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Comparison of Simulation Results for 25 kW Power Output Rooftop PV System

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ABSTRACT

The use of electrical energy from renewable energy sources has increased considerably in recent years. Photovoltaic (PV) solar energy, which is one of the renewable energy sources, takes its source from the sun, which is considered an unlimited source. With the widespread use of photovoltaic systems, some legal regulations by governments have been made for their installation. Simulation programs are used for the design, layout, technical and economic analysis of PV systems.

In this study, the design is made using the PVsyst, PV*SOL, Solarius programs, and the PVGIS website used in PV systems. The projects are designed to have an output power of 25 kW. According to the simulation results, the PVGIS website provides approximate data since technical details cannot be entered. In the results of PVGIS and all simulation programs, it has been calculated that the system can produce 42-48 MWh of electrical energy annually. Power Ratio (PR) results of the system were in the range of 78-85%. Annual electrical energy production per installed kW has been calculated to be 1436-1635 kWh/year. It is stated that the annual saved CO^2 will be 18.66-22.226 tons /year. When the simulation results are analysed monthly, the differences between the months are remarkable. The reason for these deviations can be explained by the annual solar radiation (kWh/m^2) data and databases used by the programs. It has been observed that the simulation programs consider the monthly average temperatures and sunshine durations of the region.

It is thought that there is a need to compare real-time data with simulation results in future studies. It is considered that this study will be helpful for future studies.

1. INTRODUCTION

It is predicted that global warming will lead to an increase in the average temperature of the world by more than 1.5°C after 2030 [1]. One of the causes of global warming is the fossil resources used in the production of electrical energy. With the Paris Convention, many countries have made agreements to abandon fossil resources and switch to renewable energy sources for electricity generation [2]. Countries are interested in renewable energy in line with their regulations and energy policies. The renewable energy sector has become an important shareholder and market area to meet global electricity energy in the last 20 years. The leading energy sources in the field of renewable energy are solar and wind energy. Solar and wind energy have advantages such as the absence of fossil fuels in energy production, the absence of waste, and the fact that their operation is easier and less costly than conventional sources, except for the first installation. Generating electrical energy from these renewable sources has benefits such as reducing environmental pollution, reducing greenhouse gas emissions, and preventing global warming [3]. Software or tools are used for design and simulation purposes in areas where electricity will be produced from wind energy and solar energy. Simulation programs provide users with advantages such as estimated electricity production, system performance, return on investment payback period, and layout design of the installation site. With these advantages, the investment cost can be determined at first by saving time and cost with the design of an area.

It cannot be expected that solar power plants will realize their annual electrical energy production exactly according to their installation power. Over time, due to technical reasons such as humidity, dusting, pollution, and degradation in panel power output, the annual electrical energy production estimate varies according to the installed region. The annual degradation rate is 0.5% and the annual maintenance cost is 1% of the total investment amount [4, 5]. Various anti-reflection coating techniques are used to prevent degradation caused by dusting and reflection [6]. The altitude, latitude, solar radiation intensity, wind speed, air temperature and humidity averages of the region to be installed will affect the electrical energy production values [7]. Production in Photovoltaic (PV) systems varies daily and seasonally, depending on the time of day, meteorological conditions, and solar radiation. Spatial interpolation and solar radiation modeling are used in modeling and prediction studies [8]. It is estimated based on meteorological data of previous years to estimate the expected electrical energy production compared to the installed capacity. In addition to meteorological data, sunshine-based, cloud-based, temperature-based, and hybrid meteorological parameter-based models are used in modeling [9]. In this on-grid-middle voltage level design study, meteorological solar radiation modeling was used.

Meteorological databases that are widely used in design and simulation are Meteonorm, NASA SSE, NCEP, GIS Solar Data, HelioClim, and World Radiation Data Center. Software programs and interface websites which are used in solar energy simulations are PVsyst (pvsyst.com), PV*SOL (valentin-software.com), Solarius (accasoftware.com), BlueSol (bluesolpv.com), Homer (homerenergy.com), PVCase (pvcase.com), Easy-PV (easy-pv.co.uk), PV F-Chart (fchartsoftware.com/fchart), SolarGIS (solargis.info), Global Solar Atlas (globalsolaratlas.info), Helio Scope (helioscope.com), System Advisor Model (SAM) (sam.nrel.gov), and PV-GIS (re.jrc.ec.europa.eu/pvg_tools/en/). Some of the software programs provide very comprehensive design and analysis capabilities, while others allow easy use and quick results. With simulation programs, small-scale, off-grid or grid-connected(on-grid) PV systems can be designed, and technical-economic analyses can be performed.

Among these programs, which are also used by commercial enterprises, PV*SOL and PVsyst programs are the most frequently used for more technical details [10]. Homer program can be used to design and analyze hybrid systems such as wind-solar-biomass and is often used for techno-economic evaluations [11]. In a study conducted in the PV*SOL program, simulation results and real-time data were compared, and up to 94.33% similarity was observed between real data and simulation data [12]. When the studies on the roof-top PV system are examined, in the application on the roof of a university building, the available roof area for PV applications has been determined by defining the limitations. These limitations have been determined by considering factors such as PV panel temperature co-efficiency and shading. PV*SOL software was used, and it was seen that university buildings have the potential to produce 5,389.2 MWh/year of electrical energy. According to the simulation results, it is calculated that the annual electricity generation per kWp will be 1,336.6 kWh/kWp. When the environmental analysis is performed, this utilization can save 63,727.05 tons of CO_2, 1.89 tons of CH_4, 0.27 tons of N_2O, 970.05 tons of SO_2, and 590.12 tons of NO emissions in 25 years if the PV system is applied [13].

In a study in which PV system data with an installed power of 7.8 kWp was simulated with the Homer program, it was revealed that the simulation data has an annual error margin of 1.7% from the real data [14]. The annual average Performance Ratio (system utilization rate) (PR)(Eq.1) of an off-grid system simulated with PVsyst was simulated as 72.8%. It was simulated that the highest PR was in December and the lowest PR was in April [15]. A rooftop hybrid system with a wind turbine and a PV system on the roof of a university building was designed with Homer. For a roof area of 400 m^2, the optimum PV power is simulated as 30 kW and the optimum wind turbine power is simulated as 22.5 kW. According to the simulation results, it is seen that 55% of the annual energy demand of the building can be met, with 23% PV panels and 32% with wind turbines [16]. In a study simulating the PVGIS interface and comparing the results with the real electrical energy production values, it was seen that the simulation results were realized with a 5% error from the actual production results [17]. A simulation study was performed with PVsyst on the roof of a university campus building with 30 kWp and 38 kWp installed power. It has been seen that as a result of simulation the Performance Ratio (PR) for 30 kWp power is 76.1%, the annual electrical energy production is 49.80 kWh and the annual carbon dioxide emission of 42 tons will be saved [18]. The simulation of the 301 kWp application on a roof of a hotel in Jordan was done with PVGIS and PVsyst. According to the calculation result, the daily average electrical energy production will be 4.93 kWh/kWp/day. It has been calculated that the system will have a PR of 82.8% and it has been calculated that the system will have a PR of 82.8% and will be able to produce an average of 541 MWh of electrical energy annually. According to the country's electricity tariff prices and the costs of the simulation period, the amortization period of 4.1 years has been revealed [19].

In this study, simulator programs used in PV systems were investigated first. Then, the simulators used in roof-type designs were studied in the literature and the most frequently used programs were surveyed. Using PV*SOL, PVsyst, Solarius, and PVGIS programs, a comparison of technical analysis and simulation results was made for a rooftop PV system with an installed power of 29.4 kWp, including a system loss of 15%, which can be a power output of 25 kW.

2. MATERIAL AND METHOD

There are programs used in the calculation of simulation, technical analysis, and amortization periods used in the design of solar PV systems. These programs were investigated from literature studies. As the location, Osmaniye Korkut Ata University Kadirli Vocational School of Higher Education building in Kadirli district in Osmaniye region of Türkiye was selected and a 25 kW roof-top type fixed angle PV system was designed. The reason why it is designed as 25 kW is the legal upper limit of the allowed installed power in roof-top type PV systems by the Ministry of Energy and Natural Resources of Türkiye [20]. Solarius by Acca, PVsyst, and PV*SOL programs, and the PVGIS database were used in the design. The simulations were designed in the same conditions as each other. In this study, attention was paid to the differences in technical results rather than the economic and investment analysis of the design, and the consistency of the results was desired to be discussed.

The building location is at the coordinates 37.39'N, 36.07'E, at an altitude of 114 m, in the direction of 167° South, and with non-slope. There is not any obstacle like a tree or building that can lead to shadowing around the structure. The height of the roof from the ground is 10 meters. The dimensions of the designed area are 17 meters wide and 40 meters long. All systems are designed with a power output of 25 kW, with a loss of 15%, and a total of 29.4 kWp. PV panels were selected with a power output of 545 Wp, 21% efficiency, Voc 48 V, Isc 13.9 A, Vm 41.08 V, Im 13.04 A, and monocrystalline cell panel type. Inverters are selected as 27 kWp AC 3-phase 380 Volt. The operating voltage range of the inverters is 580-850 Volts.

In the Solarius simulation, the data were taken from the Meteonorm 7.1 database. In the PVGIS database, the calculation was made with the SARAH2 database. SARAH2 database takes measurements with an accuracy of 0.05x0.05° and gives the average data between 2005-2020. In the PVsyst simulation, the data were taken from the Perez and Meteonorm databases. Hofmann and Hay&Davies techniques were used in PV*SOL simulation. The installation area and view are given in Fig. 1.


Figure 1. The location and satellite image of the building

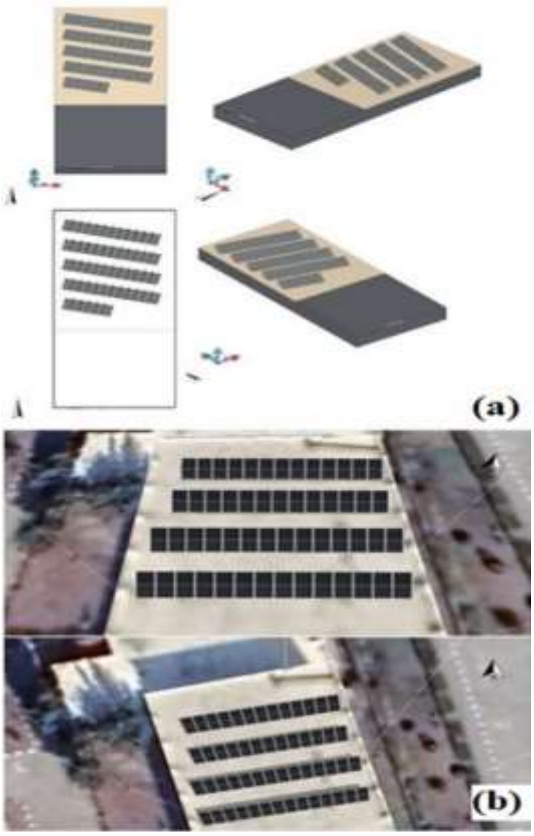


Figure 2. Design and layout prepared with Solarius(a) and PV*SOL(b)

According to the design, 54 PV panels with a 29.43 kWp total power were placed on an installation area of 140 m^2. PV panels are connected as 3 strings and 18 PV panels in each string are connected in series. Thus, inverter input is adjusted to 600-650 Volt-40 Ampere voltage and current values when the panel surface is 50°C under sunny day conditions. The design was made considering that the efficiency of the PV panel decreases between 0.25-0.5% with each 1°C increase in temperature [21]. The 3D design and layout designs of the roof-top type PV system designed with Solarius and PV*SOL program, which can output 25 kW of power, are as in Fig. 2.

3. RESULTS

The parameters considered in PV system designs are the solar radiation of the region, the ambient temperature, the temperature coefficient of the PV panel, the inverter efficiency, the maximum power that can be obtained under standard test conditions (STC), and the number of PV panels [22]. Although these parameters vary according to the modeling, they are common parameters used in the literature. In the design, these parameters were considered in the simulations. Since it is known that different databases are used in simulation calculations, the annual global horizontal irradiation (GHI) (kWh/m^2) solar radiation data of the region divided by months are given in Table 1. When the annual solar radiation data are compared, they are close to each other, except for the PV*SOL program.

TABLE I
ANNUAL SOLAR RADIATION (KWH/M^2)

Months	PV*SOL	Solarius	PVsyst	PVGIS
January	67.3	58.5	69.1	73.59
February	77.02	94.905	81.8	85.97
March	116.62	130.51	125.7	120.37
April	148.38	177.6	153.5	164.74
May	177.38	169.57	189.7	208.8
June	189.96	201.3	211.8	211.94
July	195.42	233.12	220.1	228.12
August	189.13	214.83	203.1	208.98
September	151.44	171	167.1	165.73
October	108.43	133.61	121.3	137.62
November	73.17	94.2	83.5	87.43
December	60.32	59.21	69.1	75.41
Total	1,554.57	1,738.355	1,695.8	1,768.7

In the Solarius program, daily and annual solar radiation data are taken from the Photovoltaic Geographical Information System (GIS) database. When the data of the same region is studied in the PVGIS system, it is seen that it is not exactly the same. According to the Solarius program, the annual solar radiation was 1,738.355 kWh/m^2, 1,695.8 kWh/m^2 according to the PVsyst program, 1,768.7 kWh/m^2 according to the PVGIS interface, and 1,554.57 kWh/m^2 according to the PV*SOL program in the region selected for the installation.

The average monthly temperatures and sunshine durations of the region for the last 24 years are given in Fig. 3. According to the records taken between 1987-2021, the region is a temperate region with an average temperature of 18.7°C for 24 years and the average annual sunshine duration is 5.1 hours. Considering the annual average of 4.5-5 hours of sunshine duration per day, where the average is 6 hours in the summer season in Turkey, it is considered that the annual average of 5.1 hours is quite high.

PVGIS calculated annual electrical energy production as 43,750 kWh/year, electrical energy production per kW as 1,486 kWh/kWp/year, and Power Ratio (PR) as 85%, but there is no data about CO_2 emissions. PV*SOL program estimated annual electricity generation according to location is 42,234 kWh/year, energy production per kW is 1,436 kWh/kWp/year, Power Ratio is 78%, and the saved amount of CO_2 is 19.8 tons/year. In the Solarius program, the prevented emission of CO_2 equivalent is 22.226 tons/year, the total annual amount of electrical energy is 48,053 kWh/year, 1,632 kWh/kWp/year electrical energy production rate, and the Power Ratio is 85%. As a result of the simulation in the PVsyst program, the Power Ratio is 84.54%, 48,130 kWh/year of total electrical energy production, 1,635 kWh/kWp of electrical energy production per kW and 18.66 tons of CO_2 prevented from being released in a year. The self-consumption of the electrical energy consumed by the system components in all simulations is 8 kWh/year. This consumption power is approximately 0.2% of the annual electrical energy produced by the systems and is a small power that can be ignored. The results of the simulations are given in Table 2.

TABLE II
OVERVIEW OF SIMULATIONS

Months	PV*SOL	Solarius	PVsyst	PVGIS
Annual Electrical Energy Production (kWh/year)	42,234	48,053	48,130	43,750
Power Ratio (%)	78	85	84,54	85
Annual Electrical Energy Production per kW(kWh/year) (kWh/kWp/year)	1,436	1,632	1,635	1,486
Saved CO_2 (tons/year)	19.8	22.226	18.66	n/a

According to the results shown in Table 2., it is predicted that an average of 20 tons of CO_2 emissions will be prevented per year. There is no data on carbon emissions in the PVGIS interface. According to the simulation results, the CO_2 equivalent prevented per kW is approximately 1 ton per year.

The PR was given 78% in PV*SOL and 85% in others, which resulted in a difference in the expected electrical energy from the designed system.

$$PR = \frac{P_{real}}{P_{ref}}.100 \qquad (1)[24]$$

$$P_{ref} = \text{GlobInc} \times P_{ins} \qquad (2)[24]$$

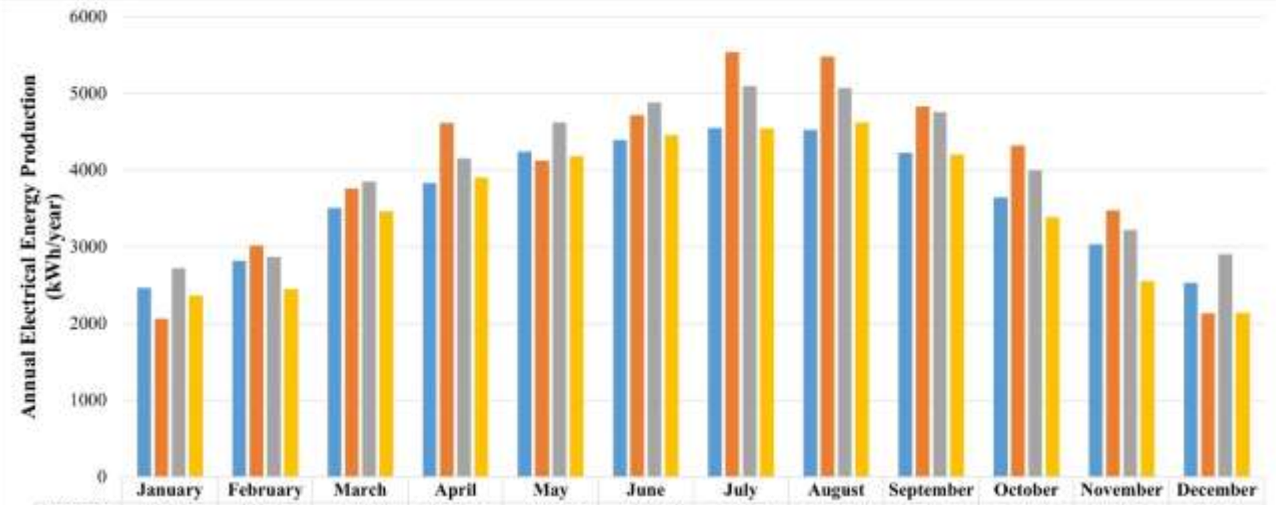
Where:

PR : Power Ratio
P_{real} : Real Power (supplied to grid)(kWh)
P_{ref} : Reference Power (simulated) (kWh)
GlobInc : Global Incident (kWh/m^2)
P_{ins} : Installed Power (kWp)

To determine the Real power exactly, the total electrical energy value produced during at least 1 year must be measured. However, the actual PR value can be expressed after that, but the PR value changes every year due to solar radiation varying from one year to the next. P_{real} value in simulations changes with factors such as pollution, reflection, aging of the PV panel, and wiring quality. For this reason, the PR value given in each simulation gives an approximate expression. The parameter with the highest probability of error in the simulations is the error rate in taking the P_{real} value in the PR calculation.

In the annual electrical energy production prediction given in Fig. 4, when separated by months, the PV*SOL program simulated more electrical energy production than the Solarius program in January, May, and December, although the total electrical energy production result was less than the other simulation results. It estimated less electrical energy in all months than the PVsyst program. In the PVGIS simulation in January, May, and December, higher electrical energy estimates were given than Solarius results. The reason why the Solarius program gives lower estimations than PVGIS and PV*SOL simulations in January, May, and December is that it shows lower solar radiation data in January, May, and December as can be seen in the solar radiation values in Table 1.

Figure 3. Annual average temperature and sunshine duration of Osmaniye province [23]



	January	February	March	April	May	June	July	August	September	October	November	December
PVGIS	2464.11	2815.44	3504.8	3832.26	4239.16	4390.48	4550.43	4521.78	4223.37	3641.32	3034.51	2531.41
Solarius	2060.26	3016.44	3759.68	4611.9	4119.9	4715.4	5536.91	5479.25	4828.8	4318.3	3474.3	2132.18
PVsyst	2717	2871	3848	4154	4619	4879	5095	5069	4759	3996	3218	2904
PVSol	2360	2445	3462	3900	4180	4452	4543	4620	4200	3385	2548	2139

Figure 4. Prediction of Annual electrical energy production (kWh)

A very high difference in the electrical energy production was observed between the Solaris simulation in April, July, and August, and the other estimates. These results do not seem to be consistent with the solar radiation in Table 1. For this reason, it has been evaluated that the deviation in the annual electrical energy production data is very high in the Solarius program. Although the total annual electrical production estimate is close to other predictions, the reliability of the data seems doubtful when studied month by month.

When the results of PV*SOL and PVGIS in Table 1., Table 2. and Fig. 4. are examined, the annual total solar radiation of PVGIS is higher than that shown in PV*SOL, but the annual electrical energy production is closer to each other. The expected PR of 78% in the PV*SOL program is effective for this result.

It has been seen that knowing the annual solar radiation data, the meteorological data of the region, and the geographical conditions reduce the error rate in simulation results. Although databases based on long-term data are used, situations such as climate change, temperature change during the year, sunshine duration, and unexpected shading depending on the geographical conditions of the region increase the error rate in the results.

4. DISCUSSION AND CONCLUSION

In this study, the factors affecting the result have been examined by comparing the simulation results in a grid-connected or off-grid roof-top PV system to be installed in any region. A system with an installed power of 29.4 kWp and maximum output power of 25 kW due to a loss of 15% is designed. PV*SOL, Solarius, and PVsyst design and simulation programs, which are frequently used in PV systems, and the PVGIS website is used. According to the results, considering the annual solar radiation data, temperature, and sunshine duration of the 25 kW output power, it has been revealed that there is an annual electricity generation potential of 42-48 MW in the region.

It has also been determined that the use of renewable energy will prevent and save an average of 20 tons of CO_2 equivalent emissions per year. Considering that 70% of Turkey's greenhouse gas emissions occur from energy production, the environmental impact of producing electrical energy from renewable sources will be very important [25].

It is thought that photovoltaic solar energy systems will gain more importance in the future considering the high market share it has achieved in recent years among other renewable energy systems, the increase in efficiency with progressing semiconductor technology, and the decrease in overall system losses. The system is designed grid-connected and doesn't have a storage system so all electrical energy produced can be transferred to the grid. Nevertheless, there is a need to compare the simulation data with the real and long-term data in connection with the grid. In future studies, attention will be paid to comparing simulation results by measuring real-time data.

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BIOGRAPHIES

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