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SOLAR POWER PLANTS

Selection and Justification of Rational Technical Solutions for Power Supply Systems based on Solar Energy

N. R. Avezova[a], E. Yu. Rakhimov[a,] *, N. N. Dalmuradova[a, b], J. O. Izzatillayev[a], A. U. Vokhidov[a], A. B. Tarasenko[c], and I. I. Yuldashev[a]

[a] *National Research Institute of Renewable Energy Sources, Tashkent, 100014 Uzbekistan*

[b] *Tashkent State Technical University, Tashkent, 100014 Uzbekistan*

[c] *Joint Institute for High Temperatures, Russian Academy of Sciences, Moscow, 125412 Russia*

**e-mail: eyurakhimov@gmail.com*

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Abstract—This article discusses the issue of choosing the location and capacity of a photovoltaic (PV) plant in a rational way for the power supply of the designed capacity of the planned devices and equipment (office equipment, night/day lighting, and alarm systems) as part of the newly constructed building of the JSCB Uzpromstroybank branch in Nukus, the Republic of Karakalpakstan. Based on the climatic and actinometrical database for the city of Nukus (for the period 2005–2020), the natural and technical potential of renewable energy sources (solar energy) of the region is determined. The average hourly power consumption of the planned part of the facility is determined on the basis of the technical parameters of the installed electrical switchboard for power supply on working days is 48.3 kWh, connection to the network of part of the facility was provided through an 80 kVA battery. According to preliminary calculations, to compensate for this energy consumption, the possibility of installing a PV plant based on a 60.3 kW grid system, using the roof section of the building to the maximum. Six different scenarios of system operation using PV*SOL and PVsyst software products have also been developed, where one of the main criteria for choosing a rational solution is the replacement coefficient of traditional energy resources of at least 30%. From the considered scenarios, the most rational options for improving the reliability and stability of the power supply system of the selected part of the facility are determined, as well as rational indicators of the orientation and angle of inclination of PV panels to the horizon, the payback period, the required number of panels, the maximum reduction of CO_2 emissions, and on the basis of these scenarios, the technical, economic, and environmental efficiency of the system are determined.

Keywords: Green banking, power supply, consumer, renewable energy sources, HOMER, PV*SOL, PVsyst, solar radiation, modeling, economical efficiency

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INTRODUCTION

The economic growth of developing countries is closely linked to reliable energy supplies, especially in remote areas where poverty is highly dependent on the availability of energy services. As stated by many international organizations such as the United Nations [1, 2], the World Bank [3], and the International Energy Agency (IEA) [4], electricity provides the necessary basis for economic, social, and human progress, having a positive impact on industry, health, education, climate change, food and water, security services, and communications. IEA projections for 2030 [4] assume that 60% of the additional capacity will be achieved through sustainable energy systems, which will increase the investment budget of mini-grids and off-grid systems based on renewable energy sources (RESs) by 63%.

Previously, photovoltaic installations were mainly based on a stand-alone type of grid and operated in isolated conditions, but thanks to advances in photovoltaic technology and power electronics, these systems began to rapidly develop as grid-mounted photovoltaic systems [5]. Currently, in most countries, photovoltaic installations operate in the grid-connected mode and contribute to the electricity supply.

In accordance with the Decree of the President of the Republic of Uzbekistan, "On Approval of the Strategy for the Transition of the Republic of Uzbekistan to a "Green" Economy for the period 2019–2030" dated October 4, 2019, tasks were defined to attract investment and introduce a system of green lending, to activate the private sector in financing projects that ensure the transition to a green economy, as well as stimulating the banking system in this direction [6].

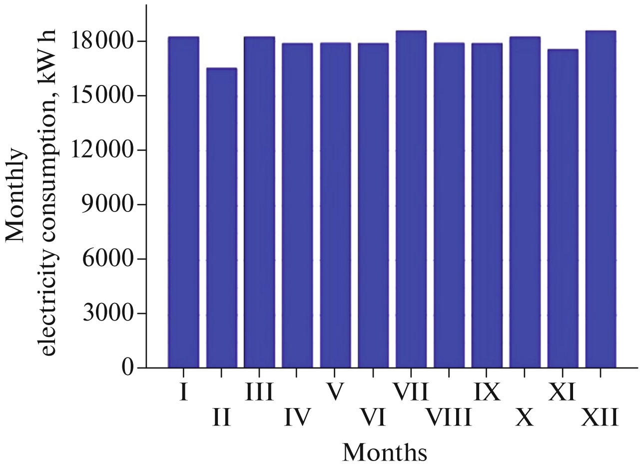


Fig. 1. Average monthly power consumption of the planned part of the facility.

Starting from 2018, as part of the transformation program developed by Uzpromstroybank with the support of the International Finance Corporation and the European Bank for Reconstruction and Development, the Green banking project was launched in connection with which the bank created a separate department [7]. Within the framework of this project, several activities are planned, which are being implemented in stages. The main goal of the department is to finance green projects of social and environmental importance.

In this context, it should be mentioned that "green banking is an activity related to improving the efficiency of internal banking processes, using physical infrastructure and information technologies, as well as implementing the bank's professional activities, taking into account the achievement of sustainable development goals and minimizing environmental risks" [8].

Also in the world, attention has recently been paid to initiatives that create uniform rules for the work of the Energy Efficient Mortgages Initiative [9], which provide for investment in assets focused on nature conservation. The Climate Bond Initiative supports the mobilization of the bond market to address the challenges posed by climate change. As part of the country's financial sector transformation program, Uzbekistan plans to assist in the development of large-scale practical use of environmentally friendly types of energy.

According to the Decree of the President of the Republic of Uzbekistan No.-UP-220, On Additional Measures for the Introduction of Energy-Saving Technologies and the Development of Low-Power Renewable Energy Sources dated September 10, 2022, a plan of measures was approved providing for "bringing up to 30% the share of alternative energy sources in the volume of consumption energy at more than 6000 facilities in the context of ministries and departments" [10], which also shows the relevance of the task set by the authors to select and justify rational technical solutions for power supply systems of the Karakalpak regional branch of JSCB Uzpromstroybank based on solar energy.

In this paper, the possibility of replacing traditional energy resources by 30% [10] is estimated through the use of solar technologies for the purpose of reliable and sustainable energy supply of the facility, taking into account all external factors, climatic and actinometric indicators of the area, and the needs of the subscriber.

OBJECT OF STUDY

A power system based on solar energy for partial coverage of the power supply system of the Karakalpak regional branch of JSCB Uzpromstroybank in Nukus. Nukus city is located at 42.483° N latitude, 59.617° E longitude, and 75 m above sea level.

The assessment of the possibilities of using solar energy at the facility is carried out on the basis of meteorological indicators of the area. Meteorological data includes solar radiation, wind speed and direction, ambient temperature, air humidity, etc. This data helps to determine the potential for electricity generation using renewable energy sources (RESs) in a certain area, together with the necessary energy technologies.

The roof area of the facility is 600 m^2 (20 × 30 m) (single-stage, slope to the horizon is 8°, and has a deviation of 10° from the south), which allows for partially satisfying the needs of the facility (office equipment, night, daylight, and alarm systems) using solar energy, taking into account the use of a battery with a capacity of 80 kVA (UPS). It should be noted that the object under study is a newly erected one, and therefore, the energy consumption of the part of the object in which office equipment, night and day lighting, and alarm systems are planned, is determined according to the technical requirements of the control panel installed for it. The peak power of the electricity consumed by the selected part of the facility during working hours, on weekdays 48.3 kW (from 9:00 before 18:00), at night and on weekends 14.5 kW, respectively. According to the planned indicators of the control panel, the daily consumption of part of the facility on weekdays and weekends is 686 kWh and 348 kWh, respectively, and in the general case, the annual consumption amounted to 215 586 kWh. Based on this, the monthly electricity consumption of part of the facility during the year ranges from 16 000 kWh to 18 500 kWh per month (Fig. 1).

MATERIALS AND METHODS

Currently, about 100 automated computer programs are used in the world to calculate various parameters of power systems based on RESs. Many computer programs are based on 3D design technology for the best choice of location of installations on the ground. Some programs do not require installation and work online. This significantly reduces design time and does not take up space on the hard disk of a personal computer. Each program has its own characteristics, for example, some show the generation of electricity, others help to correctly locate the installations on the ground or object, others calculate the profit due to the generation of electricity into the network and the payback period. For larger projects, it is necessary to use several software systems at once. This section provides a description of some of the most functional programs that are freely available.

To date, the following mathematical methods are used to solve optimization problems [11]:

• Methods for studying the functions of classical analysis.

• Methods based on the use of indefinite Lagrange multipliers.

• Calculus of variations.

• Dynamic programming.

• Principle of maximum.

• Linear programming.

• Non-linear programming.

In most problems, methods of mathematical programming are used. The categories of initial data, the nature of the required variables, and the number of optimization criteria affect the choice of the method of mathematical programming. As part of the substantiation of the optimal composition and parameters of the equipment of the energy complex based on RESs, the mathematical model will observe nonlinear dependences and random values of the initial data (wind speed, solar activity over time, etc.). Such a task will be considered multicriteria, because to evaluate the efficiency of such a complex, it is necessary to introduce several criteria (replacement of a traditional resource, reliability of power supply, minimum costs for power generation, environmental impact, etc.). The main problem in solving this problem is the inconsistency of the optimization criteria, the criteria are not interchangeable. The electrical power system must be economical and reliable at the same time. Usually, an increase in reliability indicators leads to a deterioration in economic indicators. Thus, the main task is to find compromise solutions. Methods for solving problems of multicriteria optimization are considered in detail in [12].

The application of the above methods is implemented by the following software systems: PV*SOL, PVsyst, Homer Energy Pro, RETScreen, Hybrid 2, and iHoga [13, 14].

There are several methods for modeling the operation and optimizing the parameters of autonomous power supply systems based on RESs, which for zoning of the territory, provide for ranking methods according to the criteria of economic and energy efficiency of the selected system [15, 16].

Before performing the above calculations, for an arbitrary consumer, it is necessary to evaluate its energy needs (heat and electricity), taking into account the load curves at different times of the day and season, as well as the year. RESs can solve the problem of redundancy and increase the reliability of energy supply. However, given the high cost of almost all RESs (except hydroelectric power plants (HPPs)), it is not necessary and often not economically feasible to purchase RES equipment that covers 100% of the potential needs of the customer [12]. In this regard, this article considers one of the rational solutions for ensuring the energy consumption of an object with a 30% replacement rate for traditional energy resources due to a solar energy-based system using software products PV*SOL and PVsyst. The main points of design and installation of solar photovoltaic plants in the country must be carried out in accordance with the regulation of SHNK 2.04. 15–20 Photovoltaic Plants (systems), developed by the employees of the National Research Institute of Renewable Energy Sources under the Ministry of Energy of the Republic of Uzbekistan.

According to the analysis and processing of climatic data for the city of Nukus, it was revealed that:

— The value of the outdoor air temperature is: in January –4°C, in July 30.0°C, average annual temperature 13.6°C, absolute minimum temperature—30.5°C, and absolute maximum temperature 45.1°C. The average maximum temperature of the hottest month was 36°C, and the coldest month –7.5°C. The maximum daily range of outdoor air temperature in Nukus is: in January 20.1°C and in July 31.4°C.

— The values of the average minimum relative air humidity in the coldest month were 64%, in the hottest month 19%.

— The values of the average wind speed in January were 3.5 m/s and in July 3.7 m/s. Also, for the period of 2005–2020, the number of days with a dust storm and a dusty snowfall in a year was equal to 3.

— For the period of 2005–2020 the frequency of the wind direction blowing from North to East reached the highest value, 17, blowing from the East–Northeast, 10, the wind in the East, North, and Northwest direction was also often observed (in January); in the month of July, the Western–Northwestern, Northern–Northwestern, and Northwestern directions had the highest frequency of wind direction, 11 each.

— The values of the daily average annual total (direct/scattered) solar radiation on a horizontal surface under average cloudiness conditions were 16.38/6.77 MJ/(sq.m. day).

An analysis of the climatic and actinometric data of the area shows that, for the conditions of the city of

Nukus, where the object under consideration is located, it is advisable to plan, design, and install solar photovoltaic plants (systems), which contributes to the achievement of a replacement rate of traditional resources of 30% or more for power supply systems [18]. The amount of CO_2 emissions reduced through the use of photovoltaic plants were calculated according to [19].

Modeling and planning are carried out on the example of a photovoltaic panel of the brand LG450N2W-E6 (power 400 and 450 W), the operating temperature range of which ranges from –40 to +85°C, which satisfies our requirements for providing partial power supply of the facility in the climatic conditions of the area.

Calculation of the Economic Efficiency and Technical Feasibility of Planning and Designing a Power System Based on Solar Energy

The degree of stability of the project in relation to possible changes in the conditions of implementation can be characterized by indicators of break-even boundaries and limiting values of such project parameters as production volumes, prices of manufactured products, limited resources used, etc. Break-even refers to the volume of sales at which net profit becomes equal to zero.

$E_{\text{PVper-year}}$ per year is the total energy production of the photovoltaic plant per year, determined using the following formula:

$$E_{\text{PVper-year}} = \sum_{i=1}^{365} E_{\text{day-}i} \ \text{kWh/year}. \tag{1}$$

Statistical analysis of the practical work performed by local companies MIRSOLAR LLC, ALLSOLAR LLC, SOLAR NATURE LLC, and others on the installation of solar photovoltaic plants in the republic shows that the price of 1 W of installed capacity (including construction, installation, and setup) is from 1 to 1.1 US dollars.

The cost per kWh of electricity generated is calculated for a grid-connected photovoltaic plant based on the sum of the costs associated with a year divided by the number of kWh generated in 1 year, based on the price and lifetime of the equipment.

If Q_i is the number of component i, the cost per unit of the component i is equal to C_{Ui}, and the service life of component i is L_i, then C_i is the cost of electricity generation per year for each component, calculated based on the formula below:

$$C_i = \frac{Q_i C_{Ui}}{L_i} \ (\text{Uzs/year}). \tag{2}$$

Thus, the total cost of a solar power plant installed on the roof of a facility per year takes into account the lifetime of the components, calculated as:

$$C_{\text{Tper-year}} = \sum_{i=1}^{n} \frac{Q_i C_{Ui}}{L_i} \ (\text{Uzs/year}). \tag{3}$$

The electricity tariff per kWh is the ratio of the cost of electricity generation per year to the total energy produced by photovoltaic plantss. The cost per kWh is calculated using formula:

$$C_{\text{Tper-year-kWh}} = \frac{C_{\text{Tper-year-kWh}}}{E_{\text{PVper-year}}} = \frac{\sum_{i=1}^{n} \frac{Q_i C_{Ui}}{L_i}}{\sum_{i=1}^{365} E_{\text{day-}i}}. \tag{4}$$

In (4), the cost of a kWh of electricity generated by a photovoltaic system is affected by the annual cost of the system and the total energy produced by the photovoltaic system. Reliability and price greatly influence the overall cost of the system. On the other hand, a factor of natural state is the high level of incoming solar radiation.

The average CO_2 emission factor for the production of electricity and heat for Uzbekistan in 2020 amounted to 0.462 $kgCO_2$/kWh and increased slightly due to the operation of two coal-fired power plants [20]. Using this factor, the reduction in CO_2 emissions can be determined by using rooftop photovoltaic panels during the payback period of the system, as shown in (5):

$$CO_{2\text{emission}} = \frac{E_{\text{PVper-year}} \times 0.867 n_{\text{year}}}{1000} \ (\text{T}). \tag{5}$$

Also, in order to determine a rational scenario, we calculated the net present value and profitability index according to the following formulas (6 and 7) [21]:

$$NPV = -C_0 + \sum_{i=1}^{t} \frac{C_i}{(1+r)^i}, \tag{6}$$

$$PI = \frac{\sum_{i=1}^{t} \frac{C_i}{(1+r)^i}}{C_0}, \tag{7}$$

where: NPV is the net present value of the investment project, C_0 is the investment capital (investor's costs in the initial time period), C_i is the cash flow over a period of time, and r is the discount rate.

RESULTS AND DISCUSSION

Based on the study of climatic and actinometric data from the Nukus meteorological station, the following graphs were obtained, which show the average monthly wind speed and ambient temperature (Fig. 2), the average monthly relative humidity and outdoor temperature (Fig. 3), and the average monthly total solar radiation incident on the horizontal plane and outside air temperature (Fig. 4).

As can be seen from Fig. 2, the wind speed in Nukus ranges from 3.5 to 4.42 m/s. The average max-

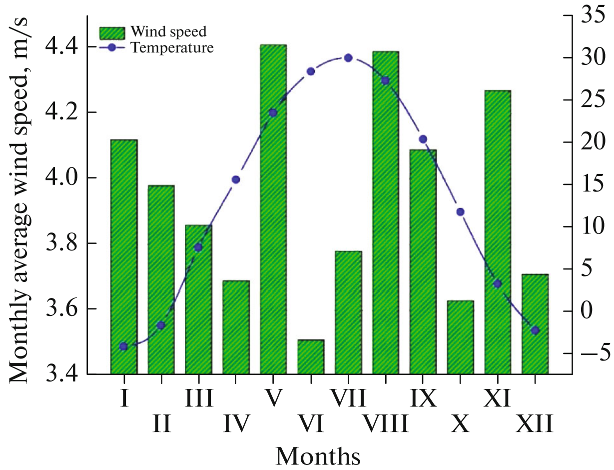


Fig. 2. Change in the average monthly wind speed and ambient temperature by months in the city of Nukus for the period of 2005–2020.

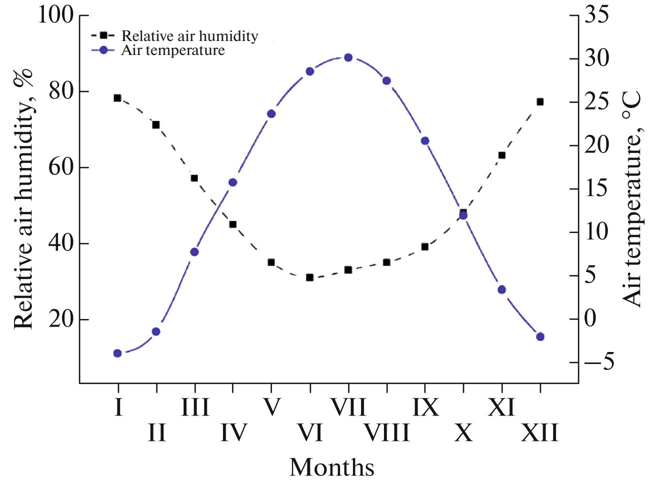


Fig. 3. Changes in the average monthly values of relative humidity and outdoor temperature by months in Nukus for the period of 2005–2020.

imum wind speed falls in the months of May (4.42 m/s), August (4.39 m/s), and November (4.27 m/s), and the average minimum speed for the months of April (3.69 m/s), June (3.5 m/s) and November (3.62 m/s). At the same time, the outdoor air temperature in the winter period of the year reaches from –1 to –2°C, in the spring season from +7 to +23°C, in the summer season from +22 to +30°C, and autumn from +3 to +20°C.

From Fig. 3 it can be seen that the relative maximum air humidity in the territory of Nukus is reached in winter (up to 80%), and the minimum falls in summer (up to 30%). At the same time, the outdoor air temperature in the winter period of the year reaches from –1 to –2°C, and in the summer season from +22 to +30°C.

Figure 4 shows that the maximum global solar radiation/diffuse solar radiation in the territory of Nukus for the period under review falls in the spring–summer period of the year: April (185.4 kW/m^2/63.7 kW/m^2), May (197.5 kW/m^2/80 kW/m^2), June (213.5 kW/m^2/76.4 kW/m^2), July (239.8 kW/m^2/72 kW/m^2), and

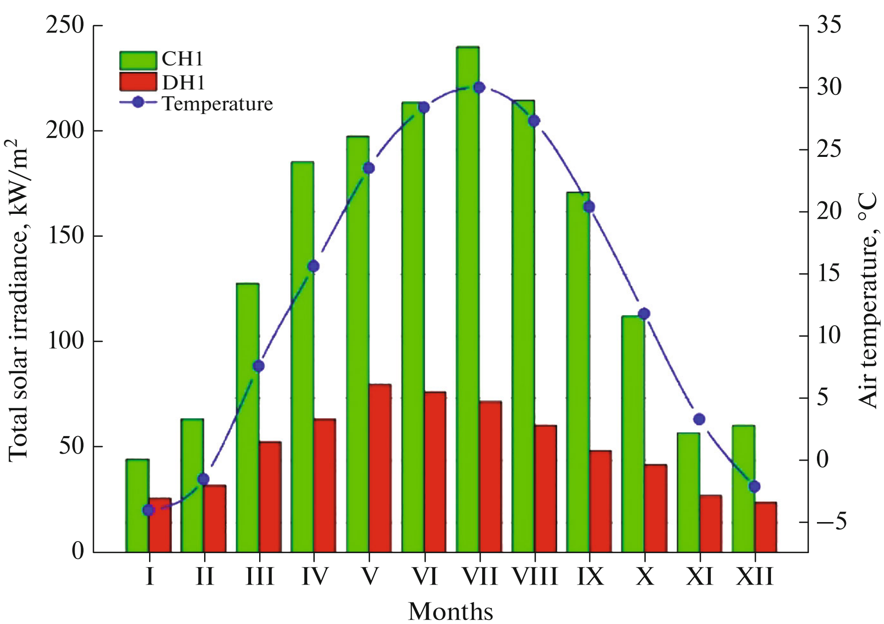


Fig. 4. Change in the values of the average monthly total solar radiation falling on a horizontal plane and the temperature of the outside air by months in the city of Nukus for the period of 2005–2020.

August (214.5 kW/m^2/60.8 kW/m^2) at ambient temperature from +15.6 to +30°C, and the minimum for the autumn–winter period of the year: November (55.7 kW/m^2/27.6 kW/m^2), December (60.9 kW/m^2/24.3 kW/m^2), January (44.6 kW/m^2/26.2 kW/m^2), and February (63.8 kW/m^2/32.4 kW/m^2) at ambient temperature from –4 to +3.3°C.

Preliminary calculations performed on the Homer Pro software in order to select a rational option for the energy supply system for the consumer show that due to low prices for electricity received from the local power grid (the price of electricity supplied from the network to the population in Uzbekistan is 450 soms per 1 kWh for legal entities), the most rational option was the local power grid itself. Also, due to the fact that the number of sunny days in Nukus is 300–320 days, and provided that the replacement rate of traditional energy resources is 30%, another rational option for providing electricity to the facility is the use of a solar power plant with a capacity of 60 kW.

Taking into account the actual values of climatic parameters in the selected region, and the energy consumption devices used in the facility, the following are determined: wind speed within 3.5–4.42 m/s, which is acceptable for the maximum performance of the solar power plant, taking into account the correct installation in the direction of the wind. If the wind speed exceeds 3 m/s, the operating temperature of the photovoltaic panel is greatly reduced (when the wind speed is 3–7 m/s, the temperature decreases by 3–5°C). This is a positive development as the more the panel is operated at standard operating temperature (25°C), the higher its performance [22]. At the same time, as indicated above, the selected part of the facility's power supply system is planned to be connected to the photovoltaic power plan through a battery with a capacity of 80 kVA (UPS), and a diesel generator with a capacity of 200 kW is also provided in the facility for emergencies.

DISCUSSION

Practice shows that the most effective angle of inclination of solar panels is: in the cold period of the year (from November 1 to April) $\alpha = 58°$, in the warm period of the year (from May to October) $\alpha = 22°$, and for maximum capture of the annual total solar energy it is necessary to install them at angle to the horizon $\alpha = 32°$ [18, 23]. Taking into account the slope of the roof itself, the optimal angle of inclination of the photovoltaic panel, the PV*SOL and PVSyst software automatically determined the inclination angle indicator to be 34°. In areas where there is little precipitation and increased dust formation, it is necessary to clean the panels. In the most dusty regions of the world, even if panels are cleaned monthly, they can still lose 17 to 25% of energy production. And if cleaning occurs every 2 months, the losses are from 25 to 35% [18].

To develop various scenarios for the choice of rational planning and design of a solar energy system, the following boundary conditions were chosen:

— Photovoltaic panels are installed on the roof of the facility.

— Photovoltaic panel technology—monocrystalline.

— Output power 60.3 kW/peak.

— Inverter power 60 kW.

— Number of inverters—1 pc.

— Connection type—on-grid.

— The minimum operating period of is 20 years.

— Replacement ratio of traditional energy resources—at least 30%.

— Climatic and actinometric data for the city of Nukus for the period of 2005–2020 given above (section Results).

The initial data of the studied six scenarios for choosing a rational solution to the problem are given in Table 1.

The results of simulation of photovoltaic stations on the roof of the selected object on the PV*SOL platform for six different scenarios are shown in Table 2.

Comparative analysis of simulation results by scenarios shows that:

– According to scenario 1 the efficiency of the solar power plant is 78.0% and the replacement ratio is 32.1% with an installed capacity of 450 W, the distance between rows of photovoltaic modules is 1.8 m, tilt angle is 34°, oriented to the south, and also contributes to the reduction of about 36 T CO_2 emissions in a year.

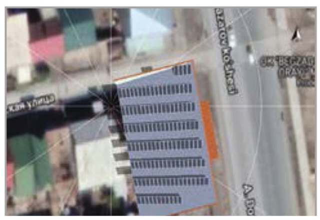
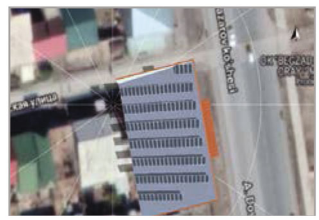
– Scenario 2 is also quite rational. The efficiency of the photovoltaic power plant is 80.5% and the replacement rate is 31.2% at an installed power of 450 W, the distance between rows of photovoltaic modules is 1.8 m, tilt angle is 34°, has a deviation of 10° from the southern orientation, and also contributes to a reduction of about 36 T CO_2 emissions in a year.

– In the case of scenario (3), at an installed power of 450 W, the distance between rows of photovoltaic modules is 2.0 m, tilt angle is 34° oriented to the south, both the replacement rate (30.6%) and system efficiency (75.3%) are reduced, as well as the reduction of CO_2 emissions per year (35 T).

– Scenario (4) has an installed power of 450 W, distance between rows of photovoltaic modules of 2.0 m, tilt angle of 34°, with a deviation of 10° from the south, both the replacement rate (30.1%) and system efficiency (80.0%) are reduced, as well as the reduction of CO_2 emissions per year (34 T).

– Scenario (5) has an installed power of 450 W, distance between rows of photovoltaic modules of 2.0 m,

Table 1. Initial data of the studied scenarios for the design of solar power plants on the roof of the facility

	Scenario 1	Scenario 2	Scenario 3
Initial parameters			
Output power	60.3 kW/peak	57.6 kW/peak	59.85 kW/peak
Surface area	294.6 m^2	281.4 m^2	292.4 m^2
Number of solar cells	134	128	133
Distance between rows	1.8 m	1.8 m	1 m
Number of inverters	2.0	1.0	2.0
Orientation	South 182°	South 190°	South 180°
	Scenario 4	Scenario 5	Scenario 6
Initial parameters			
Output power	55.35 kW/peak	58.8 kW/peak	54.4 kW/peak
Surface area	270.4 m^2	304.7 m^2	281.9 m^2
Number of solar cells	123	147	136
Number of inverters (X3-MGA-60K-G2)	1	1	1
Distance between rows	2.0 m	1.8 m	1.8 m
Orientation	South 190°	South 180°	South 190°

tilt angle of 34°, and south-facing, both the replacement rate (29.0%) and system efficiency (73.1%) are reduced, as well as the reduction of CO_2 emissions per year (33 T).

— Scenario (6) shows a similar system efficiency (73.1%) with an installed capacity of 450 W, distance between rows of photovoltaic modules of 2.0 m, tilt angle of 34°, has a deviation of 10° from south orientation, but the replacement ratio is decreasing (27.1%), as well as the value of CO_2 emissions per year is also lower (30 T).

It is worth noting that the actual output of a solar photovoltaic system may vary depending on weather conditions, the performance of modules and inverters, and other factors.

According to the simulation results, Scenarios 1 and 2 are considered the most rational, where, with an installed power of photovoltaic power plants of 60.3 and 57.6 kW (consisting of 134 and 128 pieces of photovoltaic panels with a capacity of 450 W), distance between rows of photovoltaic modules of 1.8 m, tilt angle of 33°, oriented to the south and having a deviation of 10°, the replacement ratio of traditional energy resources is 32.1 and 31.2%, and the system efficiency is 78 and 80.5%, respectively.

A comparison of the simulation results using the PV*SOL program with the simulation results based on the PVSyst program shows that when choosing a photovoltaic power plant with a capacity of 60.3 kW (consisting of 134 photovoltaic panels with a capacity of 450 W, distance between rows of photovoltaic modules of 1.8 m, tilt angle of 33°, oriented to the south and having a deviation of 10°) the replacement ratio of traditional energy resources is 32.1%, which in turn proves the reliability of the simulation results.

Table 2. Simulation results of photovoltaic panels on the roof of a selected facility on the PV*SOL platform for six different scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Energy consumption of the facility, kWh/year	215.586	215.586	215.586	215.586	215.586	215.586
Installed power, kW	60.3	57.6	59.85	55.35	58.8	54.4
Peak power, kW/peak	48.4	48.3	48.3	48.3	48.3	48.3
Number of solar cells	134	128	133	123	147	136
Area, m^2	294.6	281.4	292.4	270.4	304.7	281.9
Power, W	450	450	450	450	400	400
Distance between rows of panels, m	1.8	1.8	2.0	2.0	1.8	1.8
Tilt angle, deg	34	34	34	34	34	34
Orientation	South (180°)	Deviation by 10°	South (180°)	Deviation by 10°	South (180°)	Deviation by 10°
Annual electrical energy generation, kWh	77476	76212	74524	73084	71025	65591
Cost of generated energy by the system, USD	0.0943	0.0915	0.0973	0.0917	0.1003	0.1005
Electricl energy supplied to the facility, kWh/year, %	69311 (89.4)	67162 (88.1)	65963 (88.5)	64810 (88.7)	62453 (87.9)	58476 (89.2)
Electrical energy fed into the grid, kWh/year	8165	9050	8561	8274	8572	7116
System efficiency, %	78.0	80.5	75.3	80.0	73.1	73.1
Replacement rate, %	32.1	31.2	30.6	30.1	29.0	27.1
Production reduction due to shading, %/year	13.7	11.4	16.9	11.6	20.0	20.1
Payback period, year	14.0	13.7	14.5	13.8	14.8	14.8
Number of inverters	2	2	2	2	2	2
Reduction of CO_2 emissions, kg/year	36403	35816	35023	34345	33378	30824
Minimum operating period of the system, year	20	20	20	20	20	20

CONCLUSIONS

Rational ways and solutions have been explored to ensure the replacement rate of traditional energy resources to cover the energy consumption of a part of the selected facility, taking into account the potential of RESs in the region.

According to preliminary calculations to assess the natural potential of RESs in the region, as well as climatic and actinometric data, it was revealed, provided that the value of the global horizontal solar radiation in the region is 1688 kW/m^2/month, absolute minimum temperature is –30.5°C, and the absolute maximum temperature is +45.1°C, the use of energy systems based on solar energy will make it possible to replace traditional energy resources for one part of the facility’s power supply system by up to 31.2%.

According to the simulation results, it was found that Scenarios 1 and 2 are considered the most rational, where, with an installed power of photovoltaic power plants of 60.3 and 57.6 kW (consisting of 134 and 128 pieces of photovoltaic panels with a capacity of 450 W), the distance between rows of photovoltaic modules is 1.8 m, tilt angle of 33°, oriented to the south and having a deviation of 10°, the replacement rate of traditional energy resources of 32.1 and 31.2%, which also contribute to a reduction of 36 T CO_2 emissions per year, respectively.

It was revealed that in connection with these actual indicators of climatic conditions, as well as with the effective use of the building itself, it is possible to increase the replacement rate of traditional energy resources due to solar energy for the heat and cold and hot water supply systems of the facility.

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