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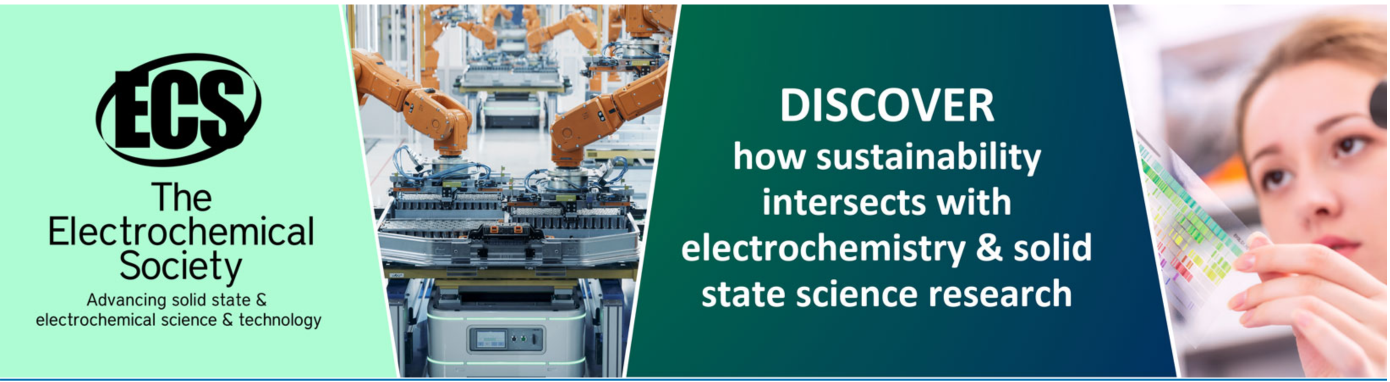

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Estimation of Wind Energy Resources in Regions of Russia for Green Hydrogen Production and Reduction of CO2 Emission

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Abstract. The problem of hydrogen production using renewable energy sources in the world and in Russia is considered. Preliminary estimates of possible volumes of hydrogen production and of carbon dioxide emission reducing in the coastal regions of the North and East of Russia using wind power plants have been carried out. Based on the calculations of the wind characteristics variability over a 30-year period for the Sakhalin Peninsula, an analysis of possible interannual and within-year variability of the capacity factor was accomplish. Estimates of the prospects for reducing of CO2 emissions due to the potential for green hydrogen production using wind power plants energy as an alternative to fuel power plants in regions of Russia are completed.

1. Introduction

In recent years, a number of countries have adopted large-scale hydrogen programs involving a multiple increase in the production of hydrogen with the prospect of using it for energy purposes - for generating heat and electricity, as well as a transport fuel. Decarbonization of the economy is proclaimed as the main incentive - a direct reduction in greenhouse gas emissions by replacing fossil hydrocarbons with hydrogen. Another important factor in the use of hydrogen is the need to stabilize the supply of energy to the grid due to the growing share of renewable energy sources. In the coming decades, we are talking about increasing the hydrogen market by tens of million tons per year. The IRENA report [1] indicates that there are great prospects for the use of energy from renewable sources for these purposes, due to a decrease in the cost of renewable energy in the world. To expand this process, it is necessary to reduce the cost and scale up the production of electrolyzers. Standardization and batch production of cell blocks, operational efficiency, optimization of material procurement and supply chains will be critical in reducing costs. Hydrogen production using wind power plants WPPs for power supply of electrolyzers will also lead to the reduction of CO2 emissions due to the replacement of fuel power plants. In this case, the global production capacity of electrolysers, which today does not exceed 1 GW, should grow to 100 GW in the next 10-15 years.

At the beginning of July 2020 The European Commission published the "Hydrogen Strategy", which includes a set of measures to promote green hydrogen in the European energy sector and decarbonize the economy, including the construction by 2030 electrolysis plants using renewable energy sources (RES) with a total capacity of 40 GW and a production of 10 million tons pure hydrogen. Other regions and countries around the world have also launched large-scale green hydrogen projects. So, Japan, which

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has many years of experience in research and development in the field of hydrogen technologies and fuel cells, put into operation in 2020 one of the world's largest solar-powered electrolysis stations in Fukushima with a capacity of 1200 m3 H2/day [2]. Saudi Arabia is pursuing a construction project by 2025 in the "city of the future" Neom electrolysis plant with a capacity of 650 tons of hydrogen per day using energy from wind (WPP) and solar power plants (SPP) with a total capacity of 4 GW. Australia, based on large-scale use of wind and solar energy, plans to achieve by 2027 electrolysis capacity production of hydrogen in 1 GW [3, 4]. The total capacity of the renewable energy-based electrolysis plants under construction and projected in the world is about 50 GW, while the projects being implemented will provide an increase in the production of green hydrogen by 3 million tons per year [5]. Most ambitious projects in the field of green hydrogen are announced in Western Europe and East Asia, macro regions closest to Russia and the largest economic partners of our country.

In the Russian Federation in October 2020 the Action Plan ("road map") for the development of hydrogen energy up to 2024 was approved [6]. The purpose of this plan implementation is to increase production and to expand the areas of hydrogen application as an environmentally friendly energy carrier, as well as the country's achievement of leading positions in the world in its export. The task of developing hydrogen energy is also set in the Energy Strategy of the Russian Federation for the period up to 2035. According to this document, the export of hydrogen from our country should reach 2 mln t/year [7]. It is planned to create a hydrogen cluster in Sakhalin Region for the development of hydrogen energy and the export of this type of fuel to Asian countries. Sakhalin's natural gas reserves and large wind potential are considered as a resource base, the use of which will make it possible to produce about 3 million tons of hydrogen per year [9]. Analysis of technical feasibility, resource availability and competitiveness of those projects requires regional assessments of green hydrogen production potential using renewable energy sources and determination of sustainability degree of energy production from wind and solar power plants sustainability [10]. Some scientific research with the using the geographic information system (GIS) were carried out for the most realistic plans of the green hydrogen industry development in Netherlands, Australia, Ukraine, South Africa [11-14].

The authors have already performed estimates of the possible volumes of hydrogen production at WPPs that are currently operating and projected by 2024 in the regions of Russia. The total potential for the production of green hydrogen using all the generated energy of the Russian wind farms by 2024 (scheduled total capacity 3.6 GW, CF 34%) we estimated at 191 kt/year. It is shown that very promising for green H2 production are energy-surplus regions: Rostov region, Adygea and Murmansk region, as well as northern and eastern territories with a very high wind energy potential [15].

2. The data and methodology

The aim of the work is to assess the feasibility of hydrogen production using wind energy in the coastal regions of the North and East of Russia. The task posed requires determining the wind energy characteristics of the territories and assessing the potential productivity of typical wind turbines. To assess the production of hydrogen, the characteristic average values of energy consumption were used (the specific power requirement: 55600 kWh/t H2). Carbon dioxide reduction potential calculation by increasing WPP capacities were carried based the assumption, that the generation of electricity in Russia is accompanied by emissions of about 500 gCO2/ kWh on average.

For preliminary estimates of the wind turbines productivity in the selected regions, we used the curves of the wind turbines generation depending on the average wind speed (Annual Energy Production - AEP) curves at the altitude of 100 m, obtained on the basis of statistical data by Vestas [16]. Average wind speeds were obtained from the GIS "Renewable Energy Sources of Russia" [17]. GIS was created in collaboration between the Renewable Energy Laboratory of the Lomonosov Moscow State University and the Joint Institute for High Temperatures of the Russian Academy of Sciences using the open NASA POWER database [18]. This approach makes it possible to obtain, in accordance with the average annual wind characteristics, the annual power generation by wind turbines of various brands and capacities, and to calculate the specific electricity generation for promising territories.

To refine the estimates, the authors used their own program for calculating electricity generation for various wind turbines based on the wind turbine power curve and sequences of average hourly wind speed values for long periods at a given geographic point. The calculations were carried out for the wind turbine Lagerwey 2,5MW based on the MERRA-2 reanalysis (hourly values of the wind speed on H=100 m for the period 1979-2019) [19]. The calculations were carried out for the three most promising areas for the export of hydrogen on the Sakhalin Peninsula. The results obtained make it possible to determine the average annual productivity of wind turbines, as well as its annual, intra-annual and intraday variations. This makes it possible to assess the potential of hydrogen production - both for satisfying consumers' own needs and for export.

3. The results and discussion

Based AEP curves [16] the CF was determined and the average annual productivity of the different Vestas wind turbine was calculated for the following locations: Yamal Peninsula (Sabetta settlement in the area of a wind farm, currently being designed by NOVATEK to supply energy for liquefied natural gas production, the Kola Peninsula (the Kola Wind Farm near the Teriberka village, which is currently under construction by ENEL), and the Sakhalin Island (the western coast, the port of Kholmsk; the northern coast, the oil production center of Okha; the southern coast, the port of Korsakov). Hydrogen production in the area of ports in the West and East of Russia seems to be the most appropriate for the hydrogen export, including to Japan. Calculations of the potential annual power generation for wind turbines Vestas of various capacities were carried out. The highest CF value was obtained for the studied areas for the Vestas 117-4.2 MW wind turbine, the production of which is established in Russia in Ulyanovsk (table 1). Only the project of a wind farm near Sabetta settlement requires consideration of a wind turbine of lower power due to lower wind speeds in Yamal than in Sakhalin and the coast of the Kola Peninsula.

Table 1. The prospects of green hydrogen production and CO2 emission reduction in coastal territories of Russia.

	Annual average wind speed m/s	Annual output (Vestas 117-4.2 MW), GWh per year	Capacity Factor	Normalized annual output GWh/MW per year	Green H2 production prospects, t/ MW per year	CO2 emission reduction, klt/MW per year
Yamal Peninsula (YaNAD, Sabetta)	6.5	10.4	28.2%	2.48	44.6	1.24
Kola Peninsula (Murmansk Region, Teriberka)	9.3	17.9	48.6%	4.26	76.6	2.13
Sakhalin Island (Sakhalin Region, Kholmsk)	9.8	18.6	50.5%	4.43	79.7	2.21
Sakhalin Island (Sakhalin Region, Okha)	9.2	17.5	47.6%	4.17	75.0	2.08
Sakhalin Island (Sakhalin Region, Korsakov)	9.4	18.2	49.5%	4.33	77.8	2.17

In the area of Sabetta the potential of hydrogen production is estimated by us at 44.6 t/MW of the wind farm installed capacity and CO2 emission reduction potential – 1.24 klt/MW per year. With the projected capacity of NOVATEK WPP at 200 MW production can be about 8920 tons H_2 with emission reduction of 247 kilotons of CO2 per year. The wind farm of the same capacity on Sakhalin in the area of the port of Kholmsk–can allow to produce 15940 tons of green H2 per year and can provide the emission reduction of 441 kilotons of CO2 per year. Construction by ENEL Kola wind farm 201 MW in the energy surplus Murmansk region according to our estimates (CF 48.6 %) will make it possible to produce for export to Europe about 15300 tons of green hydrogen per year with emission reduction potential in 426 kiloton CO2 per year. The wind resources of Sakhalin allow to produce at wind farm with a capacity of 200 MW about 15000 t/year of hydrogen in the North of the region (Okha) and about 15600 t/year in the South (Korsakov).

These estimates are the average for the year and only allow to compare the regions in terms of their potential for the production of green hydrogen. However, the unevenness of the wind speed in time will hinder the stable operation of the wind turbine and, accordingly, the production of hydrogen. This is confirmed by the results of assessing the intra-annual dynamics of the CF using the open-source "Renewables ninja simulator" [20, 21]. So, according to the data on wind speeds for 2019 for the Kola wind farm, changes in the average monthly values of CF ranged from 25.3% in August to 54.2% in March (figure 1).

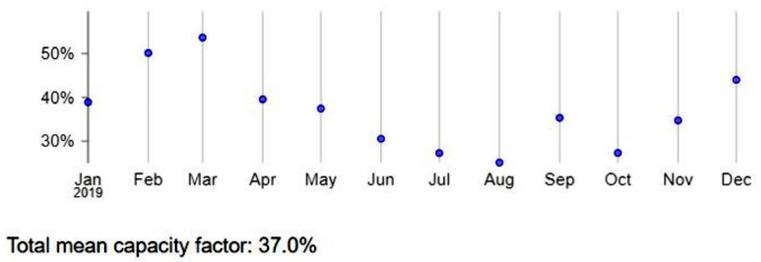

Figure 1. Intra-annual Capacity Factor changes for the site of Teriberka (Murmansk Region) Vestas V90-2.0MW for 2019 [21].

In more detail, the variability (from long-term to intraday) wind turbine productivity was studied for selected locations in the Sakhalin Region using the author's program for the Lagerwey L100-2.5MW wind turbine and the period 1979-2019 (table 2).

Table 2. Average values of productivity (1979-2019). The wind turbine: Lagerwey L100-2.5MW.

Location of the wind turbine	Kholmsk	Okha	Korsakov
Annual output, GWh	8,69	11,78	8,41
Normalized annual output, MWh/MW of wind turbine	3,48	4,71	3,36
Mean annual CF	39,7%	53,8%	39,2%

The calculations make it possible to assert that the interannual fluctuations of the annual output and CF of wind turbines for Sakhalin are insignificant and do not exceed 5% of the average (figure 2).

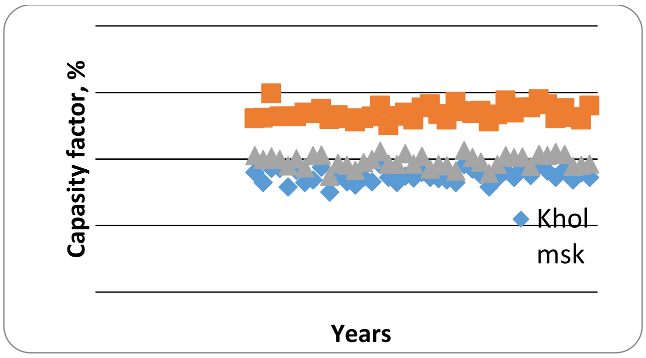

Figure 2. Average annual CF values of wind turbine Lagerwey L100-2.5MW for the sites of Kholmsk, Okha, Korsakov for the period 1979-2019.

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Calculations of CF values for a 30-year period showed a significant scatter of the average monthly values within a year. So, for the Okha site, the CF values can vary from 30% to 90% throughout the year. Even more significant intervals of CF variability were recorded by us as a result of the analysis of the dynamics of the daily and hourly energy output of wind turbines (figures 3, 4).

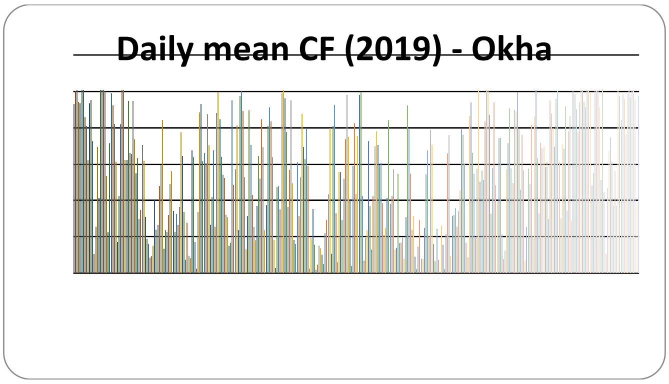
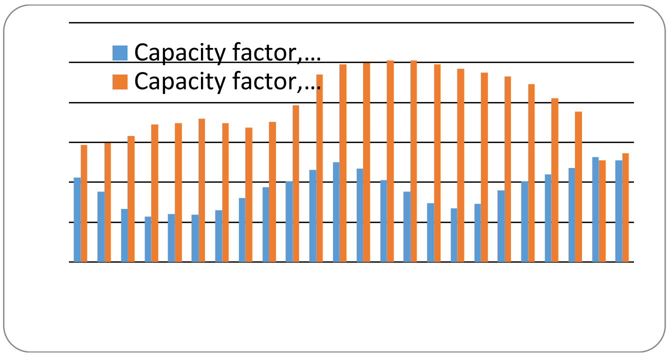
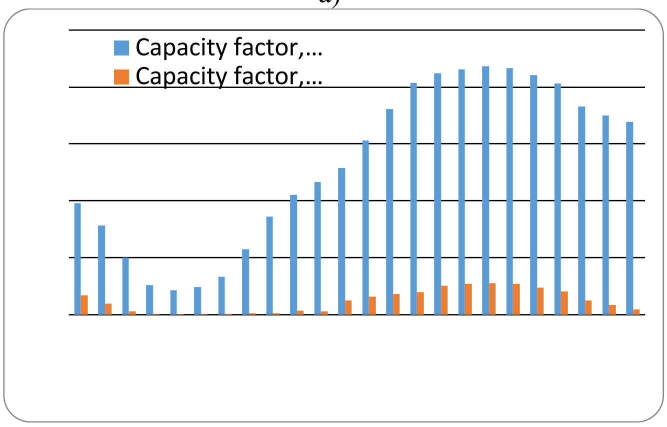


Figure 3. The daily mean CF values of the wind turbine Lagerwey L100-2.5MW for the Okha site for 2019.



a)



b)

Figure 4. Mean hourly CF values of the wind turbine Lagerwey L100-2.5MW for the a) Okha and b) Kholmsk sites for one day as on 15/06/2019 and on 15/12/2019.

In September 2019 daily CF values varied from 5% to 100% (figure 3). Such a significant interval of changes in wind conditions is characteristic of the Sakhalin Region precisely in the autumn period, when typhoons are approaching the territory of the peninsula. Apparently, the extremely low daily CF values are due to hurricane winds and a potential stop of the wind turbine. The performed calculations also make it possible to analyze the CF intraday variations. Figure 4 shows typical days for the summer (15/06/2019) and for winter (15/12/2019) periods for the Okha and Kholmsk. As of the dates presented in 2019 for Okha the summer period is characterized by higher CF values than the winter one (figure 4.a). For the same dates, for the region of Kholmsk, we obtained high values of CF for the winter period and low CF values for the summer period (figure 4.b). Such differences for Sakhalin Region can be associated with both general climatic patterns and local weather features of a specific time series (year) and require further study and analysis, since they are an important aspect for considering the Sakhalin Region as a promising area for hydrogen production - both for own consumption and as an export product.

4. Conclusion

To calculate the potential for hydrogen production, a step-by-step approach is proposed with initial estimates of the territories based on the average annual wind speeds and the application of annual production curves for various wind turbines, and then the refinement of wind energy output using the developed calculation program. The conducted assessments and calculations of wind energy resources of the coastal northern (Yamal Peninsula, Kola Peninsula) and eastern (Sakhalin Island) regions showed significantly higher CF values than for the wind power plants of Russia located in the interior regions of the country. According to our estimates the wind farm 200 MW in Sakhalin Region near Kholmsk can allow to produce 15.94 kiloton H2/year and can provide the emission reduction of 441 kiloton CO2/year, construction by ENEL Kola wind farm 201 MW in the energy surplus Murmansk Region will make it possible to produce for export to Europe about 15.30 kiloton H2/year with emission reduction potential in 428 kiloton CO2/year. Due to our calculations model wind turbines located at various areas Sakhalin Region are characterized by high annual energy output and record high CF values. Thus, even within the same region, the location of wind turbines significantly affects the intra-annual, seasonal and intraday variations of wind turbine output. With such significant variations in the energy output of wind turbines, both daily and seasonal energy storage is optimal. If daily accumulation can be realized with the use of electrochemical accumulators, the seasonal accumulation can be ensured by the production and further use of hydrogen for energy supply.

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