Prospects for green hydrogen production in the regions of Russia

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Abstract. The article discusses the possibilities of hydrogen production using renewable energy sources in Russia for energy storage and for export. The global trends in the development of green hydrogen energy reducing the CO2 emission are highlighted. The analysis of the potential for hydrogen production in regions of Russia using electricity from operating wind power plants (WPPs), as well as wind power projects planned for construction until 2024 has been carried out.

1 Introduction

The possibilities of using hydrogen as an environmentally friendly energy carrier and for energy storage have been discussed with varying degrees of intensity since the 2000s. The rise in interest in this topic - both of experts and scientific community - is associated with the concept of a carbon-free economy put forward to date and the prospects for introducing a carbon tax. In accordance with this, the so-called green and blue hydrogens are considered the most popular, the production technologies of which imply zero greenhouse gas emissions into the atmosphere: electrolysis using energy from renewable sources in the first case, steam reforming of methane with CO_2 capture - in the second [1].

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 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 1.2 thousand cubic meters of hydrogen per 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

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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]. It should be noted that the 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 the 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 the implementation of this plan is to increase production and to expand the areas of application of hydrogen as an environmentally friendly energy source, 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 per year [7].

Russia has a significant potential for the expansion of hydrogen production, taking into account the reserves and level of natural gas production (blue hydrogen), the nuclear power capacities (yellow hydrogen). Prospects for the production of green hydrogen were considered, in particular, as a method of increasing the Capacity Factor (CF) of existing and under construction renewable energy plants, including hydroelectric power plants (for example, the "Dyakovskaya Ust-Srednekanskaya HPP" in the Magadan region [8]. 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 [10]. Some scientific research with the use of GIS were carried out for the most realistic plans for the development of the green hydrogen industry in Netherlands, Australia, Ukraine, South Africa [11-14].

2 Object of study and methods

The objective of the work is to analyze the possibilities and prospects of hydrogen production using renewable energy sources in Russia. Due to the fact that a number of large grid wind power plants have been built in the country in last year, an analysis of the volume of electricity generation at these stations and the level of utilization of installed capacities was carried out. Based on the analysis of regional energy balances, the possible volume of green hydrogen production at present and in the future was estimated, taking into account the increase of electricity generation at wind farms by 2024.

In this the study computational, predictive and analytical methods, economic and geographical analysis and expert assessments were used. Information base for the research were the data of companies - energy producers, the System Operator of the Unified Power System (SOUPS) of Russia and statistical data of Federal State Statistics Service of Russia and the Association Market Council of Russia.

3 Results and discussion

There is an active increase in the capacity and productivity of WWP and an increase in electricity production by other plants at renewable energy sources and nuclear

power plants In Russia (Table 1). Increase in energy production from WPP in Russia was provided by the putting in operation of WWP of total capacity 85 MW in 2019 (Ulyanovsk region), 843.8 MW - in 2020 and 80 MW - in January 2021.

Generation station type	Electricity	generation,	Energy production
	million kWh per year		change in 2020,
	2019	2020	as % of 2019
Thermal power plants	679,881.0	620,565.1	- 8.7
Hydroelectric power stations	190, 295.4	207,416.3	+ 9.0
Nuclear plants	208,773.3	215,682.1	+3.3
Wind power plants	320.8	1,384.1	+ 331.5
Solar power plants	1,284.9	1 982.3	+ 54.3

 Table 1. Electricity generation by power plants of various types in the Russian Federation in 2019 -2020 [15]

The analysis of the potential of grid WWP in Russia for the production of green hydrogen was carried out on the basis of calculations of the Capacity Factor (CF) of all wind farms operating in 2020 [15,16], which amounted to 34%. On the basis of this value were conducted evaluation of electricity generation prospects of WPP in Russia, CO₂ emissions reduction and the hydrogen production (the specific power requirement: 55600 kWh /t H₂). Carbon dioxide reduction potential calculation by increasing WPP capacities carried based the assumption, that the generation of electricity in Russia is accompanied by emissions of about 500 gCO₂/ kWh on average. As a less optimistic scenario electricity generation for WPP, estimates for were also made for CF=17% (Table 2).

Wind Power Plants in Russian Federation	Capacity, MW	Generation potential, mln kWh/year	CO ₂ emission reduction (Kt)	Hydrogen production potential, T / year
Ulyanovsk region. Total:	85.4	254.36	127,2	<i>457 0</i>
WPP 1	35	104.24	52.1	187 0
WPP 2	50.4	150.11	75.1	2700
Rostov region. Total:	346.8	1032.91	516.5	18560
Sulinskaya WWP	98.8	294.27	147.1	5290
Kamenskaya WWP	98.8	294.27	147.1	5290
Gukovskaya WWP	98.9	294.27	147.1	5290
Cossack WWP	50.4	150.11	75.1	2700
Republic of Adygea. Total :	150.0	446.76	223.4	8030
Adyghe WWP	150.0	446.76	223.4	8030
Republic of	216.6	645.12	322.6	11,600
Kalmykia. Total:				
Yustinskaya WWP	15	44.68	22.3	803
Salynskaya WWP	100.8	300.22	150.1	5400
Tselinskaya WW	100.8	300.22	150.1	5400
Stavropol region. Total:	210	625.46	312.7	11240
Kochubeevskaya WWP	210	625.46	312.7	11240
Total for the Russian	1008.8	3004.60	1502.3	5400 0
Federation (CF=34%) :				
Total for the CF=17%		1502.30	751.2	2700 0

 Table 2. Assessment of the annual potential for green hydrogen production and CO₂ emission reduction at the operating WWP in regions of Russia as on 02/01/2021

Source: completed by the authors based on [15], [16].

Analysis of power balances (PB) of Russian regions in 2019 showed that the most power-deficiency areas are Krasnodar Territory (PB = -14078.8 mln kWh), Orenburg (PB = -5606.8 mln kWh), Ulyanovsk (PB = -2892.8 mln kWh) Regions, the Republic of Adygea (PB = -1573.6 mln kWh) and the Republic of Kalmykia (PB = -451.9 mln kWh) [17]. The construction of large wind farms in these regions will increase the reliability of power supply, improve the environmental situation and ensure the reduction of CO2 emissions, which is especially important for the Krasnodar Territory, the most important recreational region of Russia. At the same time, it should be noted that in the Republic of Kalmykia with low total energy consumption, plants on renewable energy sources (SPP – 164.5 MW, WPP - 216.6 MW) built in 2019-2024 will put Republic of Kalmykia among the energy surplus regions of the Russian Federation. As a result, renewable energy produced in this Republic can provide additional potential for the production of green hydrogen.

The most promising regions for the production of H2 are energy-surplus regions: Rostov Region (PB = +25238 mln kWh), Murmansk Region (PB = +3951 mln kWh), Stavropol (PB = +3632 mln kWh) and Perm (PB = +5054 million kWh) Territories [17]. In the Rostov Region Wind power plants with a total capacity of 350 MW are currently in operation, which at a CF=34% can provide about 1040 mln kWh of electricity per year. Estimates show that this generation from WPPs can provide 208 mln m³ H₂ or about 18700 tons of green hydrogen per year (at CF=17% - respectively 520 mln kWh and 9350 tons).

According to the conducted constant adjustment of wind farm construction plans in the Southern Federal District, in the Rostov Region it is planned for 2021 to put into operation another 3 new windfarm: in Azovsky, Zimovnikovsky and Kamensky administrative areas (AA) with the total capacity of 260 MW. LLC "Enel Rus Wind Azov" will commission a wind farm with a capacity of 90 MW in the Azovsky AA, JSC "NovaWind" - in the Zimovnikovsky AA with a capacity of 120 MW, and PJSC "Fortum" and the Russian Direct Investment Fund will commission the second phase of a wind farm with a capacity of 50 MW in the Kamensky AA. The Enel Company, constructing the Kola WPP in the Murmansk Region with the capacity of 201 MW, which will be launched at the end of 2021, is already preparing a project to use its electricity for hydrogen production.

We can also highlight Kaliningrad (PB = +2663 mln kWh) and Leningrad Regions (PB = +22552 mln kWh) as the energy surplus and very prospective territories. Although there are no large WPP projects yet, these regions are characterized by a high wind energy potential, experience in using wind power plants and high export opportunities for green hydrogen production due to location in the west part of Russia. Pre-design studies have begun in Leningrad Region for the 68.4 MW Sviritsa WPP, with a high export potential for hydrogen production.

In 2013-2020, tenders procedure were held to select projects for the construction of RES power plants in the regions of Russia until 2024 in accordance with the policy to support the development of renewable energy on the terms of Capacity Supply Agreements (CSA). It's planned to construct 3539.1 MW of wind farms in 13 regions of Russia by 2024 [16]. Our calculations of the prospects of electricity generation at the wind farms of Russia, planned for construction till 2024 and the prospects for green hydrogen production on them based on the average CF = 34% and CF=17%, are presented in Table 3.

Table 3. Regional distribution of WPP projects construction in the Russian Federation in accordance with the results of the 2013-2020 "Competitive selection of investment projects for the construction of RES generating facilities": Prospects for the green hydrogen production

Region of the Russian Federation	Wind farm projects capacity until 2024, MW	The potential of electricity generation, by CF=34% mln kWh /year	Prospects for green hydrogen production, t/year	WWP built on 1.02. 2021, MW
Astrakhan Region	183.00	545.05	9800	-
Volgograd Region	77.40	230.53	4140	-
Krasnodar Region	1052.50	3134.77	56340	-
Rostov Region	503.69	1500.19	26960	346.80
Republic of Adygea	250.00	744.90	13390	150,00
Republic of Kalmykia	226.10	673.42	12100	216.60
Stavropol Region	173.95	518.09	9310	210.00
Ulyanovsk Region	316.00	941.11	16920	85.40
Republic of Tatarstan	100.00	297.84	5350	-
Murmansk Region	350.97	1045.33	18790	-
Orenburg Region	75.6	225.17	4050	-
Perm Territory	189.90	565.60	10170	-
Kurgan Region	40.00	107.14	1930	-
TOTAL by CF=34%	3539.11	10630.24	191070	1008.80
TOTAL by CF=17%		5315.12	95500	

Source: completed by the authors based on [15], [16].

To determine the volume of prospects for hydrogen production at WPP built under the CSA program in Russia, two scenarios have been considered:

- the use for hydrogen production only "green" electricity produced by WPP located in energy-surplus regions with an established structure of electricity consumption. At the same time, in energy-deficient regions, WPP will operate on a network to supply power to the population or industrial production.

- the second scenario assumes the use of all the electricity generated for green hydrogen production. The second scenario will be relevant if the prices for green hydrogen by European importers will be at a sufficiently high level.

Thus, according to the first scenario, the potential for hydrogen production using the energy of WPPs with annual CF = 34% can be up to 80 thousand tons of green hydrogen per year, and according to the second scenario - more than 190 thousand tons per year (at CF=17%, respectively 40 kt and 95.5 kt of green hydrogen).

4 CONCLUSION

Russia is facing - in accordance with the global trend of energy transition and decarbonization of the economy - the tasks of hydrogen production using renewable energy sources, wich require a large amount of studies on research programs. The analysis of world experience showed, in addition to the need to develop technological issues, also the importance of regional assessments of the prospects for the production of green hydrogen, both for domestic consumption and for export purposes. By now, a wind industry has been created in the Russian Federation, with a localization level of more than 65%, and a rapid pace of increasing the installed capacity of WPPs. Wind electricity generation growth in 2020 amounted to 331% in comparison with the previous year. By February 2021 the total capacity of wind farms in the country is already 1008.8 MW, a number of projects are nearing completion. The operation of these

wind farms makes it possible to avoid CO_2 emissions due to the non-use of a fuel of 1502.3 thousand tons per year. The assessment made by the authors based on the data on the generation of WPPs in 2020 showed an average annual value of CF of 34%. In a number of energy-deficient regions of the country, WPP power generation is necessary to reduce the electricity supply from other regions over long distances. Other regions where wind farms are constructed or planned by 2024 (Rostov & Murmansk Regions, Republic of Kalmykia, Stavropol &Perm Territories) are energy surplus. According two considered scenarios of the green hydrogen production prospects for energy storage and for export using the energy of WPP in Russia after 2024 predicted values of 190 thousand tons (full use of the generated electricity by the WPP) and 80 thousand tons (work on export hydrogen only for WPPs in the energy-surplus regions of Russia) were obtained. However, in years when the wind characteristics will be much lower than the average, the average annual WPP can drop to 17%. In such years, the potential for hydrogen production will be 2 times lower.

The study for prospects of green hydrogen production requires also an assessment of the possibilities of using the energy of hydroelectric power plants in Siberia and East Regions, by increasing their CF, and the huge wind energy potential of the northern and eastern regions of Russia [https://gisre.ru/maps/wind-data#pot]. This is beyond the scope of this study and is planed to research in the future.

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