




An Economic and Geographical Analysis of Solar Power Plant Potential in Russian Federation Regions

R. Ibragimov*, R. Salimgareev , O. Kantor

Ufa State Petroleum Technological University, Russia
ibragimovren@mail.ru

Abstract. In the context of the global energy transition and the increasing importance of sustainable development, the issues of rational placement of renewable energy facilities are becoming particularly relevant. In this paper, an assessment of the economic and geographical potential of solar power plants (SES) on the territory of the Russian Federation is carried out on the basis of spatial analysis of NASA POWER data. Using geoinformation analysis tools and visualization methods, the regions with the highest levels of solar insolation have been identified. An economic calculation of the profitability of a 100 MW SES project was carried out using the example of the Krasnodar Krai, which showed the payback period for the project over a horizon of 6-7 years. The results obtained can serve as a basis for strategic planning in the field of renewable energy sources development in the Russian Federation.

Keywords: solar energy, SES, insolation, renewable energy sources, geoinformation analysis, economic efficiency, NASA POWER.

1 Introduction

Modern energy development is characterized by a steady increase in the share of renewable energy sources (RES) in the total energy balance. Solar generation is becoming one of the key areas, attracting attention both due to the reduction of capital costs (CAPEX) and the high speed of project deployment. In the context of Russia, which has a significant territory and diverse climatic conditions, it is strategically important to identify economically viable regions for the SES location.

The importance of studying the potential of solar energy in Russia is due not only to environmental aspects, but also to the need to reduce dependence on fossil fuels. At the same time, the development of solar energy systems can act as a driver for the diversification of regional economies, create new jobs, and stimulate the development of local production of photovoltaic module components and energy storage systems. Thus, the analysis of the economic and geographical factors of the SES location acquires an interdisciplinary character, combining energy, climate and socio-economic aspects.

2 The state of renewable energy in the world and in the Russian Federation

According to the International Energy Agency REN21, renewable energy accounted for about 28% of global electricity generation in 2022. Investments in renewable energy sources and fuels have been growing for several years in a row and have already reached 366 billion dollars, and the record growth in global electricity production has led to solar and wind energy providing more than 10% of global electricity production for the first time in history [1]. According to the Energy Institute data for 2022 (Table 1), traditional energy sources such as coal and gas still account for the predominant share in total electricity production, but the role of modern renewable energy sources is growing every year [2].

According to the International Renewable Energy Agency IRENA, the leaders in installed capacity in the solar energy sector are China (609.92 GW), the United States (139.21 GW), Japan (87.07 GW), Germany (81.74 GW), India (73.11 GW) [3]. The leaders in installed capacity in the wind energy sector are China (441.89 GW), the USA (148.02 GW), Germany (69.46 GW), India (44.74 GW), Spain (31.03 GW) [4].

Global practice shows that the development of solar energy is often accompanied by the active introduction of technological innovations and localization of equipment production. For example, in China and India, there is an increase in national production capacities for the production of photovoltaic modules and inverters, which significantly reduces the cost of projects. A similar import substitution strategy can be applied in Russia, where there is an industrial and scientific potential to create its own production base of renewable energy components.

The introduction of hybrid systems combining solar panels with energy storage devices and other renewable energy sources is becoming a promising area for the development of solar energy. This makes it possible to smooth out daily and seasonal fluctuations in generation, increasing the reliability of energy supply.

In Russia, the share of wind and solar power generation remains insignificant – 0.5% [2]. However, the government is following current trends and is starting to implement programs to support the development of renewable energy sources within the framework of the Capacity Supply Agreement mechanism (DPM-RES), which stimulates the construction of SES and wind farms in a number of regions. For example, in the framework of the PDM-renewable energy, investors build power plants, winning the selection of projects on a competitive basis, and the state guarantees a return on investment through a surcharge to the price of capacity on the wholesale market. The support is funded by consumers of the wholesale electricity market (industry, large consumers).

Regional programs and municipal initiatives are of particular importance in the development of renewable energy. Thus, a number of subjects of the Russian Federation are already implementing projects of small solar power plants focused on energy supply to remote settlements and agricultural sector facilities. These initiatives demonstrate the possibility of forming decentralized energy systems that reduce the burden on centralized networks and increase the energy sustainability of regions.

Table 1. Share of electricity production by source in 2023

Type of electricity source	Share, %
coal	35.51
gas	22.47
hydropower	14.28
nuclear power industry	9.11
wind energy	7.82
solar energy	5.53
oil	2.67
bioenergy	2.30
other renewable energy sources	0.30

However, the implementation of SES and WPP projects in Russia is associated with a number of institutional and infrastructural barriers. Among them are: limited areas with high insolation or the necessary wind speed and proximity to energy-consuming centers, high capital intensity of projects, as well as a shortage of qualified personnel in the field of renewable energy design and operation. These factors necessitate an integrated approach to the selection of sites for the construction of SES and wind farms, taking into account not only the natural and climatic, but also the socio-economic characteristics of the territories.

3 Methodology for assessing the insolation potential

In order to identify the regions optimal from the point of view of insolation, an array of NASA POWER climate data was used to accommodate the SES. This source provides highly accurate retrospective and forecast climate information, including data on solar radiation, clouds, temperature, and other parameters critical for calculating the efficiency of solar installations.

To identify regions with the highest insolation potential, open climate data from the NASA POWER API was used, representing the average long-term values of solar radiation to the surface under clear sky conditions (CLRSKY_SFC_SW_DWN). The data was processed in a Python environment using the pandas, geopandas, shapely, and folium libraries. A regular grid of coordinates with 1° increments was constructed throughout Russia, data was aggregated within the borders of the subjects of the Russian Federation, and the values obtained were visualized as an interactive map (see Fig. 1).

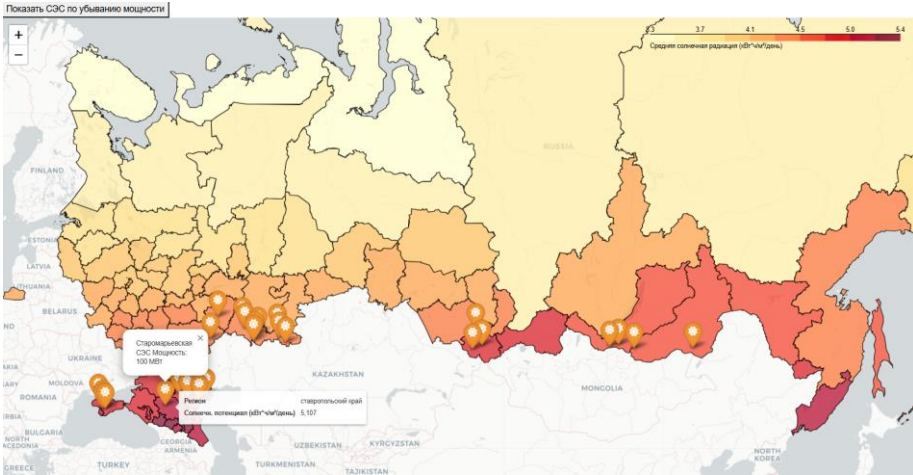


Fig. 1. Interactive map of potential SES location regions and existing SES.

About 5000 points were obtained on the territory of the Russian Federation. Monthly and annual average values of global solar radiation per horizontal surface (GHI) under clear sky conditions were calculated for each of the points. Based on the data obtained, a map of the distribution of the insolation potential was built, integrated into the administrative-territorial borders of the regions of the Russian Federation using the GeoPandas library.

According to the results of the analysis, it was found that the highest GHI values (about 5.0 kWh/m²/day) were recorded mainly in the southern regions of the Russian Federation. At the same time, in most regions of Siberia, the Urals and the Northwest, GHI values do not exceed 2.5-3.2 kWh/m²/day, which makes the construction of solar power plants in these areas economically difficult without significant government support.

The data obtained make it possible to conduct a preliminary ranking of regions by the level of solar potential (Table 2), which can serve as the basis for selecting pilot sites for the development of SES projects.

Table 2. List of regions of the Russian Federation by annual average value of insolation

Region	GHI values, kWh/m ² /day
Kabardino-Balkarian Republic	5.38
Karachay-Cherkess Republic	5.33
Republic of North Ossetia-Alania	5.32
Republic of Ingushetia	5.28
The Chechen Republic	5.23
Stavropol Krai	5.11
Republic of North Ossetia	5.09

Republic of Adygea	5.05
Primorsky Krai	5.04
Republic of Dagestan	5.02
Sevastopol	5.02
Republic of Crimea	4.90
Krasnodar Territory	4.88
Altai Republic	4.86
Republic of Kalmykia	4.85
Republic of Tyva	4.84
Astrakhan Region	4.82
The Jewish Autonomous Region	4.81
Rostov Region	4.74
Sakhalin Region	4.68

When analyzing the results obtained, it is important to take into account seasonal fluctuations in insolation. Thus, in most southern regions, the peak of solar activity occurs in May–August, which coincides with increased demand for electricity for air conditioning and irrigation systems. This creates prerequisites for balanced energy exchange within regional energy systems and minimizes the need for excess energy storage. In the northern regions, on the contrary, there is a pronounced seasonality, requiring the combination of SES with other types of generation – wind and hydraulic installations.

4 The economic model of the 100 MW SES project in the Krasnodar Krai

The key task in the field of generating facilities operating on the basis of the use of renewable energy sources is to increase the efficiency of using generation based on renewable energy sources in order to ensure the competitiveness of such generating facilities within the framework of market mechanisms for the return on investment [5]. The implementation of this task is especially relevant in regions with high potential for the development of local generation, one of which is the Krasnodar Territory. Despite the high level of socio-economic development, the region faces a number of constraints related to ensuring reliable and sustainable energy supply.

The Krasnodar Krai is a region whose pace of development is limited by the complexity of solving the problem of energy supply to all potential consumers. Multilevel and complex terrain, a variety of climatic zones, a large area (Krasnodar Krai is one of the largest regions in the European part of Russia) with a high density of settlement and development, without the concentration around several settlements typical for the eastern regions of the country and the presence of a large number of subjects in need of low and medium-power energy supply, which due to the nature of their activities, and first

of all, these are entities engaged in agricultural activities, they are located at a distance both from the main power grids and from each other [6].

At the same time, the region has significant natural prerequisites for the introduction of renewable energy generation facilities. Krasnodar Region is characterized by a high level of solar insolation (on average 4.88 kWh/m²/day), mild climate and affordable land infrastructure. The region is located in the Southern Federal District and has an advantageous geographical location. In addition, in the Krasnodar Territory there is a high proportion of energy consumption covered from external sources, which increases the relevance of local generation.

Capital expenditures for construction and commissioning play an important role in the economic efficiency of implementing projects with SES. In 2019, PJSC Fortum announced specific capital expenditures of less than 50 rub./VT for the SES project in the Stavropol Krai, which was a record low [7].

The following parameters were used to calculate economic indicators: installation capacity of 100 MW, average annual solar radiation (GHI) of 4.88 kWh/m²/day, efficiency of Longi Solar LR5-72HPH-550M solar panels of 21.5% with a surface area of 2.58 m², construction cost of 1 MW of SES of 50 million rubles, operating costs of 2%, selling price The price of electricity is 5 rub./kWh.

Under these conditions, one panel generates approximately 2.71 kWh of electricity per day, or about 989 kWh per year (1):

$$\text{Insolation} \times \text{Panel area} \times \text{Efficiency} \times 365 = E \quad (1)$$

To achieve the installed capacity of 100 MW, approximately 181.8 thousand photovoltaic panels rated at 550 W each are required. The total annual electricity generation of the plant is therefore estimated at around 179.8 million kWh.

The total surface area of the photovoltaic modules amounts to approximately 0.47 million m². Taking into account the ground coverage ratio (GCR = 0.35), the total land area required for the installation of the solar arrays is estimated at about 134 hectares.

Assuming an average electricity selling price of 5 rub./kWh in the Krasnodar Krai, the annual revenue from electricity generation is estimated at 899 million rubles. The annual operating expenses, taken as 2% of the total capital expenditures (5 billion rubles), amount to about 100 million rubles. Accordingly, the net annual income is estimated at 799 million rubles, and the expected payback period of the 100 MW solar power plant project is approximately 6.26 years.

5 Conclusions and recommendations on the deployment of SES in the regions of Russia

The insolation potential of Russia is unevenly distributed, the highest values of solar radiation are observed in the southern regions, primarily in the North Caucasus and Southern Federal Districts, as well as in the southern parts of the Siberian and Far Eastern Federal Districts. These territories demonstrate average annual insolation values exceeding 4.5-5.5 kWh/m²/day, which makes projects for the construction and commissioning of SES are cost-effective.

The conducted modeling for the Krasnodar Krai shows that at the current level of investments and tariffs, the payback period may be less than 7 years, which indicates the high investment attractiveness of the region.

The development of a federal zoning scheme for solar potential, based on data from remote sensing of the Earth and climate modeling, will make it possible to more effectively form public and private investment programs for SES.

An important area of further research may be the development of scenarios for the integration of SES into regional energy systems, taking into account seasonal and daily load fluctuations. This will increase the stability of the energy balance and reduce the risks of underutilization of capacity during periods of low demand.

In the future, it is advisable to consider the possibility of integrating solar power plants with energy storage systems and smart Grids, which will increase the flexibility of energy supply and reduce dependence on weather factors. Using the results of geospatial analysis in the planning of energy infrastructure will ensure a rational distribution of generating capacities and will contribute to achieving the goals of the energy strategy of the Russian Federation until 2035.

To improve the accuracy of forecasts for the development of solar energy, it is advisable to use machine learning and artificial intelligence methods. Such approaches make it possible to analyze large amounts of climate and economic data, identify hidden dependencies, and model industry development scenarios with different levels of support and climate change. The integration of AI technologies into planning and monitoring processes can be a key factor in improving the effectiveness of energy policy at the national level.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article.

References

1. REN21, https://www.ren21.net/wp-content/uploads/2019/05/GSR2022_Full_Report.pdf, last accessed 2026/02/07
2. Statistical Review of World Energy 2024, https://www.ren21.net/wp-content/uploads/2019/05/GSR2022_Full_Report.pdf, last accessed 2026/02/07
3. Our World in Data, <https://ourworldindata.org/grapher/installed-solar-pv-capacity?tab=table>, last accessed 2026/02/07
4. Our World in Data, <https://ourworldindata.org/grapher/cumulative-installed-wind-energy-capacity-gigawatts?tab=table>, last accessed 2026/02/07
5. Government of the Russian Federation, <http://static.government.ru/media/files/LWYf-SENa10uBrrBoyLQqAAOj5eJYIA60.pdf>, last accessed 2026/02/07
6. R. A. Amerkhanov, E. G. Armaganyan, V. V. Dvorny et al.; Possibilities of using renewable energy sources in the Krasnodar Territory. In: International Scientific Journal Alternative Energy and Ecology, pp. 12–25. Space, Krasnodar (2015)
7. A. V. Podlesnaya Renewable energy auctions in Russia: Has competition led to lower project costs?. In: Moscow University Bulletin. Series 6, pp. 151–182. Moscow University Bulletin, Moscow (2025)

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.

