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Assessing the Potential of a Rooftop Grid-Connected Photovoltaic System for Gaziantep Islamic Science and Technology University/ Turkey

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Abstract— In this paper, a grid-connected rooftop photovoltaic (PV) system is proposed to fulfill the electricity needs of Gaziantep Islamic Science and Technology University (GIBTU) in Turkey. The proposed system is to be placed on the roof of the Faculty of Engineering and Natural Sciences, which is considered as the most complex and challenging roof on campus. The system production of electricity - taking into account the possible losses caused by light-induced deterioration, soiling, etc. - is determined. The obtained simulation results reveal that installing a 121 kW PV system will be sufficient for meeting the electricity needs of the Faculty of Engineering and Natural Sciences alone, since such system is capable of generating 197.7 MWh annually with an efficiency of 81.51%. However, in order to meet the needs of the whole university, a 933.1 kW PV system - with generation capability of 1524.9 MWh/year - is required. Also, the obtained results unveil that deploying the proposed system - with its relatively low payback period of 2.19 years - will prevent the release of 989.35 tons/year of CO_2 emissions into the atmosphere.

Keywords— Photovoltaic; Rooftop PV system; Solar energy; Turkey.

1. INTRODUCTION

Renewable energy in the field of electrical energy generation is gaining importance today due to the gradual depletion of fossil fuels. The burning of fossil fuels has caused much damage such as increased greenhouse gases, temperatures, and acid rain. There has been irreparable damage to the environment and people because of this situation. Renewable energy is a viable solution to reduce environmental pollution with reduced installation costs. Solar energy is one of the first renewable energy sources that come to mind in this field. The increasing prevalence of electric vehicles, smart grid systems, developments in telecommunication systems, and many other reasons are increasing people's need for electrical energy. As the cost of photovoltaic (PV) panels decreases with the development of technology, PV plants become more prevalent, and many applications such as homes and industries start utilizing solar energy to meet their load demands.

In the last decade, the production of low-cost and high-power PV panels has increased. For example, the cost of generating electricity with PV power plants decreased by 77% in the period from 2010 to 2018 [1, 2].

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Renewable energies account for around 70% of the total installed power in 2019 [3, 4]. According to the renewable capacity statistics report in April 2022 by the International Renewable Energy Agency, the global renewable energy generation capacity amounted to 3064 GW by the end of 2021. Solar energy accounts for 28% with 849 GW of capacity. With an increase of 133 GW (+19%) in 2021, solar energy ranks first in capacity increase compared to other energy sources (hydroelectric, wind, bioenergy, geothermal) [5].

Along with the increasing installed capacity in the world, the PV power plant installation capacity has increased rapidly and continues to increase in Turkey. Fig. 1 shows electricity generation by solar PV power plants from 2014 to October, 2022 in Turkey. While the installed power plant generation was 40,2 MW in 2014, it increased more than 200 times and reached 9120,4 MW in 2022 (October) [6]. It is expected that 4 GW of new PV plant installations will be made in the year 2023.

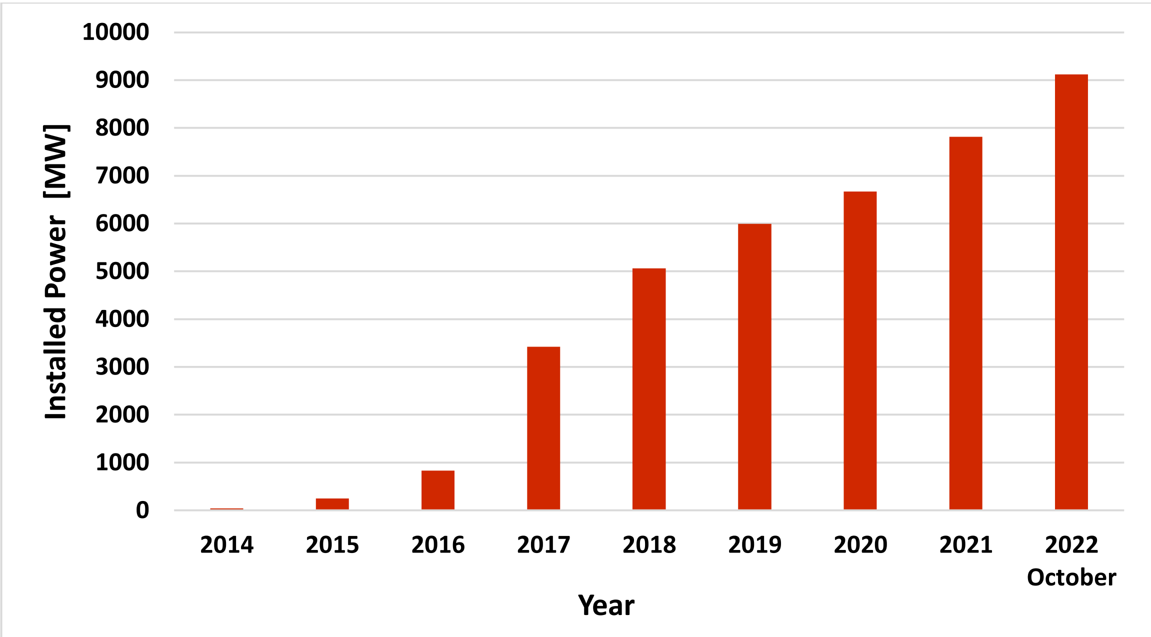

Fig. 1. Electricity generated by the installed PV power plants from 2014 to 2022 [6].

Turkey has a high level in terms of solar energy potential due to its geographical location. Turkey solar energy radiation potential map is illustrated as shown in Fig. 2. When the map is examined, the data for each province can be accessed and the total solar radiation increases as you move south.

In this study, we focused on a certain region that has a Latitude of 36°58′43.47″ N, and a Longitude of 37°18′05.10″E) where the central campus of Gaziantep Science and Technology University (GIBTU) is located in the Şahinbey district of Gaziantep as shown in Fig. 2. The average daily solar radiation value of the Şahinbey district of Gaziantep province, which has values above the Turkey average, is calculated as approximately 4.36 kWh/m^2 and the sunshine duration is 8.03 hours throughout the year.

When the solar energy potential is compared with the European Union countries, the region with the highest potential is the Southeastern Anatolia Region [8]. Gaziantep is one of the provinces with a high potential in terms of solar energy in this region [9]. When the information on the website of the Ministry of Energy and Natural Resources is examined, Turkey solar-based electricity installed power capacity was 833 MW in 2016, and it has increased approximately ten times in the last 6 years and reached 8479 MW by the end of June 2022 [10]. Turkish Electricity Transmission Corporation (TEIAS) installed power reports indicate that, as of September 2022 [6], its share of total installed power has reached 8.961%. Due to the increasing interest and decreased installed costs in solar energy power plants, it is predicted that the investments made in the roofs and facades of the buildings will increase gradually in the coming years.

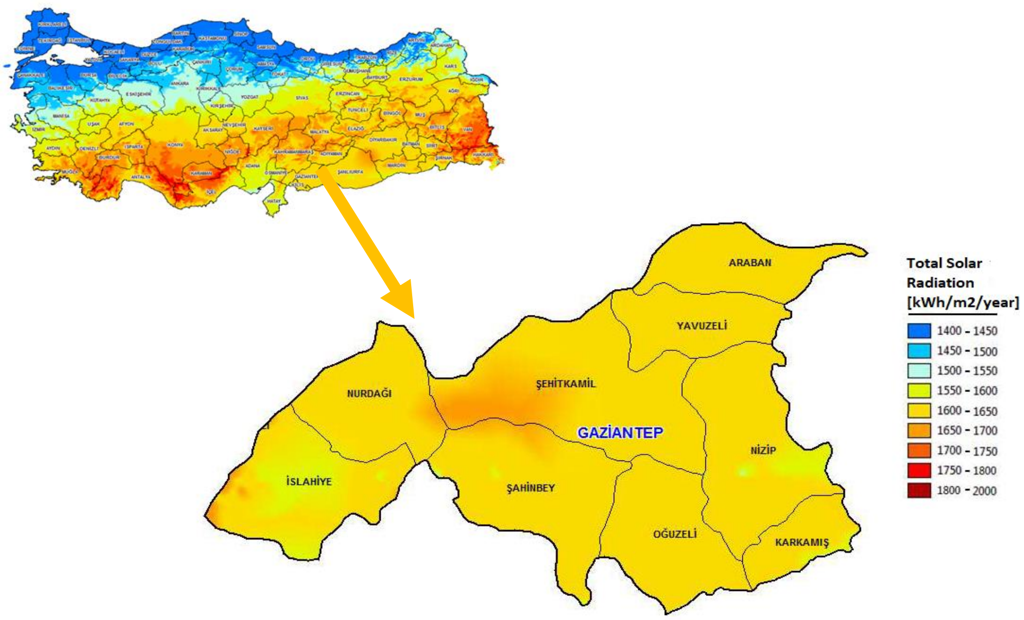

Fig. 2. Solar Energy Potential Atlas of Turkey and Gaziantep province [7].

A growing number of applications are being made using solar photovoltaic modules on the exterior surfaces of buildings or their roofs. In the literature, it is possible to come across many photovoltaic system investigations and economic evaluation studies for very different locations. The number of these studies will increase with the developing technology, some of these studies are cited and shown below.

Asif et al. examined the usable roof areas of the buildings on the university campus for PV application in Saudi Arabia [11]. In this study, the Pvsyst was also used. The performance of a grid-connected PV system consisting of panels with different technologies in Tamil Nadu in the south of India was analyzed by Ramanan et al. using the Pvsyst [12]. Cui et al. conducted the energy and economic evaluation of a grid-connected PV system using the Pvsyst for a building in Nottingham, England [13]. Ali et al. simulated a grid-connected PV battery system with the Pvsyst and worked on energy management with experimental studies [14]. They carried out a study to understand the performance, energy loss, and degradation prediction of a 200 kW roof-integrated PV system installed in northern India by Kumar et al. [15]. Behura et al. focused on the energy efficiency of a photovoltaic system installed on the roof of an Indian Institute building [16]. Yılmaz and Dinçer conducted a study to provide electrical energy with a PV-Diesel-Battery for a house in the neighboring province of Kilis, Turkey, and determined the cost calculation [17]. Ozogbuda and Iqbal designed an off-grid hybrid renewable system in Nigeria. The hybrid system consists of a PV array, an inverter, and a battery [18]. Mousavi and Iqbal researched a hybrid photovoltaic system for the energy needs of a house in Iran. The PV system was equipped with a reverse osmosis water desalination system [19]. Dabas and Iqbal proposed a stand-alone PV-Battery system for a house in Libya. They did a detailed cost analysis with real bills in calculating the load for a typical house [20]. Ahsan et al. investigated the economic feasibility of a hybrid power plant, the main component of which is photovoltaic (PV) array, for an industrial area in Pakistan [21]. In their study, Aika et al. investigated the electricity generation potential by using wind from renewable energy sources for Nigeria and presented their feasibility assessment [22].

There are widely used softwares such as PV*SOL, HOMER, and PVsyst to design and calculate the PV plants. Each has different advantages and disadvantages. Among these programs, in this study, we used PVsyst for numerical calculations. It allows the designing of three different types of grid-connected/off-grid/pumping for PV plants. In addition to its wide meteorological database, the program offers a wide database from which we can access up-to-date products in terms of system components such as PV modules and inverters in system design. It stands out from other simulation programs in terms of creating 3-dimensional structures and creating close shading simulations, calculating detailed system losses, and enabling economic evaluation.

In this study, grid-connected rooftop photovoltaic system modeling numerical calculation was carried out for solar potential investigation of Gaziantep Islamic Science and Technology University (GIBTU) in Turkey. This study is realized for the Faculty of Engineering and Natural Sciences building, which has the most complex and challenging roof on campus. After determining the location of the building and the meteorological data, the area where the system can be placed on the building is estimated and calculated.

This paper is organised as follows: section 1 presents increasing electricity energy generation sharing of PV plants which is a type of renewable energy and about the area of research the examples of studies in the literature. Section 2 introduces location selection of the proposed photovoltaic power plants. This part shows geographical coordinates and dimensions of calculated potential of the proposed plant. Section 3 is divided into 3 sub-sections. Design of the proposed system is demonstrated as systematically. In the first sub-section, the formulations of the system parameters expressed. Second sub-section, the main parameters of the system designed in the simulation program explained. Optional parameters including shadowing states and horizon information are in the third. Section 4 contains the system results. In addition to, estimated nominal PV power and total energy generation energy for campus are presented in the sub-section with a different scenario (If the building's azimuth is 0°). In section 5, the economic and environmental dimensions of the proposed model are analyzed. Finally, conclusions are realized and discussed as detailed in section 6.

2. SITE SELECTION

As part of this study, a PV panel was installed on the roof floor of the Engineering and Natural Sciences Faculty building (Latitude: 36°58′43.47″ N, Longitude: 37°18′05.10"E) at Gaziantep Science and Technology University (GIBTU) at its central campus in Şahinbey district of Gaziantep. The Google Earth image of the building, which was obtained after the map was reset to the north, is shown in Fig. 3. Table 1 includes the location information, width, height, and azimuth values of the building.

Fig. 3. A view of GIBTU Faculty of Engineering and Natural Sciences.

Table 1. Geographica coordinates and dimensions of the proposed building.

Latitude	Longitude	Altitude	Time Zone	Azimuth	Width	Height
36.98 °N	37.30 °E	902m	3	16.12°	30m	90m

3. METHODOLOGY

The proposed system is created and designed with the help of the PVsyst 7.2 simulation program. The steps followed in the system design are explained in detail below. First of all, the location of the building was determined using the Google Earth program. Distances can be measured easily using Google Earth's ruler. We used this tool for measurements when creating a 3D model of the building for shading.

After entering the location information and meteorological data for the place to be designed, the information of the system to be designed must be entered. At this stage, it is possible to simulate different designs by creating different variants. The main parameters of the system are determined by using the buttons defined as orientation, system, detailed losses, self-consumption, and storage. Buttons for the horizon, near shadings, module layout, energy management, and economic evaluation are optional.

3.1. System Parameters for Performance Analysis

This section describes numerical calculations [23-25] for evaluating the electrical energy generation efficiency of an introduced PV system and several efficiency parameters. As can be seen in Eq. (1), the total electrical energy generated by the PV system is demonstrated as E_{AC}. With this equation, the total daily and monthly electric energy amount is calculated. Here, $E_{AC,d}$ and $E_{AC,m}$ describe the total daily and monthly AC electrical energy generated by the system, respectively. Eq. (1). is given as follows:

$$E_{(AC,d)} = \sum_{t=1}^{24} E_{(AC,t)}, E_{(AC,m)} = \sum_{d=1}^{N} E_{(AC,d)}, \tag{1}$$

where N shows the number of days in a certain month while $E_{AC,t}$ gives the instantaneous measured AC energy value. The instantaneous energy output is obtained by measuring the quantity of AC energy generated by the PV system at that time. The final system yield (YF) shows the ratio of the net amount of AC electrical energy generated via the PV solar array for a specific duration to the DC power output of the installed nominal PV solar array in a unit of kWh/kW [23-25];

$$Y_F = \frac{E_{AC}}{P_{PV,rated}} \ (hours) \tag{2}$$

E_{AC} gives the net amount of alternating current (AC) energy produced by the PV series as a unit of kWh. $P_{PV,rated}$ represents nominal (rated) PV solar system power in kW. Also, parameters of reference yield (YR) and performance ratio (PR) is calculated. Reference yield introduces the total amount of in-plane solar irradiance divided by the reference solar irradiance [23-25] is given as;

$$Y_R = \frac{H_t}{G_o} \ (hours\ ) \tag{3}$$

where H_t gives the solar radiation in-collimated and G_o is the reference irradiance (1 kW/m^2). The performance ratio has calculated the ratio of total PV system yield (Y_F) to the reference yield (Y_R) of the proposed PV series system [23-25];

$$PR = \frac{Y_F}{Y_R} \tag{4}$$

3.2. Design Steps of the Proposed Model: Main Parameters

3.2.1. Location and Meteorological Information

Firstly, the location information must be entered after selecting the grid-connected option. Location information can be uploaded to the system by entering the coordinate information. This is optional. We determined the coordinates as given in Table 1. Even without this information, the interactive map option can be accessed by clicking on the desired location. Then, the weather data for this point must be loaded. If we have the measurement data of the weather (irradiation, temperature, wind speed, humidity, etc.), we can enter the data into the system ourselves (manually). It allows entering in the form of monthly weather conditions. However, since we do not have measurement data, we used synthetic data. Synthetically generated data via Meteonorm 8.0 were used. The data on the weather conditions are given in Table 2.

3.2.2. Orientation

There are more than ten different field types that can be selected under the main options, including those that follow the sun (a single-axis follower plane or a dual-axis follower plane) or fixed orientation planes that do not follow the sun. Due to the fact that sun tracking will not be performed in our system, a fixed tilted plane has been selected. In order to avoid the negative effect of the wind, our panels will be positioned on the roof at an angle of 7 degrees with the ground, facing south, in the same direction as the building. Therefore, the plane tilt is 7° and the azimuth value is 16.1°. After these settings, the orientation button will appear green and the program will allow us to click the system button.

Table 2. Meteorological data of the selected location for the proposed system.

Months	Global horizontal irradiation [kWh/m²/mth]	Horizontal diffuse irradiation [kWh/m²/mth]	Temperature [°C]	Wind Velocity [m/s]	Linke turbidity [-]	Relative humidity [%]
January	73.6	33.3	3.3	2.20	3.075	75.7
February	82.6	39.1	5.3	2.30	3.449	72.1
March	143.3	54.9	9.9	2.60	3.855	63.6
April	179.5	56.5	14.3	2.49	4.765	58.8
May	212.8	72.8	19.8	2.59	4.320	52.3
June	245.4	52.0	25.9	3.50	3.576	38.0
July	253.5	50.9	30.6	3.70	3.504	30.9
August	226.6	47.2	30.2	3.00	3.583	33.8
September	183.9	41.2	24.6	2.39	3.335	39.5
October	136.6	34.7	18.0	1.80	3.737	51.6
November	92.4	26.6	10.1	1.69	3.237	64.1
December	74.1	25.6	5.2	1.99	3.070	72.8
Annual	**1904.3**	**534.8**	**16.4**	**2.5**	**3.626**	**54.4**

3.2.3. Proposed System Diagram

A simple outline of the grid-connected PV system diagram is shown in Fig. 4. As can be seen in Fig. 4, the DC energy formed after the panel array used for energy generation is converted into AC energy with the help of the inverter and reaches the user. Module, inverter, Maximum Power Point Tracking (MPPT), optimizer selection, and array sizing are done in the system part.

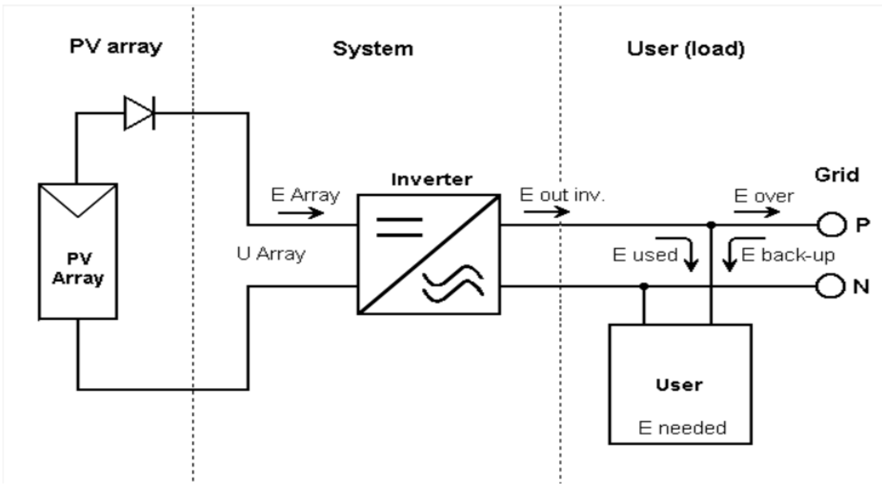

Fig. 4. Block diagram of the grid-connected PV system.

It is possible to continue the design by entering kW or m² if the area where the modules are to be placed is limited. In our building, there are ventilation units and pipes, glass roof parts to provide natural lighting for the building, air conditioners, etc. As such, we have limited space left. Because of the calculations made by taking into account the structures on the roof and the shadows that they will create, a 563 m² active area remains. A more detailed analysis of the panel layout and occupied space is described in the near-shading section.

In the selection of the PV module, consideration has been given to ensure that it is compatible with the current power values commonly used in the market (545-550Wp). Using Mono-Si technology, the module used has the highest energy production per square meter. It is also necessary for the product to have been manufactured recently and to be covered by a long warranty (30 years) as well as a long warranty period (12 years). Since it meets these conditions, the mono-silicon product with a nominal power of 550 W produced by CW Energy in 2022 was preferred. The current-voltage characteristics of the module is shown in Fig. 5.

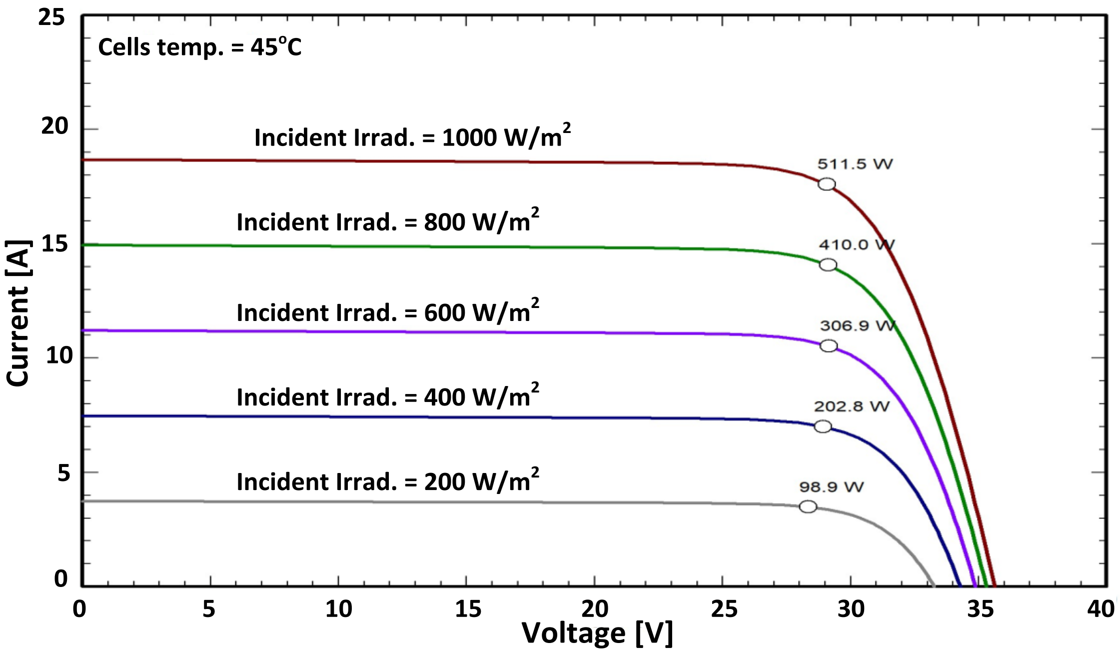

Fig. 5. Current-voltage characteristics of the selected PV panel.

In inverter selection, an inverter that can operate at 50 Hz and 60 Hz frequencies can be selected. Since the frequency of electricity in Turkey is 50 Hz, this option has been chosen. An inverter with a nominal AC power of 100 kW manufactured by Huawei Technologies has been selected. The selected inverter minimum and the maximum MPP voltage value is 200 V and 1000 V, respectively. This wide range allows the inverter to work on this feature in a wide time between sunrise and sunset. When the inverter is working on the mode of MPPT, the efficiency of the device is 97-99%, approximately. The absolute maximum PV input DC voltage value is 1100 V. While designing the solar power plant before installation, these voltage values of the panel and inverter are calculated in order to have high efficiency. Inverter main parameters are given in Table 3.

Table 3. Main parameters of the inverter for the proposed model.

Minimum MPP voltage	Maximum current per MPPT	Maximum MPP voltage	Absolute max. PV voltage	Power threshold	Grid voltage (output side)	Nominal AC power (output side)	Maximum efficiency
200 V	10 A	1000 V	1100 V	150 W	400 V	100 kVA	98.66%

The desired number of PV panels can be connected in series and the desired number of strings can be formed. Operating conditions should take into account in the design of the array. When connecting the panels in series, attention should be considered to the operating voltage of the inverter. The DC minimum input voltage of the inverter that we have chosen in our system is 200 V and the maximum output voltage is 1000 V. If the number of panels to be connected in series is too few, the input voltage of the inverter cannot be provided, and if the number of panels is too many, the input voltage of the inverter will be exceeded and the system will not work. Considering the working range of the inverter and making the calculations in a way that will provide the maximum placement in the available area depending on the panel dimensions, 22 serial modules and 10 strings total of 220 panels are placed on a 563 m^2 surface. The summary of the system as a result of all these adjustments is given in Table 4.

Table 4. Main parameters of the proposed system.

Number of modules	Module area	Number of inverters	Nominal PV power	Maximum PV power	Nominal AC power	Pnom ratio
220	563m^2	1	121 kWp	116 kWDC	100.0 kWDC	1.210

3.2.4. Detailed Losses, Self-Consumption

In this section, system losses (thermal parameter, ohmic losses, module quality-LID-mismatch, soiling loss, IAM losses, auxiliaries, aging, unavailability, spectral correction) are determined. Light-induced degradation, that is, LID loss factor of 2% and yearly soiling loss factor of 2% are predicted. Other defined parameters are not changed. Since the consumption information of the building is not known, no data has been entered. The proposed system is considered to be no storage connected directly to the grid.

3.3. Design Steps and Optional Numerical Parameters

The first step is the horizon. The option to download horizon information from web resources provided by the program is used. PVGIS 5.2 version was imported from the website using the location information that we defined in the system and the horizon was determined.

The second step is near shadings. As it is known that near shading has an important role in the electricity energy performance of PV plants. Therefore, this parameter has been taken into account when the proposed model is designed. In Fig. 6, there is a perspective view of the building created in the program. The building is positioned according to the azimuth value of 16.1°. There are two exits to the roof from the northeast and southeast directions. Also, there are an air conditioning motor, some pipes provide ventilation to the building, and the glass roof provides natural lighting to the building. The positions, heights, and tilt angle of the buildings are important as they will create a shadow situation according to the movement of the sun. For this reason, the structure was formed according to the dimensions given in Table 5.

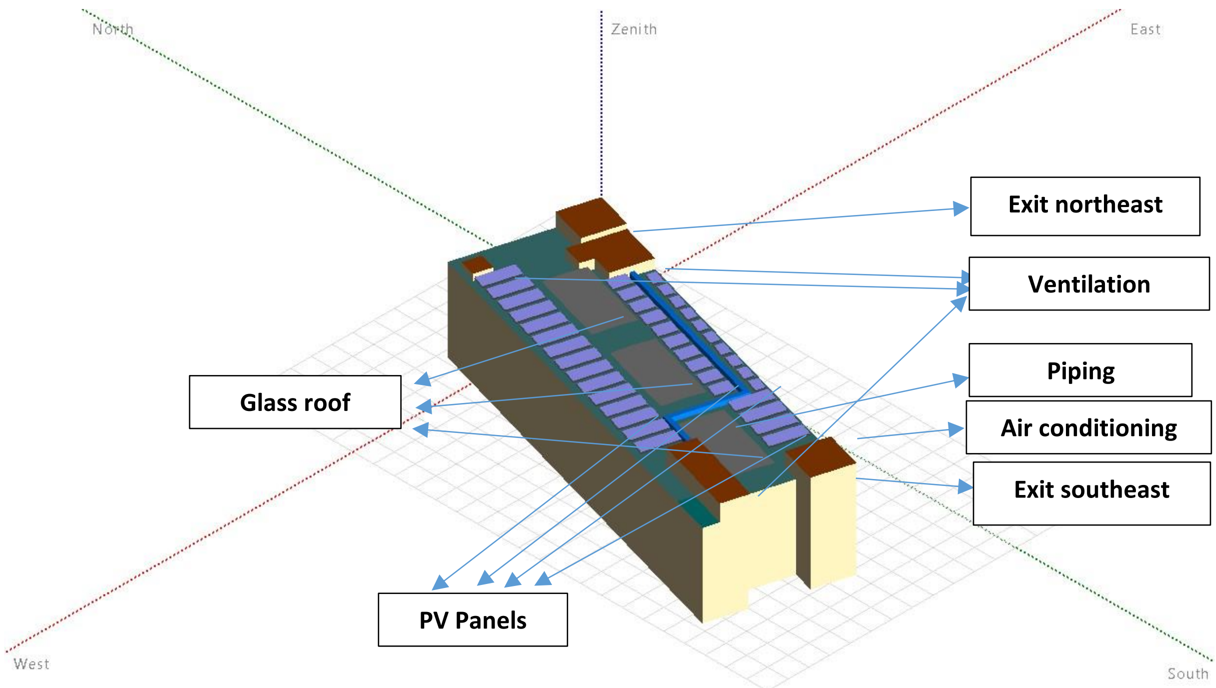

Fig. 6. Perspective view of the created building for the proposed model.

Table 5. Dimensions of the created - on the roof - structures.

Building parts	Width [m]	Length [m]	Height [m]	Tilt angle [°]
Roof	30	90 (outer edge) 85 (middle)	20 (assumed)	0
Exit northeast	9	9	3.33	0
Exit southeast	9	9	3.33	0
Glass roof (3 pieces)	9	18	1m above ground of roof	2.6
Piping	1	1	15+15.50+40=70.50	0
Ventilation 1	12	5	2.25	0
Ventilation 2	9	5	2.25	0
Air conditioning	2	3	1	0
Ventilation 3	6	19	4	0
Ventilation 4	4	4	1.5	0

The panels are placed in a 550 m^2 area in 4 arrays. A horizontally oriented array with a shed tilt of 7° was created, with a distance of 4 m between the tables. Panels are placed in such a way that they are at least 1 m inside the sides of the building and at a distance as far as the height of the building's parts when exposed to sunlight from the south. In addition, it is left in areas that can be moved in order to easily reach the panel in case of wiring and any possible damage. For the date of December 21, when the sun's height is the lowest compared to other days of the year, shadow animations were created for linear shading and attention was paid to ensure that there was no shading on the panels between 10:00 and 16:00.

4. RESULTS AND DISCUSSION

The simulation was run with the determined values according to the numerical calculations. Monthly performance values are given in Fig. 7. The performance was the highest in January and February with 87.6% due to the positive contribution of the low temperature to the module, and the lowest was in July with 77.1% due to the high PV panel temperature. The average yearly performance rate is 81.5%. It has been observed that there are small changes in the performance ratio throughout the year.

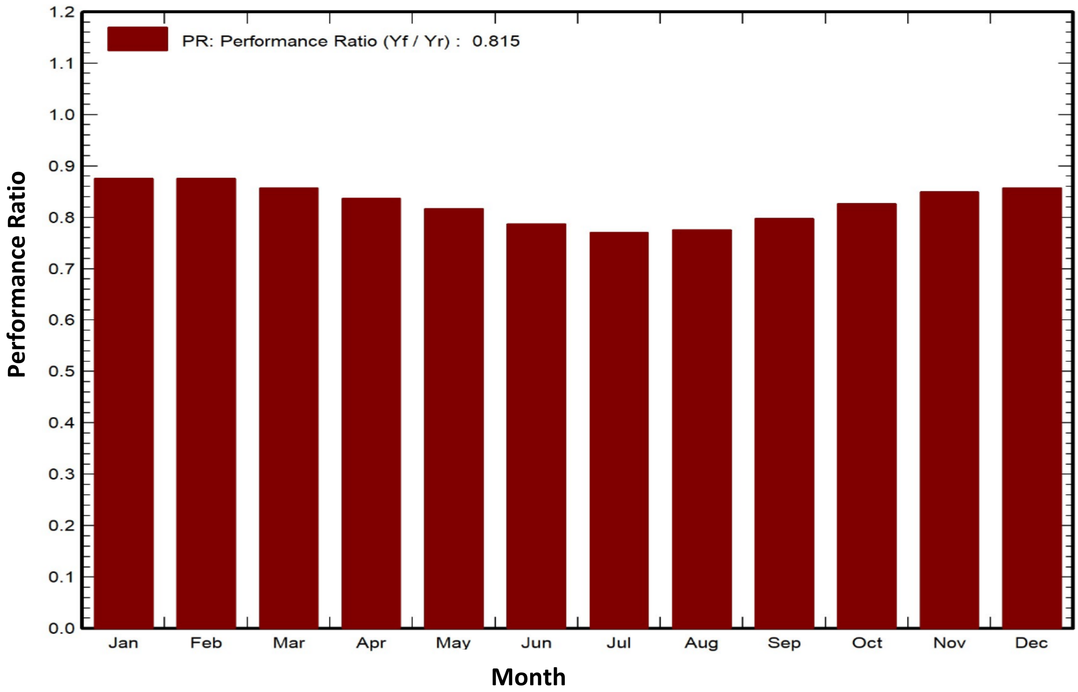

Fig. 7. Monthly performance ratio of the proposed model.

The normalized production values in the system and the inverter and panel losses formed in the system are given in Fig. 8. Production due to high radiation in summer is high. The highest production was 6.45 kWh/kWp/day in June and the lowest was 2.37 kWh/kWp/day in January. Average generation, system loss, and string loss during the year are 4.48 kWh/kWp/day, 0.08 kWh/kWp/day, and 0.93 kWh/kWp/day, respectively.

Table 6 shows numerical results for the proposed model of 121 kWp. The table consists of 8 columns. It includes variables related to radiation, meteorology and energy. These variables are global horizontal irradiation, horizontal diffuse irradiation, ambient temperature, global irradiation in the collector plane, effective global corrected for IAM and shadings, effective energy at the output of the array, energy injected into the grid, and performance ratio, respectively. The amount of PV solar energy production shows differences depending on this all radiation and temperature information. Monthly and annual values of all variables are available. The last three columns of the table include the electrical energy produced by the PV series, the energy supplied to the grid, and the system performance ratio.

According to the numerical results predicts, it has a yearly solar radiation level of approximately 1904,3 kWh/m². Furthermore, horizontal diffuse irradiation ranges from about 25.58 kWh/m² to 72.77 kWh/m². The highest ambient temperature is seen at 30.55 °C in July and the lowest temperature is 3.30 °C in January. Energy injected into the grid total is 197.745 kWh/year. The energy supplied to the grid is the highest in July with 23,804 kWh and the lowest in January with 8,877 kWh. When the effective energy at the output of the array is analyzed, it is seen that its annual value is 201.336 kWh. In the months when the produced energy value is high, the energy injected into the grid is high, similarly.

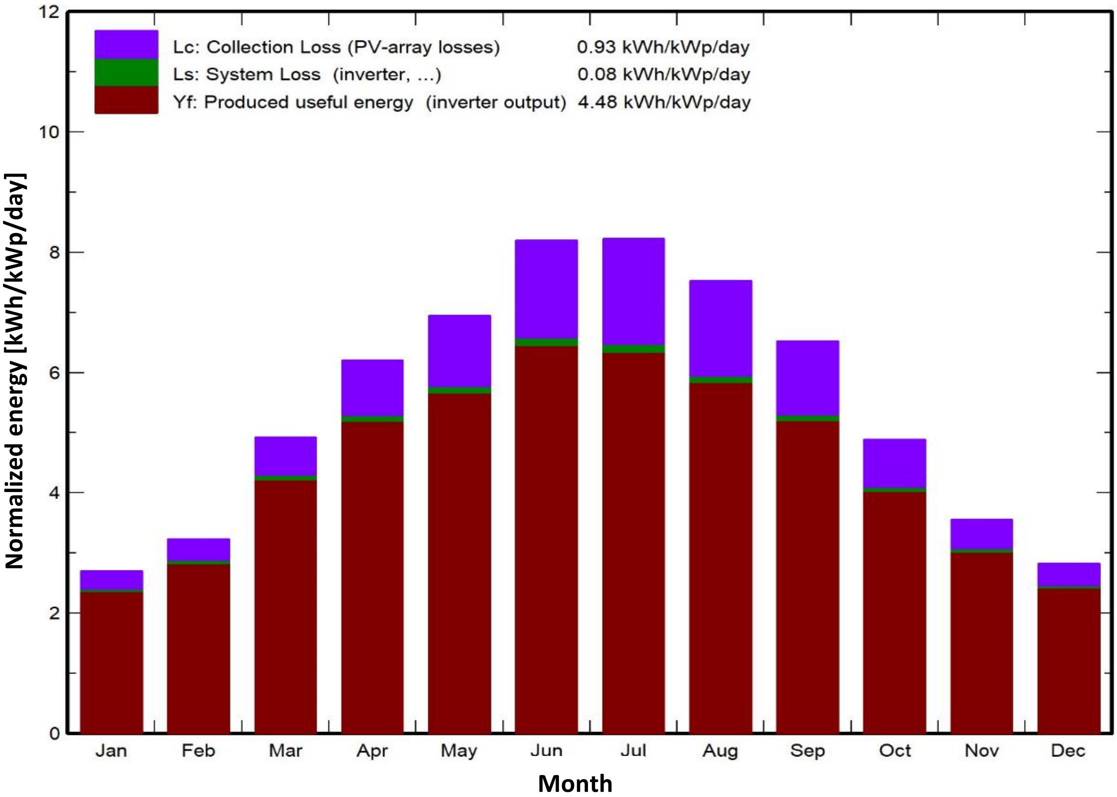

Fig. 8. Normalized electricity generation and losses for the proposed 121 kWp model.

Table 6. Numerical results for the proposed model of 121 kWp.

Months	Global horizontal irradiation [kWh/m²]	Horizontal diffuse irradiation [kWh/m²]	Ambient temperature [°C]	Global incident in coll. plane [kWh/m²]	Effective Global, corr. for IAM and shadings [kWh/m²]	Effective energy at the output of the array [kWh]	Energy injected into grid [kWh]	Performance ratio [ratio]
January	73.6	33.27	3.30	83.8	77.6	9028	8877	0.876
February	82.6	39.12	5.34	90.6	85.1	9770	9604	0.876
March	143.3	54.85	9.88	152.8	145.0	16133	15857	0.858
April	179.5	56.45	14.28	186.3	177.7	19207	18873	0.837
May	212.8	72.77	19.80	215.2	205.2	21652	21274	0.817
June	245.4	52.04	25.87	246.0	235.5	23885	23429	0.787
July	253.5	50.92	30.55	255.2	244.1	24278	23804	0.771
August	226.6	47.20	30.15	233.2	222.8	22317	21896	0.776
September	183.9	41.19	24.56	195.8	186.7	19240	18897	0.798
October	136.6	34.71	18.00	151.4	143.1	15396	15140	0.826
November	92.4	26.58	10.05	106.9	99.5	11170	10986	0.849
December	74.1	25.58	5.23	87.8	80.1	9261	9108	0.858
Year	**1904.3**	**534.69**	**16.48**	**2005.0**	**1902.5**	**201336**	**197745**	**0.815**

Generated electricity energy is approximately 230.2 MWh in the system. It is given to the grid as 197.7 MWh as a result of the losses. The highest loss in the system occurred in the panels at 8.1% due to the temperature.

Fig. 9. shows the Google Earth image of the Faculty of Islamic Sciences, Rectorate, Faculty of Engineering and Natural Sciences, Faculty of Medicine and Student Center buildings numbered 1, 2, 3, 4, and 5, respectively. The roof PV surface areas of these buildings and the Nominal PV power that can be installed in these areas and the annual energy that can be produced are calculated and given in Table 7.

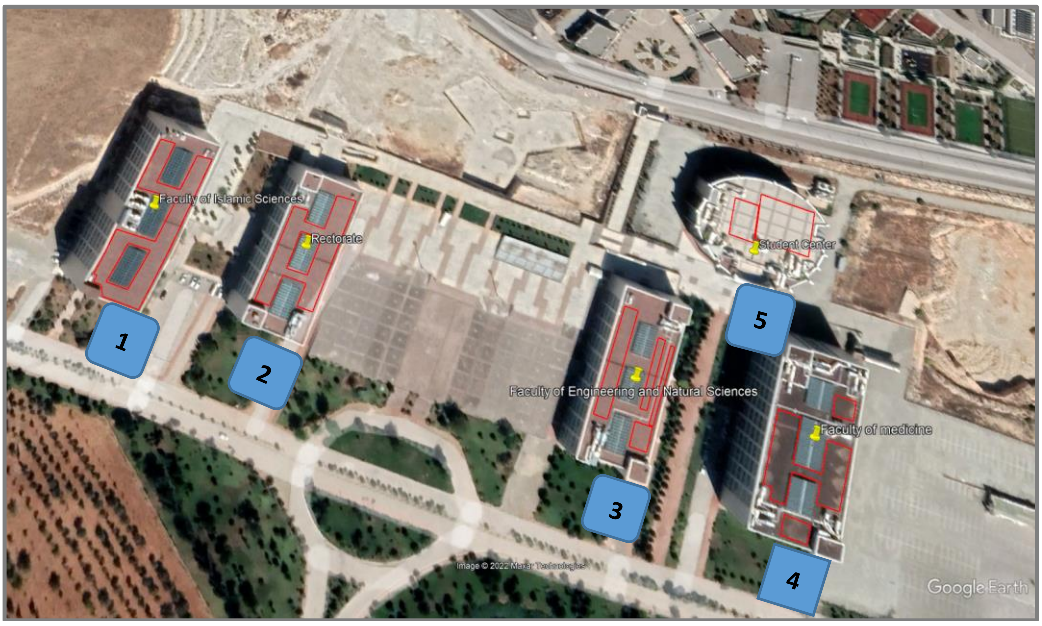

Fig. 9. General Google Earth view of the campus.

Table 7. Results for the campus of the extended model.

Building number	Roof area [m²]	Nominal PV power [kWp]	Estimated energy generation [MWh/year]
1	1350	243.4	397.7
2	1054	190	310.5
3	671	121	197.7
4	980	176.7	288.7
5	1121	202	330.3
Total	**5176**	**933.1**	**1524.9**

4.1. Scenario2: The Building's Azimuth is 0°

Here, as seen in Fig. 10, it has been investigated how the results would change if the azimuth degree of the building was chosen as 0°. When the losses are examined, the highest loss in the system is 8.0 % which occurs in the panels due to the temperature. It has been observed that the annual 230.9 MWh of energy produced in the system will be 198.4 MWh/year as a result of losses. It reveals the importance of the area on which the panel is placed, being on the south side. Only the arrangement of the panels facing south may come to mind, but it should be noted that fewer panels will be placed, as the panels will be placed at an angle to the roof.

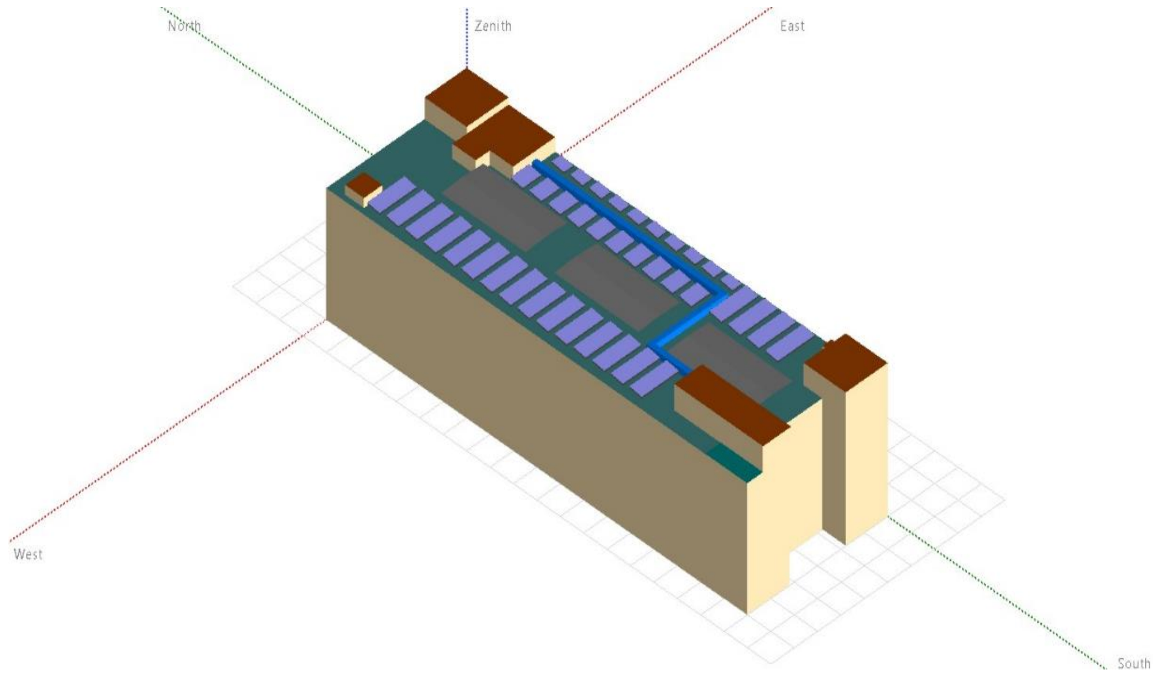

Fig. 10. Top view of the building for 0° azimuth.

By using this Scenario, the Nominal PV Power and Estimated Energy Generation capacity of the campus are determined. Calculations for other buildings are based on the Engineering faculty which has an energy generation of 198.4 MWh/year and nominal PV power of 121 kW. The calculations for the assumed scenario are shown in Table 8. According to the results, approximate the total generation increases from 1524.9 MWh annually to 1530.5 MWh with an increase of 0.37 %.

Table 8. Results for the campus for 0°azimuth 0°.

Building number	Roof area [m^2]	Nominal PV Power [kWp]	Estimated Energy Generation [MWh/year]
1	1350	243.4	399.2
2	1054	190	311.6
3	671	121	198.4
4	980	176.7	289.8
5	1121	202	331.5
Total	**5176**	**933.1**	**1530.5**

5. ECONOMIC ANALYSIS OF THE PROPOSED MODEL

The tendency to obtain energy from renewable energy sources is increasing worldwide. There are many factors that cause this situation to occur. One of them is the lack of dependence on raw materials. Renewable energy reduces the dependence on fossil resources and therefore, carbon emissions. Another factor is the falling costs with the developing technology, which also plays an important role. In this way, the installation costs of high-power energy systems are decreasing day by day. Installation costs and payback period are presented in Table 9. As can be seen in the table, the payback period of the proposed system will be 2.19 years.

Table 9. Calculed cost of the proposed PV system.

Nominal PV power [kWp]	Estimated energy generation [MWh/year]	unit installation cost [USD/Wp]	Installation cost [USD]	Operating and maintenance cost [USD/year]	Unit cost of energy [USD]	Benefit value [USD/year]	Net Benefit value [USD/year]	Payback period [years]
933.1	1524.9	0.75	699.825	7000	0.214	326.328	319.328	2.19

Electricity obtained from renewable energy sources reduces greenhouse gas emissions. There are different factors for reduction calculations. The combined margin emission factor for solar energy is 0.6488 tCO^2/MWh [26] . In other words, 0.6488 tons of CO^2 emissions are avoided for every 1 MWh of electricity to be produced by a solar power plant. Since the electricity produced in our system is 1524.9 MWh annually, 989.35 tons of CO^2 emissions will be avoided.

6. CONCLUSIONS

In this study, the solar energy potential of GIBTU University, located in the Southeastern Anatolia region of Turkey, which is rich in solar energy, was investigated. It was explained in detail how to design a rooftop PV system and determine the solar energy potential of a building readily.

The Faculty of Engineering and Natural Sciences was chosen because it is: i) the building that has the least amount of space where the panels to be placed and ii) the building that is the most difficult to model with different shading conditions due to different structures on the roof. By paying attention to these restrictions, maximum use of space was achieved with 4 different array placements on the building. However, only 21% of the entire roof area (550 m^2 of 2500 m^2), and 82% of usable space (550 m^2 of 671 m^2) could be used.

The system design aimed to keep the results more realistic by keeping annual soiling loss and LID loss factor at the level of 2%, which increases the losses.

The Faculty of Engineering and Natural Sciences has 121 kW of installed solar power. System performance is quite impressive with 81.51%. The annual energy produced by the system is 197.7 MWh/year. As expected, the highest production is in summer months (June to August) when radiation and sunshine intensity is the greatest. However, it should be noted that the highest PV-series losses occurred during this period of the year. The reason for the decrease in performance in the summer months is the string loss in the panels caused by the increase in temperature.

Based on calculations made in other buildings in the Faculty of Engineering and Natural Sciences, the total solar power plant power that can be deployed was calculated to be 933.1 kW, and the annual energy produced is 1524.9 MWh.

The performed economic and environmental analysis of the proposed system shows that the payback period of the PV system to be installed on the roof of the campus will be 2.19 years and that 989.35 tons of CO^2 emissions will be annual avoided. In this way, the energy needs of the campus will be met from an environmentally friendly source that will pay for itself in a about two years.

REFERENCES

[1] S. Gahrens, S. Alessandra, K. Steinfatt, *Trading Into a Bright Energy Future*, World Trade Organization, 2021.

[2] A. Maka, J. Alabid, "Solar energy technology and its roles in sustainable development," *Clean Energy,* vol. 6, no. 3, pp. 476-483, 2022.

[3] A. Alami, M. Rabaia, E. Sayed, M. Ramadan, M. Abdelkareem, S. Alasad, A. Olabi, "Management of potential challenges of PV technology proliferation," *Sustainable Energy Technologies and Assessments,* vol. 51, pp. 101942, 2022.

[4] R. Dominguez, M. Carrion, G. Oggioni, "Planning and operating a renewable-dominated European power system under uncertainty," *Applied Energy,* vol. 258, pp. 113989, 2020.

[5] IRENA-International Renewable Energy Agency, *Renewable Capacity Statistics 2022*, 2022. <https://www.irena.org/publications/2022/Apr/Renewable-Capacity-Statistics-2022>

[6] Teias-Turkey Electricity Transmission Corporation, 2022. <https://www.teias.gov.tr/kurulu-guc-raporlari>

[7] GEPA- Solar Energy Potential Atlas, 2022. <https://gepa.enerji.gov.tr/MyCalculator/>

[8] F. Dincer, " Electricity generation potential from solar energy in Turkey-economic analysis and comparative evaluation with EU countries," *Kahramanmaras Sutcu Imam University Journal of Engineering Sciences,* vol. 14, no. 1, 2011.

[9] K. Gulsen, M. Sonmez, M. Kabas, " Determination of solar energy potential in Gaziantep province by Analytical Hierarchy Process Method," *Journal of Geography,* no. 39, pp. 61-72, 2019.

[10] Turkish Ministry of Energy and Natural Resources, information center - solar energy, 2022. <https://enerji.gov.tr/bilgi-merkezi-enerji-gunes>

[11] M. Asif, M. Hassanain, K. Nahiduzzaman, H. Sawalha, "Techno-economic assessment of application of solar PV in building sector: a case study from Saudi Arabia," *Smart and Sustainable Built Environment,* vol. 8, no. 1, pp. 34-52, 2019.

[12] P. Ramanan, A. Karthick, "Performance analysis and energy metrics of grid-connected photovoltaic systems," *Energy for Sustainable Development,* vol. 52, pp. 104-115, 2019.

[13] Y. Cui, J. Zhu, F. Meng, S. Zoras, J. McKechnie, J. Chu, "Energy assessment and economic sensitivity analysis of a grid-connected photovoltaic system," *Renewable Energy,* vol. 150, pp. 101-115, 2020.

[14] A. Ali, A. Hamed, M. Abdelsalam, M. Sabry, M. Elmarghany, "Energy management of photovoltaic-battery system connected with the grid," *Journal of Energy Storage,* vol. 55, pp. 105865, 2022.

[15] N. Kumar, R. Gupta, M. Mathew, A. Jayakumar, N. Singh, "Performance, energy loss, and degradation prediction of roof-integrated crystalline solar PV system installed in Northern India," *Case Studies in Thermal Engineering,* vol. 13, pp. 100409, 2019.

[16] A. Behura, A. Kumar, D. Rajak, C. Pruncu, L. Lamberti, "Towards better performances for a novel rooftop solar PV system," *Solar Energy,* vol. 216, pp. 518-529, 2021.

[17] S. Yilmaz, F. Dincer, "Optimal design of hybrid PV-Diesel-Battery systems for isolated lands: a case study for Kilis, Turkey," *Renewable and Sustainable Energy Reviews,* vol. 77, pp. 344-352, 2017.

[18] J. Ozogbuda, T. Iqbal, "Sizing and analysis of an off-grid photovoltaic system for a house in remote Nigeria," *Jordan Journal of Electrical Engineering,* vol. 8, no. 1, pp. 17-26, 2022.

[19] S. Mousavi, T. Iqbal, "Optimum sizing of stand-alone hybrid photovoltaic systems equipped with reverse osmosis desalination system for a rural house in Iran," *Jordan Journal of Electrical Engineering,* vol. 7, no. 4, pp. 304-322, 2021.

[20] T. Iqbal, Y. Dabas, "Sizing and analysis of a DC stand-alone photovoltaic-battery system for a house in Libya," *Jordan Journal of Electrical Engineering,* vol. 7, no. 2, pp. 84-95, 2021.

[21] L. Ahsan, T. Iqbal, "Dynamic modeling of an optimal hybrid power system for a captive power plant in Pakistan," *Jordan Journal of Electrical Engineering,* vol. 8, no. 2, pp. 195-213, 2022.
[22] T. Aika, S. Igbinovia, P. Orukpe, "Feasibility assessment of wind energy potential for electricity generation in Nigeria," *Jordan Journal of Electrical Engineering*, vol. 6, no. 1, pp. 25-34, 2020.
[23] V. Sharma, S. Chandel, "Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India," *Energy,* vol. 55, pp. 476-485, 2013.
[24] L. Ayompe, A. Duffy, S. McCormack, M. Conlon, "Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland," *Energy Conversion and Management,* vol. 52, no. 2, pp. 816-825, 2011.
[25] N. Kumar, M. Kumar, P. Rejoice, M. Mathew, "Performance analysis of 100 kWp grid connected si-poly photovoltaic system using PVsyst simulation tool," *Energy Procedia,* vol. 117, pp. 180-189, 2017.
[26] Turkish Ministry of Energy and Natural Resources, Environment and climate, Turkey national electricity network emission factor, 2022. https://enerji.gov.tr/evced-cevre-ve-iklim-turkiye-ulusal-elektrik-sebekesi-emisyon-faktoru