential wind energy resources are the total energy of the air masses moving over the considered territory. These resources occur in nature in huge quantities. However, in practice, only a part of the potential energy is used. This energy active (recyclable) part of the wind energy is called technical wind energy resources (depending on the specific technical devices and their efficiency).

Power generated by wind-driven power-plant depends on many factors [4]: wind velocity cube, air density and turbulence, diameter square of the rotor (air wheel rotation area) and efficiency of a turbine and generator, starting and rated wind speed (the aerogenerator starts to work and develops rated power), nominal capacity of wind-driven power-plants. The first two factors depend on the choice of the installation area of wind-driven power-plants, specific production of wind power is entirely dependent on windpower and duration of the energy active speeds in the area. Other factors are the functions of aerogenerators.

It is also necessary to take into account that the energy production of is achieved only at a wind speed which is in the allowable operating range for each wind-power unit. It often happens that the wind speed is too low and the wind generator cannot work, or reaches such a high value that it is necessary to take steps to deactivate it in order to prevent destruction.

The following formula can be used [5] to calculate the specific capacity of the average wind speed cube:

$$N_{aver} = 1.16 V_{aver}^3 \quad (3)$$

N_{aver} – is power calculated from the average wind speed;

V_{aver} – the average wind speed.

For more accurate calculations, according to the Guidance document [6], the following formula is used:

$$N_{grad} = \frac{0.613 V_{grad}^3 f(V_{grad})}{100} \quad (4)$$

N_{grad} – is theoretical specific capacity, calculated by gradations;

V_{grad} – wind speed (average limit of gradation);

$f(V_{\text{grad}})$ – wind speed differential frequency of the gradation, %.

3. Results

The calculation of the wind characteristics was performed on the basis of areas of the study area. Table 1, for example, presents the main statistical characteristics of the average annual wind speed at the stations of the Altai Territory. The analysis of the data shows that the average long-term wind speed at the stations in the Altai region varies in a wide range from a minimum 1.3 ms^{-1} (Charyshsky, Soloneshnoe) to the maximum 4.8 ms^{-1} (Rubcovsk). The variation coefficient C_v characterizing the temporal variability of the wind speed relative to the average varies from 0.19 (Volciha) to 0.52 (Soloneshnoe). The analysis of the data shows that the average long-term wind speed at the stations of the Kemerovo region varies from 0.8 ms^{-1} (Ust-Kabyrza) to 3.3 ms^{-1} (Jurga, Novokuznetsk), the Novosibirsk region: from 2.4 ms^{-1} (Moshkovo) to 4.3 ms^{-1} (Kupino, Zdvinsk), the Tomsk region: from 1.3 ms^{-1} (Vanzhil-Kynak) to 3.4 ms^{-1} (Podgornoe) and the stations of the Altai Republic: from 0.6 ms^{-1} (Ongudaj) to 5.1 ms^{-1} (Kara-Turek). Accordingly, the range of the variation coefficient in the Kemerovo region varies from 0.25 (Belovo) to 0.45 (Ust-Kabyrza), the Novosibirsk Region: from 0.20 (Bagan, Tatarsk) to 0.43 (Moshkovo), the Tomsk region: from 0.18 (Aleksandrovskoe) to 0.44 (Tomsk) and the Republic of Altai: from 0.20 (Kyzyl Ozek) to 0.62 (Ongudaj, Kosh Agach). This indicates a relatively stable mode of wind in time and territory at most stations. It is also necessary to consider the annual cycle in the study of the wind characteristic. Because of the annual variation of wind speed, wind resources can vary greatly throughout the year. Figure 1 shows the monthly average wind speed characteristics for the three stations Vanzhil-Kynak, Kolpashevo and Tomsk.

Table 1. Basic statistical characteristics of the average annual wind speed at the stations of the Altai Territory (1966 to 2016)

Station	$V_c (\text{ms}^{-1})$	C_v	σ	Station	$V_c (\text{ms}^{-1})$	C_v	σ
Kamen-na-Obi	3.7	0.35	1.28	Kulunda	3.0	0.37	1.10
Talmenka	1.8	0.45	0.81	Rodino	4.2	0.25	1.05
Zarinsk	2.2	0.31	0.69	Aleiskaya	3.0	0.39	1.16
Habary	3.2	0.37	1.16	Ust-Charyshskaya	3.4	0.49	1.66
Togul	3.0	0.27	0.81	Klyuchi	3.4	0.27	0.90
Shelaboliha	3.2	0.36	1.14	Shipunovo	2.7	0.33	0.91
Barnaul	2.6	0.33	0.87	Ust-Kalmanka	3.5	0.32	1.10
Baevo	3.7	0.28	1.03	Volciha	3.9	0.19	0.74
Rebriha	3.3	0.31	1.04	Pospelihha	2.9	0.34	1.01
Tselinnoe	3.8	0.27	1.04	Krasnoshchekova	3.2	0.41	1.34
Slavgorod	3.8	0.23	0.89	Soloneshnoe	1.3	0.52	0.68
Troitskoe	2.2	0.35	0.75	Rubcovsk	4.8	0.32	1.54
Blagoveschenka	4.5	0.26	1.14	Uglovskoe	3.2	0.25	0.79
Mamontovo	3.6	0.42	1.52	Charyshskoe	1.3	0.35	0.46
Bijsk-Zonalnaya	2.1	0.31	0.66	Zmeinogorsk	2.9	0.41	1.17
Bijsk	2.9	0.29	0.83	Gorniak	3.4	0.29	0.98

The minimum wind speed is observed in the summer and the maximum speed in the transitional seasons (spring, autumn). Other stations of the considered region, except for the stations located in the mountainous regions of the Altai Republic, have the same tendency. The seasonal variation at these stations is significantly different from the seasonal variation of plain territories, figure 1.

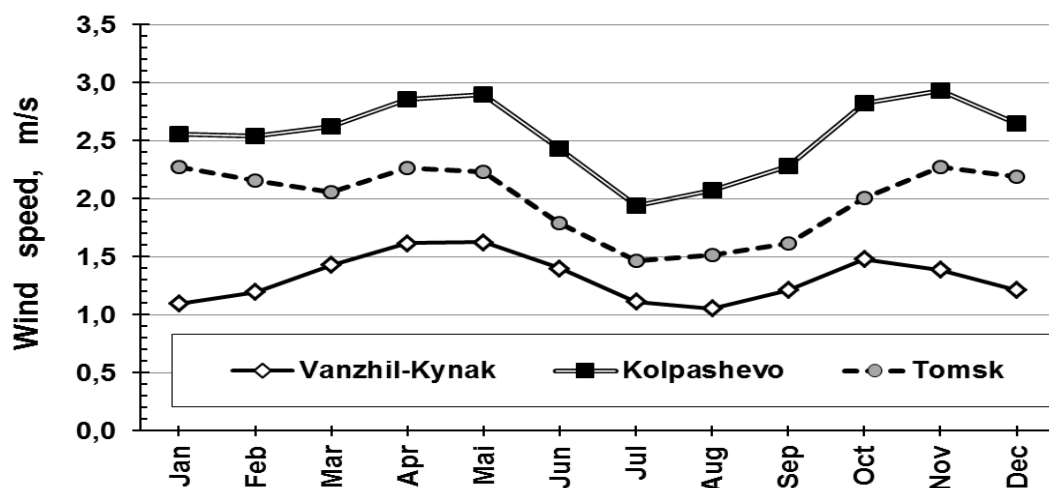


Figure 1. The annual variation of wind speed (Vanzhil–Kynak, Kolpashevo, Tomsk)

At the modern development level of wind power plants, their economically viable operation depending on the average annual speed (V_c) can be approximately estimated as follows [7]: there is a lack of prospects for any wind-driven power-plant at $V_c < 3 \text{ ms}^{-1}$, a low potential at $3 \leq V_c < 3.5 \text{ ms}^{-1}$, a potential for low-power wind-driven power-plants at $3.5 \leq V_c < 4 \text{ ms}^{-1}$, a potential for low and high power wind-driven power-plants at $4 \leq V_c < 5.5 \text{ ms}^{-1}$, and use potential for all wind-driven power-plants at $V_c \geq 5.5 \text{ ms}^{-1}$.

Figure 2 shows a schematic map of the wind speed distribution in the study area and the areas marked in accordance with the above classification for wind energy.

The distribution analysis shows that most of the territory belongs to the unpromising and hardly promising areas. Only the south-west part of the Novosibirsk region and the western part of the Altai Krai have promising areas for low-power wind-driven power-plants. There are several stations (Blagoveschenka, Rodino, Rubcovsk), where it is possible to use low and high power wind-driven power-plants, for example the station Kara–Turek in the Altai Republic. It should be noted that this distribution is caused by a significant decrease in average wind speed for the period. The schedules for all considered stations were drawn to study the dynamics of the average annual wind speed.

Figure 3 shows the dynamics of the average annual wind speed for some of the stations of the Novosibirsk region. The analysis of the wind speed change dynamics shows that there is a tendency to a wind speed decrease at almost all stations (except for a few stations in the Altai Republic). Other authors also noted decrease in wind speed in Russia.

The reasons for the wind speed decrease are divided into several groups. The first group (the most important) include an increase in the closeness of meteorological stations as a result of tree growth and development of the surrounding area.

The second group is the change of the general atmosphere circulation regime (but this fact in some studies refuted, because the article [8] shows that there is no decrease of wind speed at any aerological stations during the study of the average annual wind speed on the isobaric surfaces 850, 500 and 359 hPa for stations located in the north of Russia. Another supposed reason for the wind speed reduction is a tendency to atmospheric pressure fall.

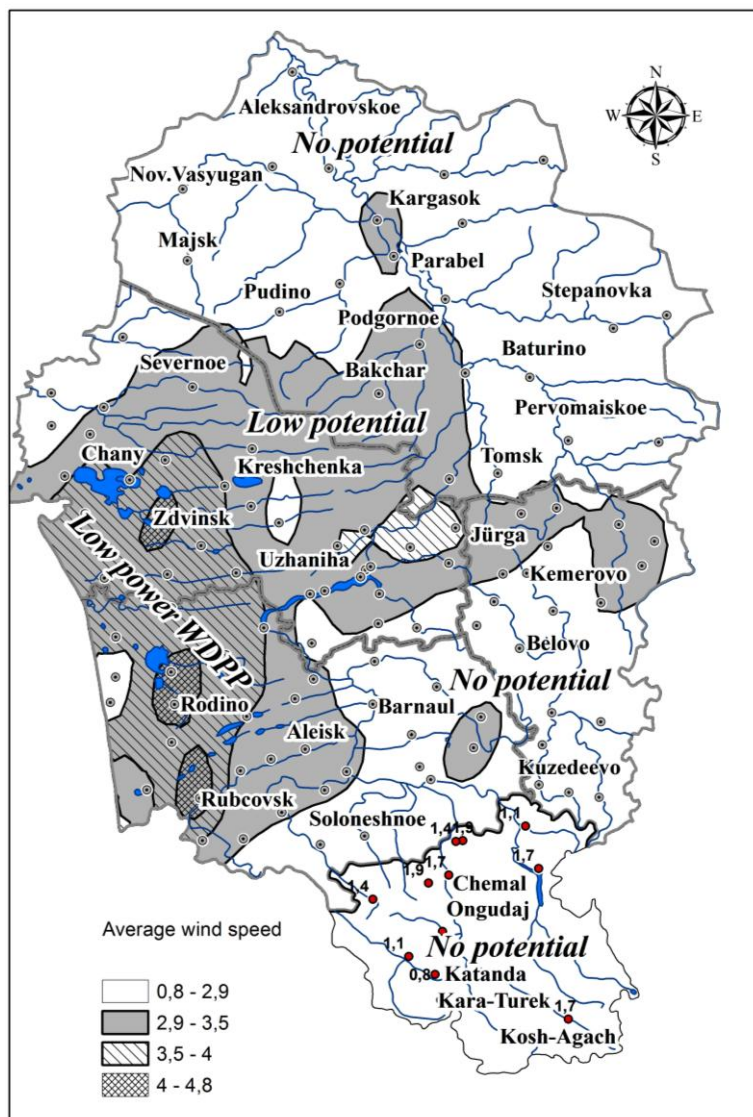


Figure 2. The distribution of the average annual wind speed and prospects of areas for wind energy

These tendencies are revealed in the article [9] for Western Siberia. The decrease in the average monthly wind speeds was noted by many authors in various parts of our planet [10-18].

The following formula was used (3) to evaluate the wind energy resources of the south-east of West Siberia for the entire reporting period.

The result of calculations according to the meteorological stations showed that the specific capacity varies within a wide range. For example, the average in the Tomsk region ranges from 3.9 Wm^{-2} (Vanzhil-Kynak) to 52.2 Wm^{-2} (Podgornoe). In this case, the maximum value of the specific capacity varies from 49.7 Wm^{-2} (Vanzhil-Kynak) to 398 Wm^{-2} (Parabel).

The specific capacity range in the Novosibirsk region is from 23.6 Wm^{-2} at the Toguchin station to 107.8 Wm^{-2} at the Zdvinsk station (maximum specific capacity in certain months were changing in the range from 136 Wm^{-2} (Kreshchenko station) to 817.8 Wm^{-2} (Chulym station)). The average specific capacity range in the Altai region was from at least 3.5 Wm^{-2} at the Charyshsky station, with a maximum 173 Wm^{-2} at the Rubcovsk station. Very high specific capacity values were observed in some months: 1858 Wm^{-2} (Krasnoshchekova station) to 2212 Wm^{-2} (Ust-Charyshskaya Pier station).

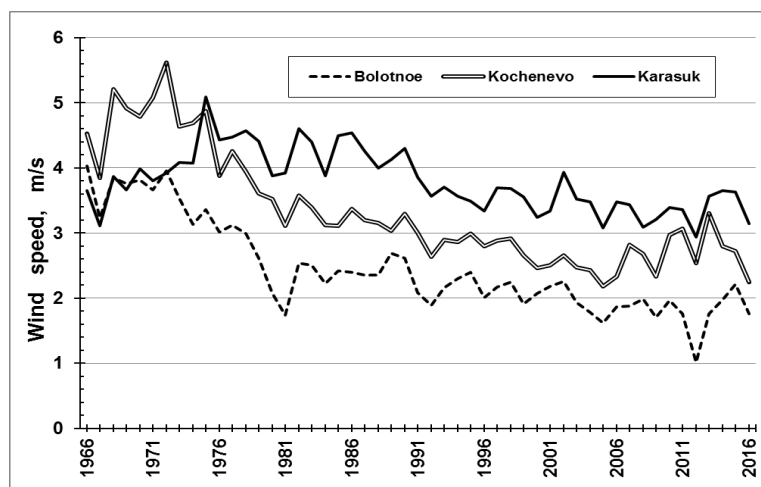


Figure 3. Annual average wind speed for the stations Bolotnoe, Kochenevo and Karasuk (Novosibirsk region).

In the Kemerovo region The minimum specific capacity 1.0 Wm^{-2} was observed at the Ust-Kabyrza station, the maximum 76.0 Wm^{-2} at the Jurga station. Specific capacity values observed in some months were changing from 687.5 Wm^{-2} (Novokuznetsk station) to 963.5 Wm^{-2} (Yaya station).

The minimum average specific capacity 0.7 Wm^{-2} in the Altai Republic is observed at the station Ongudaj. The maximum value average specific capacity 230.3 Wm^{-2} is observed at the Kara-Turek station. The maximum average specific capacity 2432.7 Wm^{-2} was registered at the same station.

The specific capacity was additionally calculated for the period from 2000 to 2016, considering the significant reduction in wind speed for the period. The formula was used (3) for calculation and the formula (4) which takes into account data on the frequency of wind speeds by gradations was used for comparison. The comparison of the data based on the formula (3) for the entire period (1966–2016) and from 2000 to 2016 shows that the average value of specific capacity for the entire period is much higher than the values for the last few years up to 3–5 times.

The comparison of calculation according to formulas (3) and (4) shows that the specific capacity, calculated according to formula (4) at all stations exceeds the value obtained by formula (3).

The difference in values for the Tomsk region can reach 65%, the Novosibirsk region 62%, the Kemerovo region 83%, the Altai Territory 78%, the Altai Republic 91%.

4. Conclusions

Thus, it is possible to draw the following preliminary conclusions according to the basic characteristics of the wind at the height of the vanes (10–14 m) for stations of the south-east of West Siberia:

- a significant part of the territory belongs to unpromising and hardly promising areas for the use of wind energy;
- a part of the territory, namely the south-west part of Novosibirsk region and the west part of Altai Krai are promising for low-power wind-driven power-plants;
- there are several stations (Blagoveschenka, Rodino, Rubcovsk, Kara-Turek), where it is possible to use low and high power wind-driven power-plants;
- given volatility (daily, seasonal, weather) wind energy can only be considered as an additional source of supply.

It is necessary to have the receivers of wind-driven power-plants at high altitudes for more efficient use of wind energy: 30–100 m and above, as the wind speed increases depending on the height under the logarithmic law.

The calculation shows that wind speed is greater than the average speed 1.7 times at a height of 30 m, and 2.4 times at a height of 100 m. The average annual air flow speed is over than 7 ms^{-1} at a height of 100 m.

When installing wind turbines at a height of 100 meters, using a suitable natural or artificial hill, then you can ensure efficient operation of wind-driven power capacity varies plants almost in any area and get significant additional supply of electric power. Furthermore, the use of wind-driven power-plants operating at low wind speeds can bring additional possibilities.

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