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To cite this article: V A Minin and A I Furtaev 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **302** 012067

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Wind potency in the western sector of the Russian Arctic and its possible uses

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Abstract. The assessment of the wind conditions in the western sector of the Russian Arctic is given. The average long-term wind speeds in the region were determined as a result of long-term wind speed observations on the meteorological stations. High wind potency areas were highlighted, which are the most promising for the use of wind power plants (WPP). Coastal areas established to have winter wind speed peak, which coincides with the heat and electricity peak demand during the cold season. This is a favorable prerequisite for the successful wind energy use for the needs of electricity and heating supply. The wind speed repeatability in the areas under consideration is studied, allowing the wind energy valuation. The possibility of flattening of actual of wind speeds distributions is shown by using the Weibull density function. Involving this, regional wind energy technical resources assessment was made, turned out to be almost two orders of magnitude higher than the current annual energy consumption of the Murmansk and Arkhangelsk regions. The most promising directions of the regional high potency wind resources possible practical use are shown. The prospects for the wind farms construction and their introduction into the Kola energy system are considered, where eleven hydroelectric power stations with a total capacity of about 1,000 megawatts operate in a high wind potency zone on the coast of the Barents Sea and where, due to this circumstance, the prospects for the systemic wind power development are most obvious. The possible economic benefit from the wind power plants participation in the local diesel power plants and boiler plants operation was also assessed. That very effect is substantial saving of expensive imported fossil fuels.

Introduction

The Russian Arctic occupies a large territory, where significant natural resources have been accumulated, and therefore increased attention is being given to the prospects for its development [1-3].

The western sector of Arctic, to which this work devoted, includes the Murmansk and Arkhangelsk regions, the Novaya Zemlya and Franz Josef Land archipelagos. The south-west of this territory is provided with centralized power supply from the Kola and Arkhangelsk power grids. There are a large number of relatively small isolated energy consumers in the eastern and northern parts of the area, which are supplied from independent power supply source. These consumers are weather stations, lighthouses, border outposts, fishing farms, special facilities. Wind potency assessment and identification of prospects for its use for electricity and heat supply for various consumers, aimed at



saving of expensive long-range fossil fuels, are of considerable interest. The use of wind energy will save significant amounts of imported fossil fuels having high transportation costs.

1. Wind conditions in the western sector of the Russian Arctic

An evaluation of the wind conditions is usually made in the development of the so-called wind cadaster [4-6]. The main cadastral characteristics are: average annual wind speed, variations in the mean wind speeds, probability function of the wind speed, specific power and of the air stream.

Wind speed observations at the hydrometeorological service basic network are usually used as initial data for the wind cadastre development. These several times a day observations span periods of decades. Average wind speeds data show a general characterization of the wind intensity in the territory in question. The elevation of the recording device is usually taken into account when average long-term wind speeds data compiled. To obtain comparable data at different meteorological stations the average wind speeds are brought to the same height, for example, 10 m above ground level. It is most frequently used for this levelling either power-law or logarithmic dependence.

The average long-term wind speeds data compilation at a height of 10 m in the areas allowed us to create a map of their distribution over the region. Such a compilation is presented in Figure 1, with regard to the western sector of the Arctic. It highlights the most favourable zones for the potential use of wind power plants. These are the White and Barents Seas coastal areas, where average annual speeds reach 6-8 m / s. The prerequisites for the wind power sector development here are most apparent.

Researches showed that with seasons changed, wind intensity varies. Seasonal variations in the mean wind speeds can be estimated by the variations in average monthly wind speeds during the year. It emerged that most pronounced nonuniformity of seasonal wind intensity is manifested in the Barents Sea coastal regions, especially where there ice-free sea and cold land are neighbours in winter time. There the average monthly wind speeds are of 4-5 m / s in the summer months and reach 9-12 m / s in winter. Thus, these areas have favourable conditions for the efficient use of wind energy. The cold season monthly wind speeds peak coincides with the seasonal consumption peak.

In addition to the mean wind intensity, an important characteristic of the air flow is the wind speed frequency. It shows how much of the time during the period under review the winds were blowing at various speeds. Frequency reveals the wind energy validation. Calculations to determine the wind speed frequency are rather time consuming task. It is associated with the processing necessity of long-term series of observations. The wind speed frequency data from work [7,8] are presented in the form of data sheets. However, to perform wind power calculations, it is desirable to have analytical dependencies describing the wind speed frequency.

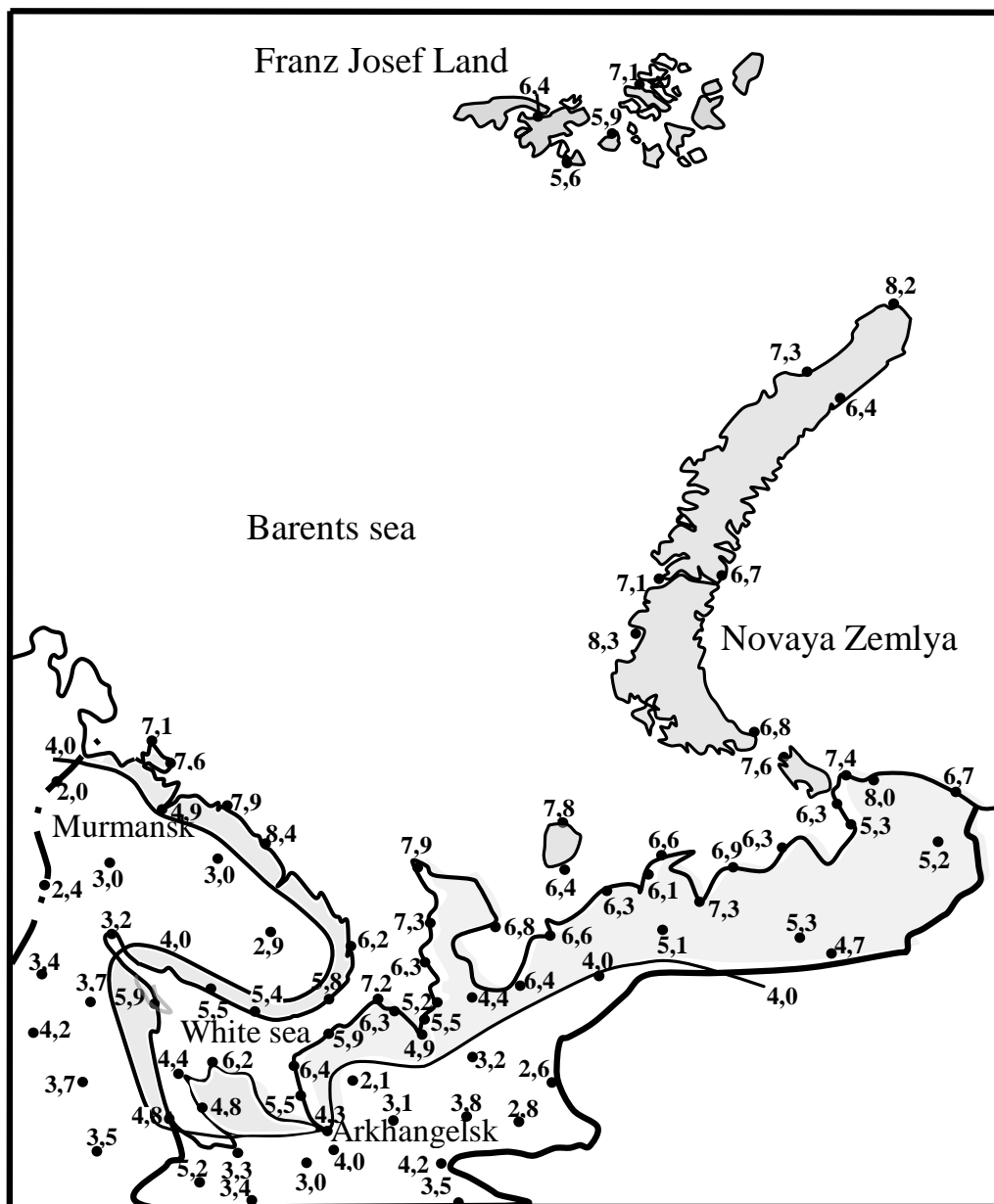


Figure 1. Average long-term wind speeds at meteorological stations of the western sector of Russian Arctic

Such data acquisition is conceivable after the flattening of empirical wind distributions using analytical dependencies such as the approximate two-parameter Weibull density function [9], which may be expressed as follows:

$$t(V) = \frac{\alpha\gamma}{\bar{V}} \left(\alpha \frac{V}{\bar{V}} \right)^{\gamma-1} \exp \left[- \left(\alpha \frac{V}{\bar{V}} \right)^{\gamma} \right] \quad (1)$$

where α and γ – the parameters of a distribution, V и \bar{V} – current и average annual wind speeds, m/s. Inquiries revealed that Weibull density function parameters are on average $\alpha = 0,90$ and $\gamma = 1,70$ for the offshore meteorological stations of the Barents and the White Seas, showing an increased wind potency.

2. Wind energy resources in the western sector of the Russian Arctic

Using the information discussed on the average long-term wind speeds (Fig. 1) and the data on the wind speed frequency, both calculated according to the expression (1), the technical resources of wind energy on a given area can be determined.

A traditional wind turbine with the horizontal axis of wind wheel rotation produces power:

$$N = 4,81 \cdot 10^{-4} \cdot D^2 V_r^3 \xi \cdot \eta_1 \eta_2 \quad (2)$$

where D – the wind wheel diameter, m, ξ – output coefficient,

V_r – the rated wind speed, which determines maximum electrical output of WPP, m/s,

η_1 and η_2 – gear and generation efficiency, respectively.

In the [3] it is shown that the WPP staggered location at a distance of 10 wind wheel diameters from each other the total installed capacity of wind turbines per 1 km² of the ground surface is as follows:

$$N_I = 4,81 \cdot V_r^3 \xi \eta_1 \eta_2 \quad (3)$$

Annual power output from 1 km² of the territory is

$$Q_I = T \int_{V_{minr}}^{V_{maxr}} N_I(V) t(V) dV \quad (4)$$

Where V_{maxr} and V_{minr} – cut-in- and cut-out- wind speeds, m/s.

For modern wind turbines $\xi=0,45$, $\eta_1=0,9$, $\eta_2=0,95$ can be taken in the high wind potency offshore areas under consideration. Then, with a ratio of the rated wind speed and the average annual wind speeds $V_r/\bar{V} = 1.6$ there can be achieved 3000 hours per year of using the wind turbines installed capacity [1, 10]. On account of this approach, tab. 1 presents the results of the calculation of the wind turbines energy capability from 1 km² of the territory. Calculations were made in zones, where average annual wind speeds are of 8–9, 7–8, 6–7, 5–6 and 4–5 m / s.

As follows from table 1, the technical wind resources of the western part of the Russian Arctic account for over 2,200 billion kWh per year. At the same time, the Kola and Arkhangelsk power grids existing in this territory currently produce about 23 billion kWh per year.

Table 1. Technical Resources of Wind Energy in the Western Sector of the Russian Arctic

Characteristics	Zones					Total
	1	2	3	4	5	
Average annual wind speed, m/s						
at a height of 10 m	8,5	7,5	6,5	5,5	4,5	
at a height of 70 m	10,7	9,6	8,6	7,5	6,5	
Rated wind speed at a height of 70 m, m/s	17,0	15,4	13,8	12,2	10,5	
Total WPP power per 1 km ² , MW	9,09	6,76	4,86	3,36	2,14	
Annual output per 1 km ² , × 10 ⁶ kWh	27,3	20,3	14,6	10,1	6,4	
Full load hours per year	3000	3000	3000	3000	3000	
Area, × 10 ³ km ²	0,5	24,5	37,9	78,4	62,7	204
Total WPP power per zone , × 10 ³ MW	5	167	185	259	129	745
Technical wind power resources, × 10 ⁹ kWh	15	501	555	777	387	2235

This means that the use of even a small fraction of the identified technical wind resources (1-2%), which are most attainable and profitable, is able to be of profound interest.

3. Possible uses of wind resources

Based on the results of the analysis performed, the following three uses can be seen. Firstly, the development of systemic wind power sector, which involves the construction of wind farms operating as part of existing power grids. When choosing sites for wind farms, it is necessary to take into account the wind potency, the access to the power grid, the state of art of the road transport network for the wind turbines delivery, and last but not least, the presence in the power grid of plants having the high level of start/stop characteristics that can compensate for wind farm power output failures during no-wind periods. It may be noted that these requirements are met primarily by the Murmansk region, where 17 hydroelectric power plants with a total capacity of about 1600 MW operate as part of the Kola power grid, and where the prospects for the systemic wind power sector development are most apparent.

Secondly, the development of autonomous wind power sector, defining the participation of wind power plants in the power supply of remote isolated consumers, such as meteorological station, lighthouse, border outpost and other objects. Wind turbines, operating in conjunction with existing diesel power plants, are able to provide part of the load and displace up to 30-50% of scarce diesel fuel [11].

Thirdly, the participation of wind turbines in providing the heating load of boiler rooms, i.e. wind energy using for heating consumers. A favourable prerequisite for the implementation of this use is that the seasonal wind intensity change and seasonal heat demand are synchronous in the considered areas. As a result, the wind turns from a shortcoming determining increased heat losses into an advantageous energy source, which allows saving up to 40-70% of imported distillate diesel fuel on local boilers [10].

4. Conclusion

The coastal areas of the White and Barents Seas and the Novaya Zemlya and Franz Josef Land archipelagos as well, have an increased wind energy potency. Average annual wind speeds at a height of 10 m reach 6-8 m / s and more. These areas have a synchronicity in the seasonal average wind intensity change and the electrical and thermal energy demand, which predetermines the wind energy use efficiency for the needs of electricity and heat supply. The technical wind resources in the western sector of the Russian Arctic are of 2,200 billion kWh. This is many times greater than the current level of electricity consumption in the Murmansk and Arkhangelsk regions (about 23 billion kWh in total). The use of the most attainable and profitable part of the identified wind resources can be of profound interest for the regional energy sector development in the future.

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