Prospects for energy supply in villages of Yakutia using wind energy resources and environmental limitations

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Abstract. The problems of energy supply in isolated villages of the Republic of Sakha (Yakutia) are considered. Mapping of the resource potential of wind energy in the Republic of Sakha was performed. Based on the performance modeling data of the Komai Haltec KWT300 wind turbine, the territory was zoned according to the level of wind potential. The analysis of the possibilities of energy substitution by the use of wind energy in the northern region of Yakutia in zones of decentralized energy supply was carried out. Using GIS tools, a multifactorial analysis of the territory based on the level of accessibility of power lines, transport routes and the presence of environmental restrictions, especially nesting and bird habitats (Important Bird Area in Republic of Sakha) was fulfilled.

1 Introduction

On the vast area of the Republic of Sakha (Yakutia) - more than 3.1 million square kilometres - there is a large zone of decentralized energy supply in the energy system of Yakutia, which contains about 40% of the region's territory mainly in the northern part of Republic. The South Yakutsk energy system operates as part of the United Energy System of the Russian East, while the Western and Central energy systems operate separately.
In the zone of decentralized energy supply, the main role in providing electricity to populated area is played by 126 diesel power plants (DPP) and gas turbine units with a total capacity of 199.5 MW, which annually consume up to 250 thousand tons of diesel fuel. Due to the high price of fuel delivery to a number of areas, the cost of electricity exceeds 200 rubls/kWh. The development of renewable energy resources has already begun in Yakutia. The high potential of solar energy resources in the central part of the Republic made it possible to construct in the period 2012-2018 20 solar power plants (SPPs) with a capacity of up to 60 kW, as well as the world's first largest SPP beyond the Arctic Circle (with a capacity of 1 MW) in the

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Batagai village. Using the mechanism of energy service contracts (ESC) in 2021-2022 6 automated hybrid energy complexes (AHEC) - solar power plants with diesel power plants - were built in Momskoye ulus (the villages of Kulun-Elbyut, Khonuu, Chumpu-Kytyl and Sasyr) and Verkhoyansk ulus with a total capacity of 6.3 MW. The annual diesel fuel saving of all commissioned solar power plants is more than 1.9 thousand tons per year. The AHEC in Honuu, territory of with is crossed by the Arctic Circle, includes the largest northern solar power plant in Russia with an installed capacity of 1.5 MW (according to Official website of PJSC RusHydro. https://rushydro.ru/activity/production/solnechnaya-generatsiya/) The development of wind energy resources has begun only near the large village of Tiksi, with a population of more than 5 thousand people, where a wind-diesel complex has been successfully operating since 2020 (WPP 900 kW - 2018 and DPP 3 thousand kW - 2020). According to the energy development Program of the Republic of Sakha (Yakutia), it is planned to increase the total capacity of energy facilities from 2031.38 MW in 2023 to 3512.30 MW by 2030, to build new gas-fired thermal power plants, low-power nuclear plants, hybrid wind power plants and solar power plants with back up diesel generators, to update the local power generation facilities (according to Investment program of SAKHAENERGO JSC 2023 – 2027. https://gipro.su/base/investicionnaya-programma-sakhaenergo-page-4/).

2 Object of study and methods

To assess the prospects for energy supply using wind energy resources in the Republic of Sakha (Yakutia) we did the calculations by the use of the characteristics of the wind speed regime at a height of 50 m over a 20-year period (2000–2020), from the NASA POWER open data base on a regular spatial grid with a step of 1°x1 (according to NASA POWER database https://power.larc.nasa.gov). The calculations of the Capacity Factor (CF) and of the values of specific generation potential (SGP) for the wind turbine (WT) Komai Haltec KWT300 kW for the entire region were made. The objective of this study is to analyze the wind resources of the Republic of Sakha (Yakutia) and the potential of wind energy to provide electricity to the settlements of the region, taking into account the consumer load in different seasons of the year. To calculate the distribution of wind turbine output by month throughout the year, we used the data for wind energy presented in the GIS RES of Russia (GIS “Renewable Energy Sources of Russia” https://gisre.ru/winddata/winddatabase/). To determine the required number of wind turbines, a comparison was made of the average annual energy consumption in each of the villages under study and the electricity production of one wind turbine. An important stage of the study was to conduct a multifactorial analysis using GIS methods, taking into account environmental restrictions on the use of wind turbines, such as the exclusion of key ornithological areas of habitats and nesting of migratory birds.

3 Results and discussion

The results of the calculations made it possible to prepare a map of the distribution of the Capacity Factor (CF) throughout the territory of Yakutia (Figure 1). The Central south-eastern part of the territory of the Republic is characterized by low values CF - less than 5% and high risks of using wind energy. Significant characteristics of the average annual CF for this wind turbine (>10%) are typical for territories north of 68° north latitude. in the western and eastern parts of Yakutia and north of 69° north latitude. (Ust-Yansky, Allaikhovsky, Nizhnekolymsky uluses, as well as the northeast of Oleneksky ulus), and reaching values of

more than 20% in the very north of the Republic (Anabarsky and Bulunsky uluses, and islands territories).

Figure 2 shows the distribution of the specific generation potential (SGP) values for the northern – the most prospective zone of the Republic for the development of wind energy, where the values SGP exceed 1.0 thousand kWh/kW per year. For 28 settlements of the decentralized energy supply zone of Yakutia with a population from 27 to 5055 inhabitants, based on the ratio of the projected average annual generation and average annual energy consumption, the number of Komai Haltec KWT300 wind power plants required to completely replace electricity production from diesel generators was calculated.

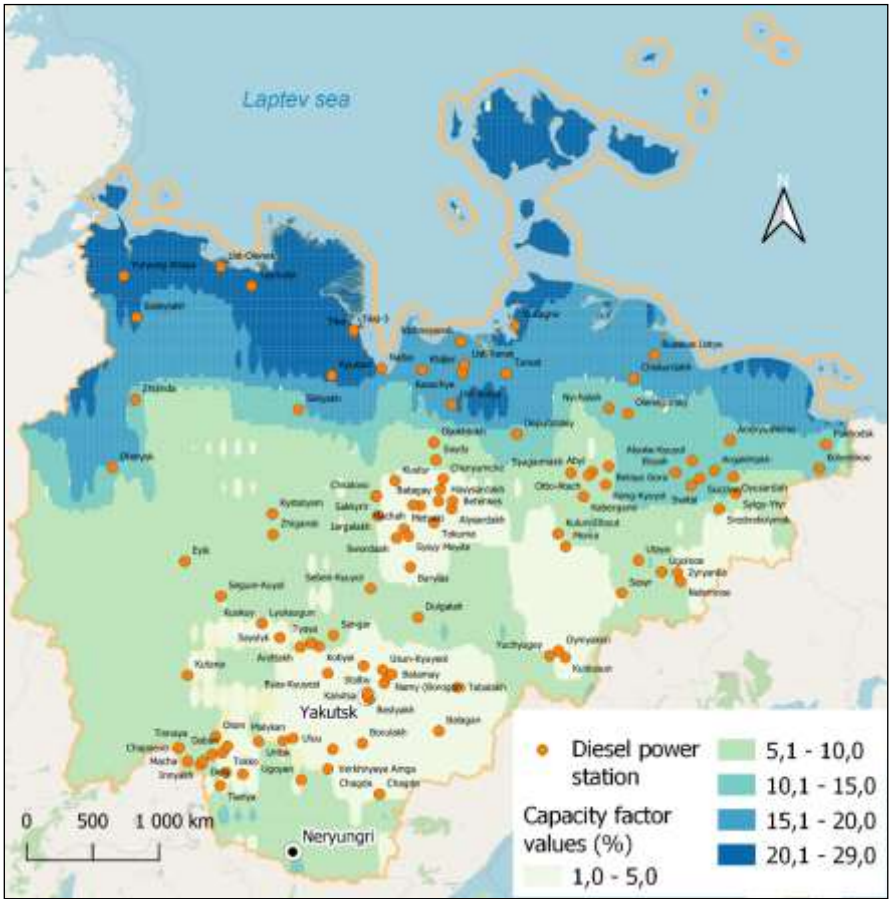


Fig. 1. The Distribution of Capacity Factor values (%) of the Komai Haltec KWT 300 wind turbine across the territory of the Republic of Sakha (Yakutia) based on the calculated data.

The largest populated settlements were excluded from further analysis (Belaya Gora, Chokurdakh, Deputatsky and Tiksi), as their annual energy consumption was more than 9 thousand kWh and for complete power replacement it required from 40 to 60 wind turbines, which does not seem economically feasible. However, wind turbines can partially reduce the load on diesel power plants and provide fuel savings, as it is in the village of Tiksi now (Windfarm with 3 Komai Haltec KWT 300). For two villages (Ust-Kuiga and Saskulah), the requirements for 14 wind turbines were obtained, that is also not effective due to very high financial costs. For the Ust-Kuiga village, where industrial gold mining is taking place and

energy consumption will increase, an alternative plan has already been developed to begin in 2024 construction of the low-power nuclear plant (about 50 MW).

A spatial analysis of average annual production and capacity factor using GIS tools [1-4], as well as an analysis of the territory from the point of view of environmental restrictions (exclusion of Important Bird areas (IBA) and wetlands) made it possible to identify promising settlements with a high potential for replacing diesel generation with wind energy. These include 15 isolated villages with a population of less than 2,000 people, with backup diesel generators (in Bulunsky, Ust-Yansky, Anabarsky, Allaikhovsky and Nizhnekolymsk ulus). For a number of north villages, despite the high specific potential for wind power generation (about 1500 kW·h/kW), the installation of wind turbines is limited by high environmental risks, since these villages are located in the International Important Bird Areas (IBA): the village of Pokhodsk - in the "Kolyma Delta" IBA, the village of Chokurdakh and the village of Russkoye Pole in the "Kytalyk" IBA, the village of Nizhneyansk in the IBA "Yana Delta and the Syuryuktyakh River", the village of Sittyakh in the "Muna-Besiuke" IBA) [5].

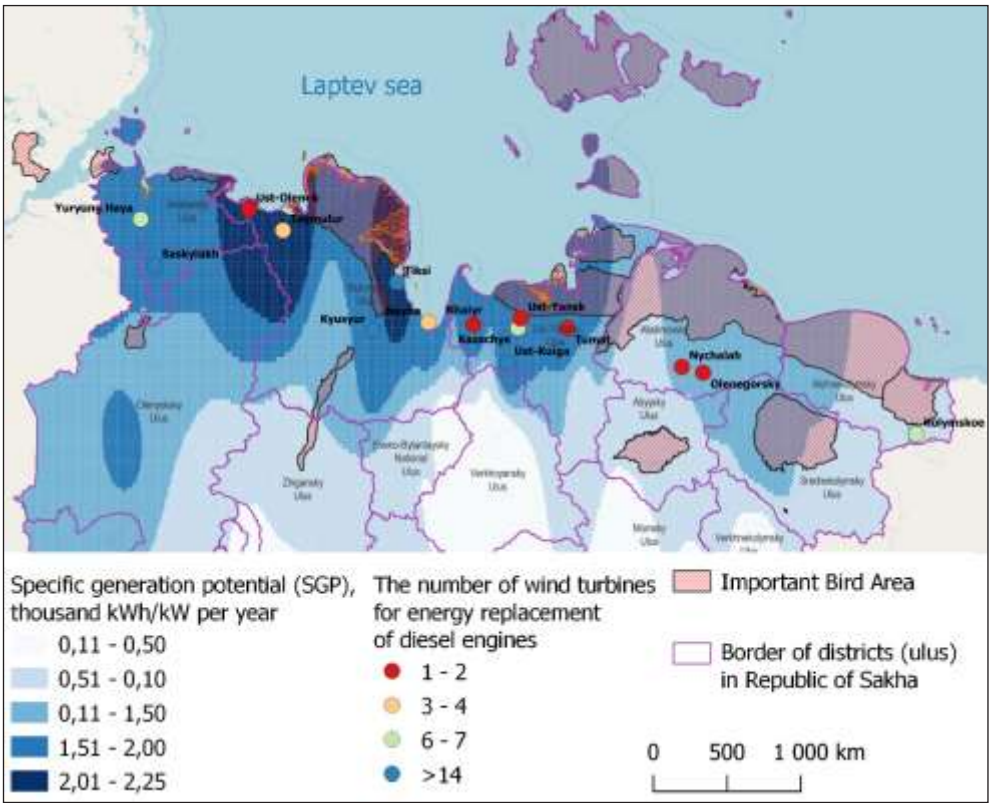


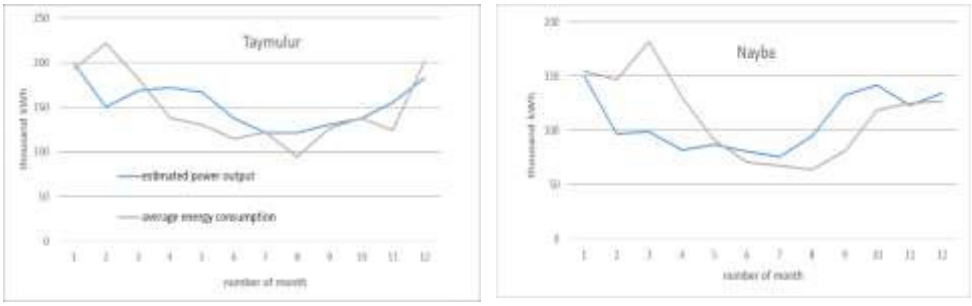
Fig. 2. The distribution of the specific generation potential (SGP) of the Komai Haltec KWT300 wind turbine across the northern territory of the Republic of Sakha (Yakutia).

To assess the prospects of energy supply to villages in Yakutia using wind energy resources, a comparison of the dynamics of changes in energy consumption in villages and electricity generation schedules for the calculated number of wind turbines throughout the year was made. By the total annual load co In Fig. 3 are given graphics of changes in energy consumption and estimated power generation for the villages of Taymulur and Nayba with the construction option of 3 wind turbines. During winter months (January-March) for the

village Taimulur electricity generation is significantly lower than energy consumption, while during the rest of the year the graphs are very close. For the village of Nayba, located at a considerable distance to the southeast of the village of Taymulur, a different trend was noted: if in the first half of the year the production of electricity at wind turbines is lower than the power needs, but from June until the end of the year - electricity consumption can be fully provided by wind turbines generated energy.

Table 1. The estimated required number of wind turbines for settlements of the Republic of Sakha (Yakutia)

Village of the of the Republic of Sakha (Yakutia)	Number of inhabit	Average annual energy consumption, mln kWh	Capacity Factor %	Annual power output, mln kWh per one WT	SGP, thousand kWh/kW per year	The required number of wind turbines
Saskylakh	2317	7.417	20.66	0.543	1.81	14
Yuryung Haya	1148	3.737	20.87	0.548	1.83	7
Taymulur	757	1.790	25.63	0.673	2.25	3
Kyusyur	1718	4.136	22.36	0.587	1.96	7
Nayba	522	1.357	19.42	0.510	1.70	3
Khaiyr	433	0.617	18.96	0.498	1.66	1
Kazachye	1367	3.376	19.58	0.514	1.71	7
Ust-Kuiga	979	7.721	20.44	0.537	1.79	14
Ust-Yansk	275	0.523	19.58	0.514	1.71	1
Tumat	533	0.786	19.64	0.516	1.72	2
Nychalah	117	0.402	12.55	0.329	1.10	1
Olenegorsky	250	0.619	13.44	0.353	1.18	2
Kolymskoe	811	1.883	11.43	0.300	1.00	7



A) B)

Fig.3. The Comparison of average energy consumption and estimated power output of 3 Wind Turbines Komai Haltec KWT 300 during the year for Taymulur village (A) and Nayba village (B).

Calculations of the monthly energy balances (“production minus consumption”) during the year make it possible to determine the periods of possible full energy supply to the consumer due to the operation of wind turbines and periods when additional energy supply

is required due to standby power capacities (diesel generators). Autonomous operation of wind power complexes for energy supply in the Republic of Sakha (Yakutia) requires the accumulation of energy according to daily and seasonal schedules. For daily accumulation, energy storage electrochemical devices of various types can be used [6].

The problems of seasonal accumulation by power supply to large settlements in Yakutia can also be solved in the future with the involvement of the "green hydrogen" production, since there are significant periods of excess electricity generation at wind farms in comparison with energy consumption schedules [7-10].

4 Conclusion

1. This study, conducted to assess the prospects for energy supply in the Republic of Sakha (Yakutia) using wind energy resources, showed high spatial variability in the distribution of wind resources. The maximum average annual CF values (more than 15-20%) and the specific generation potential of the Komai Haltec KWT300 wind turbine (more than 1500 kW·h/kW) are typical for territories north of 68° N latitude. In the rest part of the Republic, with a high potential of solar energy resources, the use of wind energy resources is not effective, since the development potential of wind energy is extremely low (CF less than 10%).
2. Based on the data of energy consumption in isolated villages in the north of Republic calculations were made of the required number of wind generators to replace diesel generators, that is necessary due to the very high cost of delivering fuel and maintaining the environmental balance in the Arctic zone of the Russian Federation. The IBAs with birds habitats and nesting places for migratory birds were taken into account as an important factor limiting the use of wind energy resources in this zone, which significantly reduced the number of perspective sites for the development of wind energy. That factor led to a reduction in the number of villages proposed by the authors for energy supply by wind energy from 28 to 15.
3. The multifactor analysis, carried out in the work using GIS technologies, made it possible to identify 11 villages for the energy supply using wind energy. The construction of wind turbines with a total capacity of 12.3 MW in these isolated villages presented in Table 1 (with the exception of the villages of Ust-Kuiga and Saskylakh) will provide annual savings of 8.1 thousand tons of diesel fuel and will reduce carbon dioxide emissions in the Arctic zone of the Sakha Republic (Yakutia) about 20 thousand tons.
4. Comparison of data on energy consumption and estimated power output of wind turbines for isolated villages based on the total annual load coverage showed significant intra-annual discrepancies. Due to the high level of intra-annual variability in wind energy production, a sustainable energy supply will require backup capacity with diesel generators. Autonomous wind power complexes in the Republic of Sakha (Yakutia) require energy accumulation according to daily and seasonal schedules.

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References

1. S.V.Kiseleva, N.V.Lisitskaya, O.S.Popel', Yu.Yu.Rafikova et al. Thermal Engineering, **70** (2023), 939-949.

2. Martínez-Martínez, J. Dewulf, and Y. Casas-Ledón. Renewable Energy **182**, 363–376 (2022).y
3. Santoli, F. Mancini, and D. A. Garcia. Sustainable Cities Soc. **46**, 101413 (2019).
4. Sliz-Szkliniarz and J. Vogt. Renewable Sustainable Energy Rev. **15**, 1696–1707 (2011)
5. Geoinformation database of spatial data on Important Bird Areas of Russia, 2023. Russian Bird Conservation Union, 2023.
6. S.V.Kiseleva. A.B.Tarasenko, ISJAEE, **19-21** (2018)
7. A.M. Elberry, J. Thakur, J. Veysey J. Energy Storage, **44**, 103474 (2021)
8. L. Nefedova. K. Degtyarev. S. Kiseleva. M. Berezkin, E3S Web of Conf. **265.** 04011 (2021)
9. A.B.Tarasenko. S.V.Kiseleva. O.S.Popel, Int. Journal of Hydrogen Energy **47**, 23, 11991–11997 (2022)
10. I.A. Hassan, H.S. Ramadan, M.A. Saleh, D. Hissel. Renew. Sustain. Energy Rev. **149**, 111311 (2021)