Available online at www.sciencedirect.com
ScienceDirect
Energy Reports 7 (2021) 137–148
www.elsevier.com/locate/egyr

Tmrees, EURACA, 28 to 30 May 2021, Athens, Greece

Green energy development in an industrial region: A case-study of Sverdlovsk region

Anzhelika Karaeva[a,b], Elena Magaril[b], Vincenzo Torretta[a], Marco Ragazzi[c], Elena Cristina Rada[a,*]

[a] Insubria University, Department of Theoretical and Applied Sciences, via G.B. Vico, 46, 21100, Varese, Italy
[b] Ural Federal University, Department of Environmental Economics Mira-str., 19, 620002 Ekaterinburg, Russian Federation
[c] University of Trento, Department of Civil Environmental and Mechanical Engineering, via Mesiano, 77, 38123, Trento, Italy

Received 28 July 2021; accepted 7 August 2021

Abstract

The development of renewable energy is one of the strategic directions of eco-modernization of the Russian energy sector, which will not only reduce the negative impact of the industry on the environment, but also provide remote territories with the stable access to electricity. Despite the fact that the Russian regions have a great potential for the development of renewable energy, the full transition of the energy sector to the "green" vector of its development is currently impossible. Moreover, most of current studies consider the development of renewable energy without reference to the regions, which, according to the authors, does not provide an objective assessment of the potential for the use of renewable energy in Russia. The purpose of the present research is to evaluate the potential for the introduction of various renewable energy sources (RES) in the energy sector of the Sverdlovsk region — one of the largest industrial regions of Russia. The full-scale assessment of their potential use at the regional level helps to accelerate the process of their introduction into the energy sector, since during the assessment, scientists analyze not only the possibilities of use, but also the barriers to development. Authors applied various research methods among which analysis of state programs, analysis of the official statistical reports, analysis of natural conditions on the territory of the region, etc. As a result, authors developed a map of potential use of renewables in the territory of Sverdlovsk region, evaluated prospects of their development and revealed key barriers. The proposed algorithm of assessment might be applicable for other Russian regions.

Peer-review under responsibility of the scientific committee of the Tmrees, EURACA, 2021.

Keywords: Renewable energy; Green energy development; Energetics; Energy sector

1. Introduction

The fuel and energy complex is the main sector of Russian economy that includes three main industries: the fuel industry, the electric power industry, energy transportation and distribution. The Russian energy system consists

* Corresponding author.
E-mail address: elena.rada@uninsubria.it (E.C. Rada).

https://doi.org/10.1016/j.egyr.2021.08.101

Peer-review under responsibility of the scientific committee of the Tmrees, EURACA, 2021.

of seven unified energy systems. The present electricity consumption in Russia reached to 1,075 billion kWh in 2019 [1].

Russia is one of the key players in the global energy market: in 2020, the country exported 238.6 million tons of oil and 199.2 billion m^3 of natural gas [2]. The availability of depleted energy sources and the relative low cost of their extraction determines the nature of the electric power industry: more than 62% of electricity is generated at traditional energy enterprises (CHPP, TPP), 19.3% at nuclear power plants and 17.8% of electricity production is accounted for by renewable energy sources (RES), mainly hydroelectric power plants.

The predominance of traditional energy facilities in the Russian energy system has led to an increased anthropogenic impact on the environment: about 17% of emissions of harmful substances into the atmosphere are accounted for by the energy sector (Fig. 1).

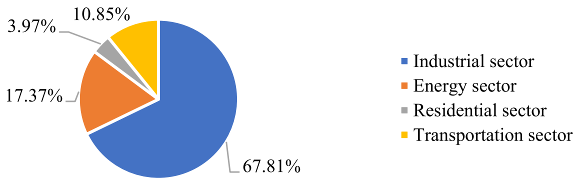

Fig. 1. Total emissions by sector in Russia, 2019, % [3].

In 2016, Russia signed the Paris Agreement, according to which, the volume of greenhouse gas emissions in Russia should be no more than 70% of the level of 1990 by 2030. Moreover, Russian government also aims to achieve the Sustainable Development Goals (SDGs) by 2030, which implies achieving environmental sustainability in all sectors of the economy [4]. Achieving environmental sustainability in the energy sector means reducing the impact of energy facilities on the environment to minimum levels, improving energy efficiency and switching to renewable energy sources.

The green energy development is one of the strategic directions of Russian energy sector's modernization. The prospects of its development are considered in the works of many scientists.

Changes in the global economy and the sustainable development agenda have a significant impact on the development of both global and Russian energetics [5]. Proskuryakova and Ermolenko [6] analyzed four scenarios for the development of Russian energy: scenario 1 "New energy paradigm (3D)", scenario 2 "Relying on hydrocarbon exports", scenario 3 "The worst forecast comes true", scenario 4 "Centralized diversification". According to the authors, scenario 1 is the most promising for the Russian economy and energy sector, as it provides various opportunities for the development of renewable energy and the growth of its share in the structure of energy production up to 10%. In addition, the scenario involves attracting a large amount of investment in the energy sector and carrying out eco-modernization of existing energy facilities.

In [7] Kapitonov, Voloshin and others analyzed the trends in the development of renewables in the world and the possibilities of applying the world experience in the introduction of green energy in Russia. The article also examines the government and business approaches to the process of energy sector eco-modernization and presents the results of a large-scale analysis of statistical data, regulatory legal acts and state programs for the development of green energy both in Russia and in the world. Despite the fact that opponents of the development of green energy in Russia note that most of the country's territory is not suitable for usage of solar energy due to the low level of solar insolation, and wind energy is inefficient and unsafe for the biosphere, the authors highlighted wind energy as the most promising direction for the development of renewable energy in most of Russian regions.

A similar opinion on wind energy was presented by Kudelin and Kucherov [8]. The authors analyzed 25 regions and compiled a rating of the technical potential of wind energy development. The three leaders included the Ulyanovsk Region, the Rostov Region and the Republic of Crimea. The article also examines the legislative and administrative barriers to the development of renewable energy in Russia and the social aspect of the development of green energy. According to the authors, "the future development of energy sources in Russia is almost impossible without social demand and a strong political will to switch energy paradigms to the "green side" [8].

Many authors point out the high prospects for the development of RES in the field of small-scale energy. In the northern and north-eastern regions of Russia, a large number of autonomous power supply systems with a capacity of 200 kW to 4 MW are already operating [9]. The article [10] provides a case study of the commissioning of a solar-diesel power plant in the Irkutsk region. The authors found that the combined use of solar panels and a diesel generator could significantly increase the power of an energy facility while reducing emissions of harmful substances into the atmosphere. Despite the fact that such systems allow to provide remote areas from the central power system with electricity and in general can become one of the key incentives for the development of renewable energy in Russia, gaps in legislation and insufficient control over the conduct of tenders in the field of renewable energy create serious barriers to the development of this industry [11].

In the works [5,7,12–15], the authors note the possibilities of using solar power plants, bioelectric power plants, small hydroelectric power plants and geothermal power plants in the field of small-scale energy in Russia. They will meet the demand for electricity in the regions, create a decentralized energy supply system and reduce the human-induced impact on the environment. A complete replacement of RES for traditional energy facilities is currently impossible due to the climatic, geographical and infrastructural features and the enormous amount of investment required to implement a large-scale eco-modernization of the industry. However, the use of renewable energy both by individual households (for example, the installation of solar panels for water heating in spring and summer) and in small settlements can become the foundation for the development of green energy in Russia in the future.

Many authors consider the development of renewable energy without reference to the regions, which, according to the authors, does not provide an objective assessment of the potential for the use of renewable energy in Russia. Some works of Russian scientists contain case studies that analyze the possibility of using a particular type of RES in a certain region, but they are not numerous [10,11,16–19]. State programs for the development of energy in the regions, on the contrary, contain information about the potential of using various types of RES. According to the authors, conducting a full-scale assessment of the potential for RES use at the regional level helps to accelerate the process of their introduction into the energy sector, since during the assessment, scientists analyze not only the possibilities of use, but also the barriers to development.

The purpose of this study is to assess the potential use of various types of renewable energy (solar energy, wind energy, bioenergy and small hydropower) on the territory of the Sverdlovsk region.

2. Methods and materials

2.1. Research methods

The assessment of the potential for the development of renewable energy in the territory of the Sverdlovsk region was carried out using the following methods:

- analysis of state programs for the development of the energy sector in the region in order to determine the main strategic vectors of its development and potential barriers;
- analysis of the scientific works and official statistical reports that evaluate the potential of the region in the field of renewable energy [20,21];
- SWOT-analysis methodology that allows to identify the strengths and weaknesses of the Sverdlovsk Region's energy sector, opportunities and threats to its development;
- collection and analysis of information about existing and prospective renewable energy facilities in the Sverdlovsk region from various open sources;
- assessment of natural conditions on the territory of the region (the level of solar insolation during the year, the level of wind supply, assessment of the river network of the region) and prospects for the use of various types of renewable energy (small hydropower, solar energy, wind energy and bioenergy);
- evaluation of the approximate potential of RES use in MW in the territory of the Sverdlovsk region and drawing up a map with the territorial location of potential RES facilities.

2.2. Research materials

The object of this study is the Sverdlovsk Region, which is located in the northern and middle part of the Ural Mountains and the western edge of the West Siberian Plain. The region is the largest financial, industrial and research center of the Ural Federal District. The administrative center of the Sverdlovsk Region is Ekaterinburg. The population of the Sverdlovsk Region is 4,310 thousand people in 2020 [22].

The fuel and energy complex of the Sverdlovsk region is mainly represented by traditional energy facilities and is characterized by a fairly developed infrastructure. The region operates two power units of the Beloyarsk Nuclear Power Station (BN-600 and BN-800), which are the largest power units with fast neutron reactors in the world [23].

The region has a limited amount of fuel and energy resources. In the north-east of the region, insignificant oil reserves have been explored; moreover, there are natural gas deposits, and large peat reserves (approximately 3 billion tons). Coal mining in the region is almost suspended due to its insignificant reserves [24].

The installed capacity of the power plants belonged to the regional power system in 2019 was 10,567 MW [25], the balance of the power system of the Sverdlovsk region is presented in Table 1.

Table 1. Balance of electrical power generation and consumption in Sverdlovsk region.
Source: Calculated by authors using data from [25].

Name of the indicator	2014	2015	2016	2017	2018	Relative change, %
Maximum Power Consumption, MW	6629	6323	6620	6460	6349	95.78
Power generation, MW	6862	6387	8406	7714	7932	115.59
Surplus (−)/ Deficit (+)	−233	−64	−1786	−1254	−1583	–

The power system of the Sverdlovsk region is characterized by excess capacity and excess electricity production. According to the latest statistical data, the achieved level of electricity production at energy facilities amounted to 54.8 billion kWh [22]. The structure of energy production by different energy facilities is shown in Fig. 2.

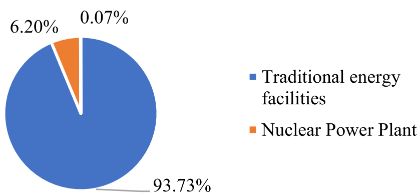

Fig. 2. The structure of energy production in Sverdlovsk region by the type of energy facility in 2020, %.
Source: Calculated by authors using data from [25].

A key role in energy production is played by traditional energy facilities, which are represented by TPP and CHPP. More than 51% of the energy produced is accounted for by the two largest CHPP in the region — Sredneuralskaya GRES and Reftinskaya GRES, the latter being the largest coal-fired power plant in Russia [26]. Fig. 3 shows the structure of the fuel balance of the electric power industry of the Sverdlovsk region.

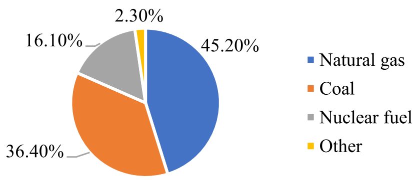

Fig. 3. Structure of the fuel balance of the electric power industry in the Sverdlovsk region in 2020, %.
Source: Calculated by authors using data from [25].

Natural gas and coal occupy 45.2% and 36.4% respectively, in the structure of fuel consumption by energy facilities. The use of coal and natural gas as fuel for electricity production leads to the formation of huge emissions of harmful substances into the atmosphere, and Reftinskaya GRES is the largest polluter of the region. Fig. 4 shows the dynamics of total emissions of harmful substances into the atmosphere in the region and the share of emissions by energy enterprises.

In 2014, the share of energy in the structure of emissions was 41.6%, by 2018 its share decreased to 31.4%. It is a positive trend that indicates the ongoing eco-modernization process of the regional energy sector. The total reduction in emissions by energy enterprises was 36.7%. The share of energy enterprises in the total discharge in

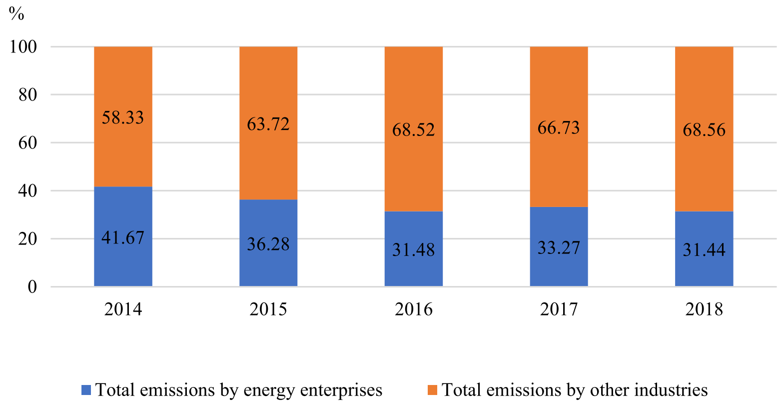

Fig. 4. Structure of emissions of harmful substances into the atmosphere in the Sverdlovsk region 2014–2018, thousand tons. *Source:* Calculated by authors using data from [25,27].

the Sverdlovsk region is about 3%: in 2018, 14.7 million m^3 of polluted wastewater was discharged, in 2014, this figure was 29.4 million m^3 [27]. Another positive trend is the reduction of waste generation by energy enterprises from 5,473 thousand tons in 2007 to 4,650 thousand tons in 2018. Reftinskaya GRES has the largest share in the structure of waste generation as it uses coal as the main fuel that leads to the formation of a huge amount of ash and slag waste.

The energy sector of the Sverdlovsk region is characterized by a surplus of capacity: the installed capacity of the entire power system of the region is more than 10,567 MW, while the level of energy generation as of 2018 was only 7,923 MW. The prevalence of traditional energy facilities operating on coal and natural gas is due to the availability and cheapness of natural energy resources in the domestic market of the Russian Federation. Due to the use of natural resources as the main fuel, energy enterprises produce a huge amount of emissions of harmful substances into the atmosphere, which worsens the environmental situation in the Sverdlovsk region.

3. Analysis of prospects of renewable energy's implementation in the energy sector of Sverdlovsk region

The key goals of the Sverdlovsk Region's energy development until 2024 are to achieve the energy comfort targets, achieve the targets of the Sverdlovsk Region's Environmental Safety Concept, and increase the share of small-scale generation and renewables in the regional energy production structure [25,28].

The main problems of the energy sector in the Sverdlovsk region are the deterioration of the main assets of the energy system, significant environmental pollution caused by energy enterprises and the lack of stable access to electricity in a number of localities.

The Sverdlovsk region has the potential for the development of small-scale generation and renewable energy: the climatic and geographical conditions are suitable for the use of small-scale hydropower and bioenergy. Solar energy and wind energy can also enter the energy system of the region, but their use is largely dependent on seasonality, which reduces their prospects. Further, the possibilities and barriers to the development of alternative energy sources in the territory of the Sverdlovsk region are considered.

3.1. Small hydropower development

Small hydropower is the most promising area of renewable energy development in the Sverdlovsk region. The river network of the region is represented by 18,414 rivers, most of which belong to streams and small rivers. On the territory of the region there are more than 100 reservoirs with a volume of water resources above 1 million m^3. The average annual river flow is 30.2 m^2/year [29]. Indicators of water resources, namely the area and number of reservoirs, swamps, wetlands are characterized by variability due to high dependence on natural and anthropogenic factors.

On the territory of the region there is the Verkhoturskaya HPP with an installed capacity of 7 MW, which was put into operation in 1949, and the Vogulskaya HPP, which has a capacity of 2.4 MW. Five mini-HPPs (Alapaevskaya, Afanasyevskaya, Verkhne-Sysertskaya, Irbitskaya and Rechkalovskaya) are abandoned.

The installation of large hydroelectric power plants in the region is impossible due to the prevalence of small rivers and streams in the water system of the region, but the development of small hydropower is possible [25]. Currently, the prospects of installing mini-hydroelectric power plants with a capacity of more than 1 MW in three localities (Serov, Verkhnyaya Tura, Kamensk-Uralsky) on existing hydraulic structures are being considered [21].

The government of the Sverdlovsk region estimates the total hydrological potential of the region at the level of 300 MW [25]. The list of hydraulic structures with an expected power level of more than 1000 kW consists of 13 items, the total power of which is 31,301 kW [21].

The main barriers to the development of small hydropower in the Sverdlovsk region are the following:

- a large number of artificial reservoirs, where a regulated spillway is made from a height of no more than 10 m [29];
- lack of large rivers;
- the need to attract a large amount of investment in the development of hydropower and the restoration of abandoned hydroelectric power plants.

Small hydropower could be effective in the production of electric energy for small settlements and remote territories of the Sverdlovsk region.

Prospective locations of small hydropower facilities in the Sverdlovsk region: Alapaevsky district, village Afanasievsky, village Upper Sysert, Irbitskiy district, Verkhotursky district, Serovsky district, Kamensk-Uralsky.

3.2. Biomass energy production

Bioenergy is also one of the key areas of renewable energy development in the Sverdlovsk Region. In the regional agricultural complex, livestock occupied more than 60% of its structure in 2019 [22]. The list of the largest livestock farms in the region includes three poultry farms, the Ural State farm, the Bogoslovsky State farm, and the Artinsky State farm. Table 2 shows the potential of bioenergy use in the Sverdlovsk region.

Table 2. Potential of biomass energy in Sverdlovsk region [21].

Type of animal	Livestock	Produced biogas, m^3/day	Replaceable fuel, tons of fuel equivalent/day
Cattle	309,000	750	750
Swine	194,000	62	60
Bird	11 million	214	200

Thus, the daily savings from the development of bioenergy can be about 1,010 tons of fuel equivalent/day or 368,650 tons of fuel equivalent/year [25]. The potential for the use of bioenergy in the region is 75 MW [22]. Despite the high energy potential, the production of energy from biomass remains an unclaimed area of eco-modernization of the fuel and energy complex. Barriers to the development of bioenergy in the Sverdlovsk region and in Russia are:

- insufficient level of the state support, lack of tax preferences for the bioenergy industry;
- low level of development of the bioenergy segment infrastructure;
- long payback period for bioenergy projects due to the large amount of initial investment;
- insufficient industrial base for the development of the bioenergy industry.

Bioenergy facilities should be located near large livestock enterprises.

Table 3. The average annual and maximum wind speed in large settlements of the Sverdlovsk region.
Source: Made by authors using data from [21,25,30].

The name of the settlement	Average annual wind speed at an altitude of 10 m, m/s	Maximum wind speed, m/s
Ekaterinburg	3.8	25
Alapaevsk	1.6	23
Bisert'	2.2	24
Verkhoturye	3.0	24
Visim (Gornouralsky o.)	2.8	22
Gary	3.0	25
Ivdel'	2.5	26
Irbit	2.6	22
Kamensk-Uralsky	1.4	17
Kamyshlov	2.4	21
Krasnoufimsk	1.5	20
Nevyansk	3.3	24
Nizhny Tagil	3.6	30
Revda	2.2	20
Severouralsk	1.5	25
Serov	2.2	24
Sysert	2.2	21
Tavda	2.3	23
mount Blagodat'	5.8	23

3.3. Wind energy development

Wind energy is one of the most promising areas of renewable energy development in the region. Table 3 provides data on the average annual and maximum wind speed in large settlements of the Sverdlovsk region provided by specialized sources.

The northern mountain regions of the Sverdlovsk region (spurs of the Ural Ridge) also have good wind availability, where the average annual wind speed is from 5.5 to 10 m/s [25]. Presumably, the construction of wind farms with a total capacity of up to 200 MW is possible in the region [21,22]. For the development of wind power in the region, it is necessary to install wind generators with a vertical axis of rotation, which allow generating electricity at wind speeds of 1 m/s.

The development of wind energy is possible only within the framework of the eco-modernization of the small-scale energy system, since the Sverdlovsk region does not have a high level of wind security as the leading countries of wind energy (in most regions of Germany and Spain, the average wind speed is 4–5 m/s).

Prospective location of wind power facilities in the Sverdlovsk region: Ekaterinburg, Kushvinsky district (Blagodat), Gornozavodsky district (Nizhny Tagil, village Gornozavodsk, etc.), Nevyansky district, village Gary, Verkhotursky district.

3.4. Solar energy development

To analyze the prospects for the development of solar energy in the Sverdlovsk region, we will analyze the changes in the value of solar insolation in Yekaterinburg, the largest city and administrative center of the region (Fig. 5). The required minimum level of daily solar insolation for the operation of solar power plants is 3.5 kWh/m^2.

The Sverdlovsk region has a small potential for the development of solar energy: the average annual level of daily solar insolation in Yekaterinburg is 3.45 kWh/m^2, for comparison, in Sochi, which is located in the south of Russia, the average value of this indicator is 4.46 kWh/m^2 [31].

One of the barriers to the development of solar power generation in the region is the insufficient level of daily solar insolation (less than 3.5 kWh/m^2) in the autumn–winter period. In this regard, it is possible to use solar energy at the level of individual households or small settlements in the spring and summer period for heating water and generating electricity. By 2025, the Government of the Sverdlovsk Region has included in the regional electricity

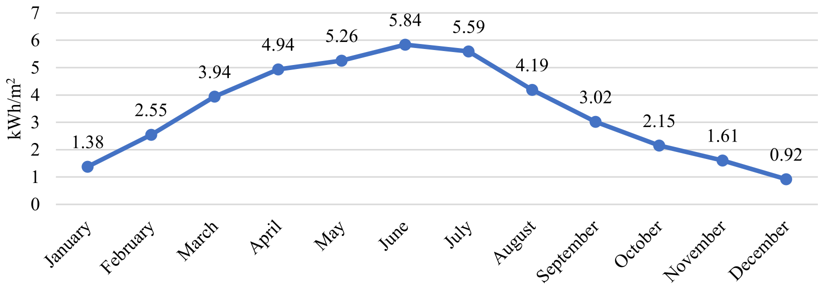

Fig. 5. Daily solar insolation from January to December in Ekaterinburg in Sverdlovsk region in 2019, kWh/m^2.
Source: Calculated by authors using data from [31].

scheme a project for the construction of solar power plants with a capacity of 28MW in the south of the region (Artinsky district) [25].

4. Results and discussion

Despite the ongoing measures for the eco-moderation of individual facilities, the energy industry of the Sverdlovsk region is one of the largest consumers of natural resources and environmental pollutants. The development of renewable energy in the region will significantly reduce the anthropogenic impact on the environment. Table 4 shows the SWOT-analysis of the energy sector of the Sverdlovsk region.

Table 4. Results of SWOT-analysis of the energy sector in Sverdlovsk region.

Strengths	Weaknesses
1. Excess capacity of the region's power system 2. Development and implementation of joint projects of the Government of the Sverdlovsk region and regional energy enterprises in the field of eco-modernization of the industry. 3. Ongoing reconstruction and eco-modernization of individual energy facilities 4. A sustainable electricity market. 5. Growing demand for electricity in the region due to the implementation of major investment projects. 6. The solvency of consumers. 7. Well-developed animal husbandry. 8. High potential of the region in developing the small-scale renewables.	1. Insignificant reserves of natural resources (natural gas, coal) in the territory of the Sverdlovsk region. 2. Significant predominance (more than 90%) of traditional energy facilities in the structure of energy production. 3. Depreciation of fixed assets of the power system, which leads to an increased risk of accidents 4. Some localities in the region are not covered by centralized power supply. 5. High level of environmental pollution by energy companies. 6. High capital intensity of the industry.
Opportunities	**Threats**
1. Fostering the small-scale hydropower generation in the region in order to provide small settlements with stable access to electricity. 2. The bioenergy sector's development by implementing the bioenergy stations near the largest livestock. 3. Development of the wind energy in places with the sufficient level of wind availability. 4. Increase in the use of solar panels within individual households. 5. Increase in the share of renewables in the structure of energy production in the immediate future. 6. Improving the efficiency of the use of natural resources by energy enterprises.	1. The emergence of environmental threats at traditional energy facilities. 2. High risks of power outages in the region due to heavy depreciation of fixed assets. 3. The growth of domestic prices for energy carriers (coal, natural gas) and, consequently, the increase in the cost of electricity.

The mentioned weaknesses might lead to serious threats to the energy security of the region and do not correspond to the concept of sustainable development.

The development of green energy in the territory of the Sverdlovsk region is possible as part of the eco-modernization of the small-scale generation system to ensure stable access to electricity in remote regions of the

Table 5. Evaluation results of RES development in Sverdlovsk region.

Type of RES	Potential capacity, MW	Ways of development	Barriers of development
1. Small hydropower	300	• installation of mini-hydroelectric power plants at existing hydropower facilities with a capacity of 1 MW or more; • restoration of abandoned hydroelectric power plants; • construction of new hydroelectric power plants to provide clean electricity to remote areas of the region.	• a large number of artificial reservoirs, where an adjustable spillway is made from a height of no more than 10 meters; • lack of large rivers; • the need to attract a large amount of investment in the development of hydropower, including the restoration of abandoned hydroelectric power plants.
2. Biomass energy	75	• construction of bioenergy stations near large livestock farms to provide them and the nearest settlements with electricity.	• insufficient level of state support, lack of tax preferences for the bioenergy industry; • long payback period for bioenergy projects due to the large amount of initial investment; • insufficient industrial base for the development of the bioenergy industry.
3. Wind energy	200	• construction of wind farms in the northern (mostly mountainous) regions of the region and in a number of large settlements with wind capacity of more than 3 m/s.	• it is possible to use wind turbines only with a vertical axis of rotation; • the uneven level of wind supply in the region, which makes it possible to build wind farms only in certain areas.
4. Solar energy	28	• use of solar panels by individual households in spring and summer; • construction of small SES near small settlements	• insufficient level of solar insolation for energy production in the autumn–winter period; • the inability to produce energy on a large scale due to the geographical and climatic features of the region.

region and small settlements. Table 5 shows the results of the assessment of the implementation of various RES in the territory of the Sverdlovsk region and the identified barriers to development.

Thus, the potential of RES use in the territory of the Sverdlovsk region is 603 MW or 5.7% in the structure of the total regional energy capacity. The most promising direction of renewables development is the small hydropower sector (potential capacity of 300 MW).

The potential of bioenergy development was estimated by the authors at 75 MW that corresponds to the results of the study [20]. It should be noted that energy production is also possible from organic and inorganic waste, plant and forest residues, and sewage sludge. Namsaraev Z.B. and others in the article [32] estimate that more than 10% of the electricity produced in the Ural Federal District, of which the Sverdlovsk Region is a part, can be produced by bioenergy enterprises.

The results obtained in the framework of the development of wind energy generally correspond to the results of the work of other scientists. For example, in [8], the technical potential of wind energy use in the Sverdlovsk region is estimated to be quite low (90–120 million MWh/year). Despite the relatively low wind availability indicators, it is possible to use wind energy as autonomous power systems in the region, while the implementation of large-scale projects for the construction of large wind farms can be unprofitable in terms of the amount of investment spent and the final energy production.

The least promising direction of renewable energy development in the Sverdlovsk region is solar energy. In [20,21], scientists pointed out high prospects for the use of solar energy at the level of individual households for heating water in the spring and summer period. Serga L., Chemezova E. and others note that the Ural Federal District, of which the Sverdlovsk Region is a part, is included into the list of regions where the development of solar energy is necessary to ensure stable access of the population to electricity [33].

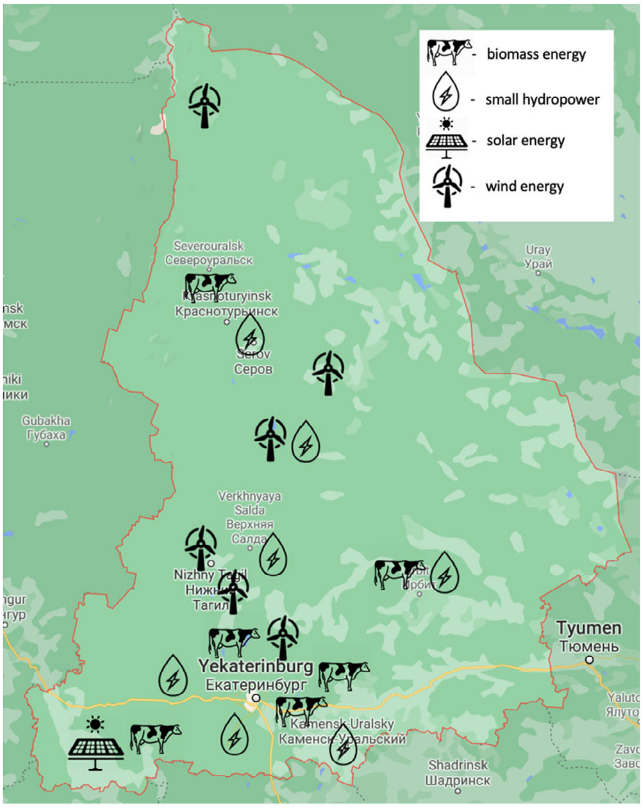

Fig. 6. A map of perspective implementation of various RES in the Sverdlovsk region.

The development of renewable energy in the Sverdlovsk region is a promising direction of eco-modernization of the regional energy sector that will increase the energy security of the region and to some extent reduce the negative impact of energy on the environment. The location of potential RES facilities is shown in Fig. 6.

The most promising areas for the development of renewable energy are the south of the Sverdlovsk region and its central part. The uneven distribution of the potential for using alternative energy sources is due to climatic, geographical and partly economic factors (for example, the restoration of abandoned mini-HPPs may be more profitable than the construction of new ones due to the availability of the necessary infrastructure).

Due to administrative, economic and natural barriers, it is currently impossible to fully replace traditional renewable energy in the region. However, the development of small-scale generation and renewable energy will increase the energy security of the region, reducing the anthropogenic impact on the environment and ensuring access to inexpensive and relatively clean electricity for the entire population of the Sverdlovsk region.

5. Conclusion

The development of green energy is one of the priority areas for the energy sector development in the Sverdlovsk region. The region has the greatest potential in the field of hydropower and wind energy, which together can produce up to 500 MW of energy. Solar energy has the least potential in the region: most of the year, the level of insolation is below the necessary standards which are required for electricity production.

Based on the given results, the authors identified the following assumptions regarding the green energy development in the Sverdlovsk region:

- green energy might currently replace no more than 6% of the total energy production in the region;
- bioenergy has a great potential for growth in the region: the predominance of animal husbandry in the structure of agriculture allows to use a huge amount of animal waste for energy production in the future;

- construction and use of bioelectric power plants near large livestock farms allow to generate electricity for the needs of livestock enterprises and small settlements that are located near them;
- the development of wind power and small hydropower might ensure stable access of remote territories and small settlements of Sverdlovsk region to the clean energy;
- it is necessary to attract a large amount of investment for the full development of renewable energy in the region.

Thus, it can be concluded that renewables might considerably reduce the anthropogenic impact of the energy sector on the environment, but in order to achieve the goals set by the Government of the Sverdlovsk region in the framework of environmental protection, it is necessary to conduct a large-scale eco-modernization of existing traditional energy facilities, in particular, such a large polluter as Reftinskaya GRES.

Based on the results of the study, the authors identified the following areas of eco-modernization of regional energy in Russia:

- development and implementation of environmental technologies at the traditional energy facilities [34];
- amendment of ecological legislation that will force energy enterprises in Russia to decrease emissions of harmful substances by using new technologies;
- development of renewable energy in Russian regions through construction solar power plants, wind farms, biomass plants, etc.;
- investment attraction to the green energy by ensuring the state support for the enterprises that work on the green energy projects;
- enhancing the approaches to the ecological and economic assessment of investment projects in the energy sector [35];
- increasing environmental awareness among the population [36].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

This research was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0006.

References

[1] The Ministry of Energy of the Russian Federation. Main characteristics of the russian electric power industry. 2021, https://minenergo.gov.ru/node/532. [Accessed 25 April 2021].

[2] Oil market in 2020. The Federal State Statistics Service; 2021, https://www.gks.ru/bgd/free/B04_03/IssWWW.exe/Stg/d02/33.htm. [Accessed 30 April 2021].

[3] National report on the environment in 2019. 2021, [in Russia]. https://www.mnr.gov.ru/docs/gosudarstvennye_doklady/proekt_gosudarstvennogo_doklada_o_sostoyanii_i_ob_okhrane_okruzhayushchey_sredy_rossiyskoy_federat2019/. [Accessed 30 April 2021].

[4] Report on human development in russia: Sustainable development goals UN and russia. 2021, https://ac.gov.ru/files/publication/a/11068.pdf. [Accessed 28 April 2021].

[5] Markovska N, Taseska-Gjorgievska V, Pop-Jordanov J. SWOT analyses of the national energy sector for sustainable energy development. Energy 2009;34(6):752–6. http://dx.doi.org/10.1016/j.energy.2009.02.006.

[6] Proskuryakova L, Ermolenko G. The future of Russia's renewable energy sector: Trends, scenarios and policies. Renew Energy 2019;143:1670–86. http://dx.doi.org/10.1016/j.renene.2019.05.096.

[7] Kapitonov I, Voloshin V, Filosofova T, Syrtsov D. Development of experience in the application of technologies in the field of alternative energy: World experience, Russian practice. Renew Energy 2021;165(1):773–82. http://dx.doi.org/10.1016/j.renene.2020.11.063.

[8] Kudelin A, Kutcherov V. Wind energy in Russia: The current state and development trends. Energy Strategy Rev 2021;34:100627. http://dx.doi.org/10.1016/j.esr.2021.100627.

[9] Ivanova I, Korneev A, Tuguzova T. Assessment of feasible power supply options for new projects in the Arctic zone of the Republic of Sakha (Yakutia). In: International multi-conf. on ind. eng, and mod. technol. 2019, p. 8934060. http://dx.doi.org/10.1109/FarEastCon.2019.8934060.

[10] Ivanova I, Pasechnikov T. Experience of solar-diesel power plant introduction in the village of Nerkha of the Irkutsk region. In: E3S web conf. 7704004. 2019, http://dx.doi.org/10.1051/e3sconf/20197704004.

[11] Karamov D. Autonomous renewable energy systems in Russia. Critical review of the current situation. Energy Rep 2020;6(9):31–7. http://dx.doi.org/10.1016/j.egyr.2020.10.033.

[12] Haines JR. The geopolitics of russia's networked energy infrastructure. Orbis 2015;59(4):557–99. http://dx.doi.org/10.1016/j.orbis.2015.08.010.

[13] Kyzyngasheva E, Proskuryakova L. Global energy trends and their implications for russia: a pathway to the new energy wave. 2016, https://publications.hse.ru/mirror/pubs/share/folder/j54ivqykw2/direct/186802241.

[14] Cherp A, Kopteva I, Mnatsakanian R. Economic transition and environmental sustainability: effects of economic restructuring on air pollution in the Russian Federation. J Environ Manag 2003;68(2):141–51. http://dx.doi.org/10.1016/S0301-4797(03)00018-5.

[15] Lanshina T, Laitner J, Potashnikov V, Barinova V. The slow expansion of renewable energy in Russia: Competitiveness and regulation issues. Energy Policy 2018;120:600–9. http://dx.doi.org/10.1016/j.enpol.2018.05.052.

[16] Salonen H. Modernization of Russian district heating systems with the help of biomass energy – A Gordian knot? Environ Innov Soc Trans 2020;36:291–302. http://dx.doi.org/10.1016/j.eist.2019.10.006.

[17] Tsvetkov NA, Krivoshein UO, Tolstykh AV, Khutornoi AN, Boldyryev S. The calculation of solar energy used by hot water systems in permafrost region: An experimental case study for Yakutia. Energy 2020;210:118577. http://dx.doi.org/10.1016/j.energy.2020.118577.

[18] Pristupa A, Mol APJ. Renewable energy in Russia: The take off in solid bioenergy? Renew Sustain Energy Rev 2015;50:315–24. http://dx.doi.org/10.1016/j.rser.2015.04.183.

[19] Denisov S, Denisova M. Analysis of hydropower potential and the prospects of developing hydropower engineering in south ural of the russian federation. Proced Eng 2017;206:881–5. http://dx.doi.org/10.1016/j.proeng.2017.10.567.

[20] Low-carbon future for the Sverdlovsk Region: opportunities and prospects. 2021, [in Russian]. http://rusecounion.ru/sites/default/files/UES_48.pdf. [Accessed 20 April 2021].

[21] Modern problems of renewable energy and energy saving (Lectures and Seminars): The potential of renewable energy sources in reducing the environmental burden of the sverdlovsk region. 2021, http://media.ls.urfu.ru/604/1664/3998/. (Accessed 22 April 2021].

[22] Department of the federal state statistics service for the sverdlovsk region and the kurgan region. 2021, https://sverdl.gks.ru/. [Accessed 20 April 2021].

[23] Official page of beloyarskaya nuclear power station. 2021, https://www.rosenergoatom.ru/stations_projects/sayt-beloyarskoy-aes/. [Accessed 21 April 2021].

[24] Natural resources of Sverdlovsk region. 2021, http://midural.ru/100034/100083/100294/. [Accessed 21 April 2021].

[25] Scheme and program development of the electric power industry of Sverdlovsk region for 2020–2024. 2021, http://www.pravo.gov66.ru/media/pravo/214-%D0%A3%D0%93_tvOvHVX.pdf. [Accessed 21 April 2021].

[26] Official page of reftinskaya GRES. 2021, https://sibgenco.ru/about/company/generation/reftinskaya-gres/. [Accessed 21 April 2021].

[27] Statistical review on air pollution in Sverdlovsk region. 2019, https://mprso.midural.ru/article/show/id/10008. [Accessed 21 April 2021].

[28] Environmental Management and Environmental Safety Strategy of Sverdlovsk region for the period up to 2035. 2021, http://www.pravo.gov66.ru/media/pravo/353-%D0%9F%D0%9F_NYq84LD.pdf. [Accessed 21 April 2021].

[29] Water in Russia: Sverdlovsk region. 2021, https://water-rf.ru/%D0%A0%D0%B5%D0%B3%D0%B8%D0%BE%D0%BD%D1%8B_%D0%A0%D0%BE%D1%81%D1%81%D0%B8%D0%B8/2564/%D0%A1%D0%B2%D0%B5%D1%80%D0%B4%D0%BB%D0%BE%D0%B2%D1%81%D0%BA%D0%B0%D1%8F_%D0%BE%D0%B1%D0%BB%D0%B0%D1%81%D1%82%D1%8C. [Accessed 25 April 2021].

[30] Energy Wind: The average speed of wind in Sverdlovsk region. 2021, http://energywind.ru/recomendacii/karta-rossii/ural/sverdlovskaya-oblast. [Accessed 24 April 2021].

[31] Daily solar insolation in ekaterinburg. 2021, https://www.betaenergy.ru/insolation/ekaterinburg/. [Accessed 21 April 2021].

[32] Namsaraev Z, Gotovtsev P, Komova A, Vasilov R. Current status and potential of bioenergy in the Russian Federation. Renew Sustain Energy Rev 2018;81(1):625–34. http://dx.doi.org/10.1016/j.rser.2017.08.045.

[33] Serga L, Chemezova E, Makaridina E, Samotoy N. Analysis of prospects of using solar energy in russian federation economy. Proced CIRP 2016;40:41–5. http://dx.doi.org/10.1016/j.procir.2016.01.04.

[34] Sabyrzhan A, Balgimbekova G, Shestak V. Economic and legal regulation of the use and development of renewable energy sources. Sci J VolSU Ser 3 Econ Ecol 2019;21(1):92–9. http://dx.doi.org/10.1007/s10784-021-09532-9.

[35] Karaeva A, Magaril E, Rada EC. Improving the approach to efficiency assessment of investment projects in the energy sector. WIT Trans Ecol Environ 2020;246:113–23. http://dx.doi.org/10.2495/EPM200111.

[36] Karaeva A, Cioca L-I, Ionescu G, Magari El, Rada EC. Renewable sources and its applications awareness in educational institutions. In: Proceedings of 2019 international conf. on energ. and environ. CIEM; 2019, p. 338–42. http://dx.doi.org/10.1109/CIEM46456.2019.8937582.