Potential and Risk Identification of Solar Generation Development in the Republic of Tatarstan

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Abstract: The relevance of this work is associated with the entry into force of the federal law of 02.07. 2021 № 296 "On limiting greenhouse gas emissions" and the need for a partial transition to affordable and environmentally friendly sources of power supply. One of such sources is solar energy. The purpose of the work is to determine the potential of solar energy in the Republic of Tatarstan, identification and risk assessment of projects for construction of solar generation facilities. The work determines insolation in the region as a whole and districts, in particular. Also identified the potential power output of generation facilities of different levels with the calculation of conventional crystalline silicon (C-Si) modules as the most common technology in the market of solar photovoltaic systems. The factors influencing the development of solar power generation are considered. A SWOT analysis has been conducted in view of the research findings on the potential for realization of different level of solar power generation projects. Identification and assessment of risks was carried out with determination of the degree of damage and probability. Risk management opportunities were identified for the identified risks: training of specialists abroad and in Russia (opening of new educational programs), the need and possibility of developing autonomous stations, long-term guarantees from manufacturers of equipment components, localization of PV module production.

1 INTRODUCTION

In recent years, solar energy has been actively developing. New technologies are being developed to increase the efficiency of solar panels, expand the range of operating temperatures (for different regions). The advantages of solar energy, in addition to renewability and environmentally friendly operation, include silence, the possibility of autonomous use of power plants, application in various spheres. The disadvantages of solar energy are high cost of solar panels, use of rare-earth metals for their production, irregularity of power generation, as well as problems of utilization of spent solar modules.

Currently, solar energy is not so widespread in Russia, but modern technologies in this field and their rapid development suggest the possibility of further development of this type of generation in our country.

The purpose of the work is to determine the potential of solar energy in the Republic of Tatarstan, identification and risk assessment of projects for the construction of solar generation facilities. Design and construction of solar power plants are long and complex processes with a large number of surveys for site selection, consideration of climatic conditions and equipment selection, feasibility studies, etc. All these items require financial investments. Consequently, before the financial investment phase, it can be very useful to get a first idea of the future energy output at the beginning of the process in order to consider the risks and make sure that the project is profitable (Kou, Pamucar, Dinçer, Yüksel, 2023; Strielkowski, Civín, Tarkhanova, Tvaronavičienė, Petrenko, 2021).

Solar atlases are often used for this purpose. A solar atlas is a dataset that provides at a particular location an estimate of the solar resource, average daily amounts of solar radiation, direct normal

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irradiance, horizontal irradiance, optimal angle oblique irradiance, etc. (Wald, 2019). In recent years, the use of solar atlases has accelerated with the development of open access datasets such as Global Solar Atlas.

The estimation of solar resource generation for a particular area by Global Solar Atlas are suitable for preliminary studies because they consider default values for many factors that are important for the selection of solar power plant sites.

2 MATERIALS AND METHODS OF RESEARCH

The paper uses general scientific methods of comparative analysis, study of information sources, SWOT-analysis.

The source materials for the analysis are the data obtained from Global Solar Atlas. In the work direct normal irradiation, global oblique irradiation under the optimal angle of day and year for the Republic of Tatarstan are determined. The results are given in the form of a histogram. Also the existing technologies in solar energy were analyzed with determination of the acceptable ones for this region.

Identification of risks of projects for construction of solar energy facilities was carried out according to the results of SWOT-analysis. The list of the most significant risk factors was determined using the Delphi method.

3 RESEARCH RESULTS

3.1 Solar insolation of the Republic of Tatarstan

For preliminary assessment of the insolation level of the Republic of Tatarstan and potential power generation, data were obtained from literature sources and Global Solar Atlas (Torres, Petrakopoulou, 2022).

Average values of indicators for April 2024 from the Global Solar Atlas for Tatarstan are given in Table 1.

Direct normal irradiation and global oblique irradiation at an optimal angle for the Republic of Tatarstan during a year are shown in Fig. 1 and 2.

According to the radiation maps it can be seen that insolation of the territory of Tatarstan is almost uniform. There is a slight decrease in insolation against the general background of the northern and northeastern part of the Republic.

Table 1: Map data.

Indicator	Meaning	Unit of measurement
Specific photovoltaic output power	1094,9	kWh/kWp
Direct normal irradiation	1079,1	kWh/m^2
Global horizontal irradiation	1092,0	kWh/m^2
Diffuse horizontal irradiation	518,4	kWh/m^2
Global oblique radiation at an optimal angle	1293,9	kWh/m^2

Figure 1: Direct normal exposure in the Republic of Tatarstan.

Figure 2: Global oblique radiation at an optimal angle.

Values of direct solar radiation and inclined radiation at an optimal angle (W/m²) by districts of the Republic of Tatarstan are given in Table 2.

Table 2: Insolation by districts of Tatarstan.

Municipal districts (urban districts)	Specific photovoltaic power output PVOUT, kWh/kWp	Direct normal irradiation DNI, kWh/m^2	Diffuse horizontal irradiation DIF, kWh/m^2	Global tilted irradiation at optimum angle GTI opta, kWh/m^2
Agryzsky	1090,1	1070,6	515,1	1285,0
Aznakaevsky	1118,0	1108,3	522,7	1315,8
Aksubaevsky	1108,1	1092,4	524,8	1310,8
Aktanyshsky	1107,4	1101,9	513,9	1306,5
Alekseevsky	1122,7	1113,4	520,1	1323,7
Alkeevsky	1119,8	1096,7	528,4	1324,6
Almetyevsky	1115,6	1099,5	520,6	1316,0
Apastovsky	1111,4	1089,5	524,0	1313,2
Arsky	1097,9	1068,1	517,9	1292,7
Atninsky	1096,1	1071,2	517,1	1291,5
Bavlinsky	1137,7	1126,2	523,4	1339,3
Baltasinsky	1100,0	1077,1	514,7	1297,1
Bugulminsky	1125,5	1113,2	523,4	1325,6
Buinsky district	1113,7	1093,1	527,8	1316,9
Verkhneuslonsky	1110,2	1098,8	520,6	1313,6
Vysokogorsky	1095,8	1071,0	517,9	1291,7
Drozhzhanovsky	1111,4	1084,3	532,2	1315,1
Yelabuzhsky	1095,2	1080,4	517,2	1294,3
Zainsky	1094,2	1071,1	519,2	1291,2
Zelenodolsky	1098,2	1073,1	518,6	1297,3
Kaibitsky	1101,9	1077,9	523,4	1302,1
Kamsko – Ustinsky	1111,3	1091,5	523,2	1312,8
Kukmor	1096,2	1069,5	515,3	1290,6
Laishevsky	1026,0	1116,6	519,0	1329,2
Leninogorsk	1132,2	1124,9	520,1	1331,3
Mamadyshsky	1118,9	1102,1	516,5	1315,3
Mendeleevsky	1098,0	1076,3	512,9	1295,2
Menzelinsky	1104,1	1099,4	512,3	1303,9
Muslyumovsky	1097,8	1077,5	516,9	1295,8
Nizhnekamsk	1115,3	1112,0	515,8	1316,9
Novosheshminsky	1118,0	1104,5	524,4	1321,4
Nurlatsky	1131,4	1126,0	525,0	1338,9
Pestrechinsky	1104,4	1078,2	522,5	1303,4
Rybno-Slobodsky	1118,3	1101,3	520,1	1316,5
Sabinsky	1105,7	1083,6	517,9	1302,7
Sarmanovsky	1101,8	1077,5	520,0	1303,2
Spassky	1129,0	1119,0	522,7	1335,4
Tetyushsky	1118,4	1104,5	520,5	1321,6
Tukaevsky	1093,4	1076,6	517,4	1290,5
Tyulyachinsky	1102,9	1081,1	519,8	1303,1
Cheremshansky	1118,0	1100,6	524,8	1318,5
Chistopolsky	1111,5	1094,8	521,6	1314,1
Utazinsky	1124,5	1100,3	523,3	1325,0
Kazan	1087,2	1074,4	510,2	1284,4

Insolation in the Republic of Tatarstan differs insignificantly. Slightly lower indicators in the northern and northeastern part of the Republic. It is also necessary to take into account air pollution, especially in large cities, as it affects the accuracy of measurement.

To identify potential electricity generation in the Republic of Tatarstan, it is necessary to determine the average insolation by month, taking into account the optimal angle of inclination of stationary PV modules towards the equator (Table 3, Fig. 3). This will allow to calculate the maximum efficiency for any time of the year. To control the tilt angle, trackers can be used or the angle can be moved independently using special fasteners (Torres, Petrakopoulou, 2022).

Table 3: Solar insolation with regard to optimal tilt angle (Torres, Petrakopoulou, 2022)..

Month	Solar insolation, кВт•ч/m^2	Optimal tilt angle, °
Jan	1,45	71
Feb	2,47	63
Mar	3,85	50
Apr	4,92	35
May	5,77	20
Jun	6,19	11
Jul	5,99	17
Aug	4,79	29
Sep	3,49	44
Oct	2,25	57
Nov	1,68	69
Dec	1,39	74
Annual average	**3,69**	**44,9**

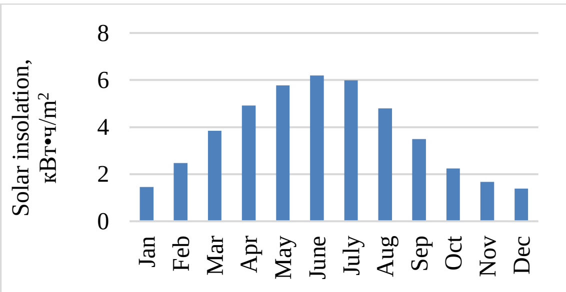

Figure 3: Solar insolation of the Republic of Tatarstan by months.

It is also of interest to determine the total photovoltaic power output for different levels of solar generation. In Fig. 4 shows the monthly average values of the total photovoltaic power output for a large scale project with an installed capacity of 1000 kWp. Fig. 5 shows the monthly average values of total PV power output for a medium-sized commercial facility with an installed capacity of 100 kWp. Fig. 6 shows the monthly average values of the total PV power output of the installation for a small residential building (installed capacity of 1 kWp).

In the Global Solar Atlas modeling, the calculation is based on conventional crystalline silicon (C-Si) modules as the most common technology in the solar PV market.

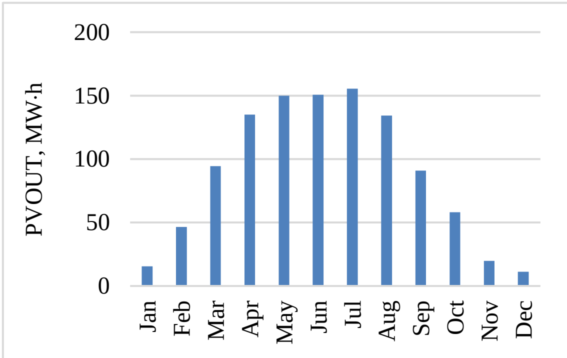

Figure 4: Total photovoltaic power output of an industrial plant with an installed capacity of 1000 kWp.

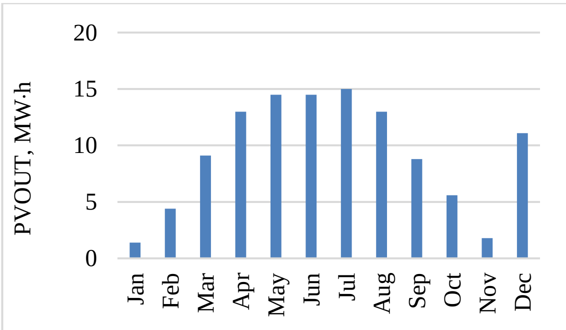

Figure 5: Total photovoltaic output of a commercial facility with an installed capacity of 100 kWp.

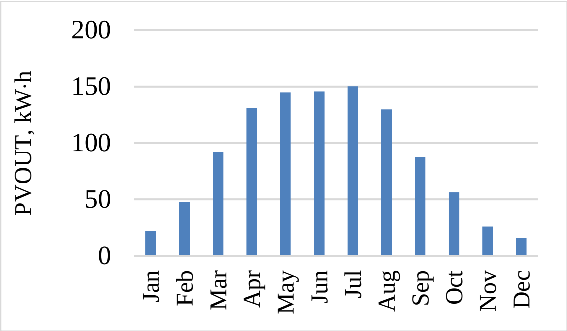

Figure 6: Total photovoltaic output of the installation for a small residential building (with 1 kWp installed capacity).

Solar modules produce electricity even when there is no direct sunlight. Therefore, even when the weather is cloudy, the PV system will generate electricity. However, the best conditions for electricity generation will be when the sun is bright and the panels are oriented perpendicular to the sunlight (Platonova, Toropov, Tulikov, 2019).

3.2 Availability of modern technologies

Scientists all over the world are working on increasing the efficiency of photovoltaic modules. Currently, the efficiency of such technologies is 15-30%. It is assumed that the theoretically possible limit of efficiency factor for semiconductor technology is 85-88 % (Kochmarev, Malozyomov, Kuznetsova, Ignatev, 2020).

The efficiency factor of solar cells depending on the material is shown in Figure 7.

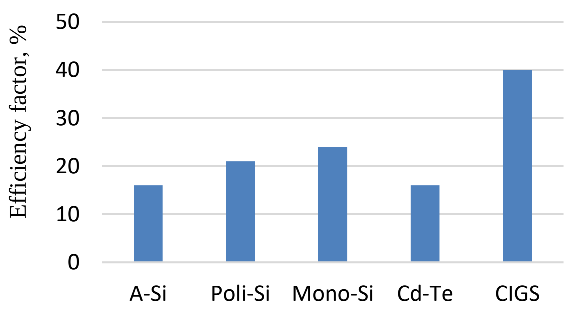

Figure 7: Efficiency factor of different semiconductor materials (Baiju, Yarema, 2022).

Amorphous silicon, thanks to thin-film technology, has raised the efficiency to 16%, and it is able to absorb even weak and diffuse light. The multidirectional arrangement of polycrystalline silicon crystals also maintains performance even when light conditions deteriorate. Monocrystalline silicon can give the highest energy yield, however, changing conditions such as temperature (high temperature) or position relative to the sun affects a significant reduction in efficiency. Cadmium telluride with average efficiencies is popular due to its low price. The most efficient and most expensive is rare earth copper-indium-gallium sulfide, which is only used in aerospace applications (Baiju, Yarema, 2022; Chatzipanagi, Jaeger-Waldau, Cleret de Langavant, Letout, Latunussa, Mountraki, Georgakaki, Ince, Kuokkanen, Shtjefni, 2022; Mustafa, Gomaa, Al-Dhaifallah, Rezk, 2020).

Other materials and technologies are also in development. But in this paper we consider the currently available ones for solar power plant design.

3.3 Economic situation in the country

Russia and Tatarstan, in particular, have large areas for solar energy development. The state supports clean generation despite a surplus of electricity generation in some regions of the country. There are benefits for producers and consumers of clean energy in accordance with Federal Law No. 42 of April 5, 2003. Also, solar generation can be very profitable under affordable conditions in some industries and remote communities as an autonomous source of energy (Guskov, Kolesnichenko, Korotkov, 2019).

3.4 Infrastructure

Tatarstan is one of the most developed regions in the country with a well-developed power grid infrastructure, which means that potential solar power plants can be connected to the grid in any region of the republic. However, the high level of gasification in the republic does not stimulate the development of solar energy.

Since the program of carbon footprint reduction is still relevant, there are prospects for solar generation both for the construction of new production facilities and for the private sector.

Tatarstan has long been using autonomous solar power plants to maintain road equipment (traffic lights, cameras) and street lighting. Since March 2021, microgeneration facilities have started to connect to the electric grid (Suslov, Doroshin, Kabanov, Pereverzev, 2023).

3.5 Risk identification and analysis

To make a decision on the development of solar energy in the Republic of Tatarstan we applied SWOT-analysis. At the first stage, strengths and weaknesses, opportunities and threats were identified (Fig. 8). For the objectivity of the analysis we used the Delphi method, which consists in expert evaluation of a group of people according to a questionnaire. It identified the items in the SWOT analysis and decision groups. The results are summarized in a new questionnaire and so on until complete consensus.

Taking into account the results of the study, the Delphi method was used to identify and assess the risks of solar energy construction projects.

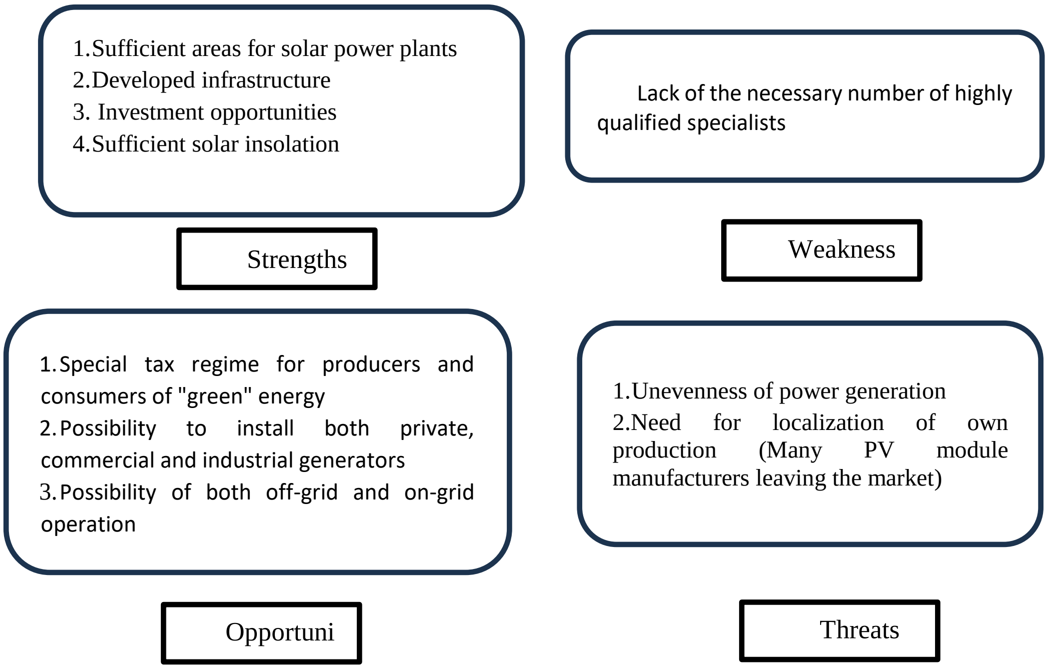

Figure 8: SWOT analysis.

The risk factors, degree of damage and probability obtained as a result of expert assessment are summarized in Table 4.

Table 4: Risk factors.

Risk factors	Probability/damage
Lack of the necessary number of highly qualified specialists	40%, low
Uneven power generation	70 %, high
Necessity to localize own production (Many PV module manufacturers leaving the market)	60 %, middle

Risk management opportunities obtained as a result of SWOT-analysis include: Training of specialists abroad and in Russia (opening new educational programs), necessity and possibility of development of autonomous stations, long-term guarantees from manufacturers of equipment components, localization of PV module production.

4 CONCLUSIONS

Insolation studies for the Republic of Tatarstan in general and for municipal districts in particular showed good values from March to August inclusive. A calculation of specific photovoltaic power output for a conventional crystalline silicon (C-Si) module, as the most common technology on the market of solar PV systems, was carried out. The results are given for Tatarstan by month, for districts - annual average value.

Factors affecting the development of solar energy and its assessment using SWOT-analysis were also considered.

SWOT analysis was used to assess the risks in planning the construction of solar generation facilities taking into account various factors, which showed the degree of damage and probability of these risks. Based on this assessment, the risk management opportunities are given.

The data obtained shows sufficient potential for realization of different level of solar power generation projects.

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