The Development of Simulation Parameters for Photovoltaic Systems

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Abstract- In this study, a model for monocrystalline photovoltaic systems is calibrated and validated using the computational tool System Advisor Model (SAM) for the simulation of electricity generation, taking into consideration the meteorological characteristics of a city near the equator at high altitude in Turkey (Mount Ararat). The electrical performance is achieved by deploying photovoltaic panels with specific characteristics, such as roofs with local characteristics and different orientations. The efficiency of a climate file for the year 2023 can be calibrated with meteorological data collected over the course of 18 days. A photovoltaic system's yields are estimated based on its inclination, orientation, and technical characteristics. There are losses in the plates due to dirt accumulation and temperature increases. A linear regression analysis is performed to validate the model. The simulated values are compared with data obtained from in situ measurements of a horizontally positioned panel. The results indicate that dirty conditions lead to a 2.78 % efficiency loss, and increased temperatures can result in a 30% efficiency loss. The model's validation showed a coefficient of completion of R2 of 0.987 and RMSE of 8.17 %. The study also concluded that, due to the particular latitude of the site, the arrangement of photovoltaic panels in any orientation considering low slopes does not significantly reduce the yield in annual electricity generation. This study uses the System Advisor Model (SAM) to calibrate and validate a monocrystalline photovoltaic system model in Turkey, accounting for high-altitude meteorological conditions near the equator. The study factors in losses from dirt accumulation and temperature increase as it estimates electricity generation yields from specific panel characteristics and orientations.

Keywords: Renewable energies, Monocrystalline, SAM, photovoltaic simulation

1. Introduction

The growing energy demands and climate changes caused by anthropogenic processes call for the use of clean, renewable energy sources that expand more sustainably. Renewable energy sources such as solar and wind power do not produce any emissions and are more sustainable than traditional fossil fuels. They are also more abundant, making them a better long-term option for meeting energy demands. The use of traditional energy sources like coal or oil will further degrade the environment since they are finite resources [1]. Renewable energy sources are also important for reducing air pollution and global warming. They can also create new jobs and help to stimulate the economy. Renewable energy sources are more sustainable and have lower environmental impacts [2]. Renewable energy sources, such as solar and wind, are replenished naturally and do not use finite resources. This makes them more sustainable and less likely to run out of resources in the future [3]. Additionally, renewable energy sources have little to no air pollution and can help reduce global warming. The deployment of these technologies is ideal in buildings and urban contexts. Renewable energy sources such as solar and wind power are replenished naturally and don't rely on finite resources such as fossil fuels, which will eventually run out. Furthermore, renewable energy sources produce little to no emissions, which can contribute to global warming [4]. The cost of coal and oil is continuing to rise, making renewable energy sources more economical over time. This makes renewable energy sources a more sustainable and cost-effective solution in the long run and can reduce our dependence on fossil fuels. The efficiency of renewable energy sources is also improving, which makes them an even better choice for cities [5]. The global energy crisis can be resolved with solar photovoltaic technology because of its existing expansion potential and increasingly affordable costs. Solar photovoltaic technology is already becoming more affordable and efficient, and its potential for further expansion is huge, making it a viable option for resolving the global energy crisis [6]. The use of solar photovoltaic technology is also beneficial to the environment, as it does not produce any emissions or pollutants that are linked to climate change. Solar photovoltaic technology is also renewable, meaning it does not require the use of finite resources like fossil fuels, and it is cost-effective in the long run. Additionally, solar photovoltaic technology is relatively easy to install and maintain, making it an attractive option for many countries [7]. Solar photovoltaic technology can also create more jobs and increase economic growth through its use of renewable energy sources. Solar photovoltaic technology is also relatively inexpensive compared to other renewable energy sources, making it a viable option for many countries [8]. Additionally, solar photovoltaic technology has a relatively low environmental impact, making it an attractive option for many countries. There have been studies conducted at these locations that have indicated Mount Ararat is located at a latitude that has significant solar potential. These studies have found that Mount Ararat's latitude is optimal for capturing the sun's rays and converting them into energy [9]. This means that Mount Ararat could be an ideal location for installing solar panels to generate electricity. Ecuador's energy consumption is increasing, and its seasonality does not vary much throughout the year, so the amount of irradiation is relatively constant. This means that the country can capitalize on renewable energy resources such as solar, wind, and hydropower, which are abundant in the country [10]. Additionally, the country's geographical position means that it can benefit from the sun's energy throughout the day, providing a consistent and reliable source of energy. Furthermore, solar energy holds great potential for harnessing in the fight against climate change and atmospheric pollutants. Each city has distinctive characteristics in terms of its resources and energy demands, so determining the variable energy generation capacity in each urban environment is an essential first step in developing urban planning standards and regulations [11]. This is important because it allows cities to create a plan that is tailored to their specific needs and resources. It also helps cities to identify areas where renewable energy sources such as solar and wind could be implemented to reduce energy costs and emissions. Additionally, it allows cities to focus on sustainability initiatives, such as reducing waste and increasing energy efficiency, which can help reduce emissions and improve air and water quality [12]. A large area of envelopes and roofs can be used to enclose solar collectors, on top of energy efficiency measures in buildings involving distributed energy production. The International Renewable Energy Agency (IRENA) has recommended that large areas of envelopes and roofs be used to encapsulate solar collectors. It is possible to reduce urban impact with solar photovoltaic and solar thermal technologies by making collector surfaces coplanar with building envelopes [13]. It is also important to coordinate deployment with the building's consumption model, which should be tailored to the building's specific needs. Photovoltaic panels (from now on PV) will be developed as architectural structural elements that generate energy. By coplanarizing and building-integrated PV, it is possible to minimize the impact of urban sprawl on the natural environment. Moreover, by coordinating deployment with the building's consumption model, it is possible to maximize the efficiency of the PV system [14]. The PV building integrated photovoltaics (BIPV) cladding panels, glass, solar filters, and roof tiles respect geometry and are part of the envelope. It is the purpose of this work to determine the performance and yield of monocrystalline PV panels according to tilt and orientation to develop a model to predict the performance and yield of other PV technologies [15]. The model can then be used to compare the performance and yield of PV technologies, including polycrystalline and thin-film PV panels, to select the best technology for a particular application. The performance of the system is measured at various inclinations and orientations. A city such as Mount Ararat has no clearly defined optimal tilt and orientation parameters, with any tilt and orientation near horizontal considered acceptable. There have been documented losses of 5 to 35 % in the efficiency of the system as a result of dirt accumulation and lack of consideration for coplanar adaptation to buildings [16]. PV installation efficiency is influenced by a variety of factors, including surface temperature. Economic factors and energy demands must also be considered when maximizing production during times of high demand or high energy costs [7]. Based on a simulation model developed with SAM (System Advisor Model) programme, it proposes a methodology for estimating PV panel electrical output. The simulation model takes into account the surface temperature, panel efficiency, and irradiance to accurately estimate the electrical output of the PV panels. This model also takes into account the economic and energy demands of the situation to provide the most accurate results [17]. This validation is conducted using monocrystalline PV panels; in this model, the conditions and consequences of orientation, inclination, and efficiency losses resulting from dirt accumulation and temperature increases are investigated in the particular context proposed, and the model is calibrated based on these parameters. This model allows for more accurate predictions of the power output of a PV system, as it takes into account the real-world effects of factors such as dirt accumulation and temperature increases. Monocrystalline PV panels are more reliable and efficient than polycrystalline PV panels, so they provide the most accurate results. The model must be adjusted in SAM along with the corresponding climate file. In the simulations, a valid model concerning real production values is obtained, eliminating the need to conduct in situ measurements for at least one year to determine PV yields, or to use models with greater uncertainty and that are not freely accessible to the user. This would enable the calibration methodology to be replicated at other sites.

2. Materials and Methods

This study examines the calibration and validation of a simulation model of a monocrystalline photovoltaic system based on short in-situ measurements, as well as a local climate file of software-readable format (SAMCSV). The effects of dirt accumulation and temperature increase on performance are also examined as functions of global irradiance and climate [9]. Measurements were conducted on-site during December 2022 and January 2023. This was achieved by installing three monocrystalline PV panels adjacent to a weather station (-2.901691◦S, -79,010151◦E). Panels with a rated power of 100 W, dimensions of 0.54 m wide and 1.2 m long, 36 cells are connected electrically to a set of resistors used as loads depending on the amount of irradiance received by the panels to achieve maximum power, and to a set of measuring equipment (Figure 1). A five-minute interval of DC voltage, current, and power was recorded, which was then transformed into an hourly interval. The tilt and orientation of the panels were measured in situ for 12 days in December 2022 between 07:30 and 17:00. Using data from four horizontal panels and three inclination panels (in all directions: N, S, E, W), the SAM model was validated [10]. A low-rise building in Mount has typical roof slopes, which are taken into account for the inclinations. The methodology shown in Table 1 was used to measure performance based on slope and orientation. Equation (1) was then used to calculate the efficiency

Fig 1. Monocrystalline solar panels at different inclinations

$$\eta = \frac{P}{E \; X \; A_c} \text{ X 100 -------- (1)}$$

Table 1. Monocrystalline panel performance based on inclination and orientation

Day	Panel-1	Panel-2	Panel-3
East			
Day	**Panel-1**	**Panel-2**	**Panel-3**
1	0°	15.00°	17.27°
2	0°	19.27°	27.57°
3	0°	27.57°	15.00°
South			
Day	**Panel-1**	**Panel-2**	**Panel-3**
4	0°	15.00°	17.27°
5	0°	19.20°	27.57°
6	0°	27.57°	15.00°
West			
Day	**Panel 1**	**Panel 2**	**Panel 3**
7	0°	15.00°	19.27°
8	0°	19.27°	27.57°
9	0°	27.57°	15.00°
North			
Day	**Panel-1**	**Panel-2**	**Panel-3**
10	0°	15.00°	19.27°
11	0°	19.27°	27.57°
12	0°	27.57°	15.00°

An efficient panel has an output power of P, a collector area or area of the panels called Ac, and the irradiance of the sun is E. The best inclination for each orientation was selected from the three proposed ones, and a three-day measurement was conducted to determine which configuration (both inclination and orientation) is optimal for this time of year (see Table 2 for methodology). The following configurations from the four examined were selected based on the average energy production values during the measurement days of the four examined configurations [13]. The energy losses due to dirt accumulation can, however, be estimated by calculating the energy losses. To determine the optimal orientation and inclination of the PV system, weekly PV performance measurements were performed starting on 11 January 2023 and culminating on 1 February 2023, locating the determined orientation and inclination as the optimal orientation and inclination. The panels in this case fulfilled the control function and received cleaning during the measurement days while the other two did not receive any intervention [18]. However, due to the frequent precipitation events in Mount Ararat, the panels that did not receive manual maintenance manually presented changes in the surface due to precipitation surface changes due to precipitation surface changes resulting from precipitation which cleaned the panels during the study days. Rainfall is high in the local climate, varying throughout the year to a greater or lesser extent to a greater or lesser extent. Over the course of the year, rainfall occurs to a greater or lesser extent, with periods without rainfall lasting more than a month being rare [19]. To estimate the losses caused by an increase in temperature, the surface temperatures of the monocrystalline panels, as well as the power output of the monocrystalline panels and the monocrystalline panels were measured. Based on the irradiance data obtained from the weather station, as well as the meteorological station, average values of efficiency loss were determined per range of irradiance and Irradiance ranges were established [14]. SAM was calibrated using the data of average performance losses caused by dirt accumulation and irradiance ranges. According to the information incorporated and taken from on-site readings, a climate file with hourly information for the locality was created during the year 2022 according to hourly values of direct radiation (W/m2), diffuse radiation (W/m2), global radiation (W/m2), relative humidity (%), zenith angle (%), atmospheric pressure (Mbar), ambient temperature (C), precipitation (mm), wind direction and speed (and m/s). Thus, the climatic file of the study site is not the result of the interpolation of climate variable values between two locations, which causes two locations, which result in a higher degree of uncertainty in model predictions in the predictions of the models, but rather the validation of results is based on a comparison between PV production readings and climatic conditions that were detected at the PV readings and instantly detected climatic conditions [20]. Furthermore, technical data on the PV panels used were also incorporated into the software specifications, as shown in Table 3.

Table 3. Simulated photovoltaic panel specifications

Specifications			
Silicon Type	Monocrystalline Cell	V_{oc}	21.6 V
Module area	0.646 m^2	Coefficient of Temperature Voc	-0.39 %/°C
NOCT	47	Coefficient of Temperature Isc	0.2%/°C
V_{mp}	17.4 V	Coefficient of Temperature MPP	-0.4 %/°C
I_{mp}	5.79 A	Number of cells in series	37

In this study, aspects related to energy processing are defined. The maximum power point of the panel was considered for each panel for each estimation. The losses in the system were established based on efficiency readings obtained in situ for irradiance ranges in intervals of 200 W/m2 and for losses in the intervals of 200 W/m2 and losses due to dirt accumulation, due to the accumulation of dirt, which for calculation purposes is used as a default loss of 5 % is used as a basis for calculation purposes [16]. The simulated performance data was compared with the measured on-site values of the horizontal panel and the following metrics were calculated using the simulated performance data. There are four factors to be considered: coefficient of determination R2, root mean square error (RMSE) and its normalised value (Equation 3), mean bias error (MBE) and standardised value (Equation 4); finally, a 90% confidence interval (Equation 5) is computed. Equation 5 establishes the 90 % confidence interval (90 % CI) for hourly intervals (Equation 6). Some SAM validation studies recommend this [21]. Based on the maximum value reported in situ, the RMSE and MBE values were normalised.

$$R^2 = \frac{\sum_i^N (SAM_i - Measured_{avg})^2}{\sum_i^N (SAM_i - SAM_{avg})^2} \text{ ---------- (2)}$$

$$RMSE = \sqrt{\frac{\sum_i^N (SAM_i - Measured_{avg})^2}{N}} \text{ ------------ (3)}$$

$$MBE = \frac{\sum_i^N (SAM_i - Measured_i)^2}{N} \text{ -------------- (4)}$$

$$IC_{90\%} = 1.645\ X\ [Std\ (SAM_i - Measured_i)] \text{ ------------ (5)}$$

3. Results and Discussion

Parametric variance was used to measure performance and efficiency calculations for December. Table 4 presents the results from highest to lowest, based on the results from December. highest to lowest in Table 4. According to Table 4, the south orientation outperforms the north orientation at any inclination due to the position of the sun at this time of year. Due to high irradiance mornings and high cloud cover afternoons, the east to 14 orientations gave higher efficiency, therefore the south had high cloud coverage, so it was chosen for the subsequent analysis of soiling effects. The amount of weekly precipitation accumulated during the first week of measurements did not adversely affect performance during the analysis of soiling (41.8 mm). There was a total precipitation of 6 mm during the second week of monitoring, which resulted in dirty spots on the surface and an insignificant decrease in the efficiency of the panels (0.7%). In the third week, rain events did not occur or deposited material did not appear on the panels' surface [17]. The corresponding measurements showed an average reduction of efficiency of 2.77 %, a maximum reduction of 3.68 %, and a minimum reduction of 2.77 %. One week after this measurement, the accumulated precipitation (13.4 mm) shows a significant amount of particles have been removed from its surface, making surface losses eligible. SAM simulations were run with the predefined efficiency loss value of 5% as the average. In the locality, rainfall does not occur for long periods, which is typical for high-altitude Andean cities. The generated data enabled us to calibrate and calibrate a comparative basis for calibrating and validating the SAM model, which was based on the parameters specified in the methodology. In Table 5, the results of the model are compared with those obtained by in situ measurements of the horizontal panel. From this comparison, the statistical data of interest are calculated.

Table 4. Best inclinations by orientation

Orientation	Best inclination
East	15.00°
South	27.56°
West	19.26°
North	19.26°

Table 5. Calculated metrics

Metric	Value
R2	0.987
RMSE (W)	5.274
NRMSE (%)	8.147
MBE (W)	-1.15
NMBE (%)	-1.627
IC 90%	8.533

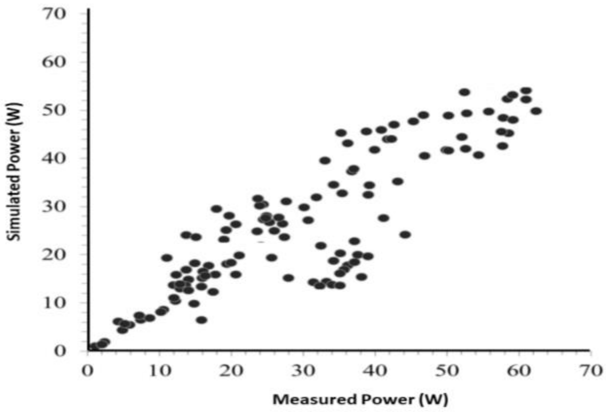

Fig 2. Scatterplot of measured and simulated power simulated

Figure. 2 illustrates how the in-situ data and the model-derived data are represented graphically based on the in-situ data. The in-situ data are represented by the green line and the modeled data are represented by the orange line. The in-situ data are plotted on the y-axis and the modeled data are plotted on the x-axis. Based on the model data shown in Figure 2, the results of the analysis were obtained. There is a strong linear correlation between the two variables according to the value of R2. This indicates that the model data is an effective representation of the in-situ data and that the two variables have a strong correlation [18]. These two measures of estimation errors are quite acceptable in this particular case, and they indicate the difference between estimated and real readings. The difference between the two measures is indicative of the accuracy of the estimation process. If the difference between the two measures is small, it indicates that the estimation process is accurate. According to the mean bias error (MBE) and its standardised value, the model performance is 1.61 % understated. This means that the model underestimated the predictions by 1.61%. This could be due to incorrect assumptions, a lack of data, or other factors.

According to the TRNSYS validations, maximum generation values represent trend values [8], and Figure 3 compares the actual with predicted system behavior. The maximum generation values represent the point at which the system is predicted to reach its maximum efficiency, and Figure 3 compares the predicted and actual system behavior at these points. An analysis of two-day simulated and in situ values was conducted in one study, while another examined time resolution at intervals of less than one hour was carried out in another study. In Table 5, the 90 % CI (90 % confidence interval) indicates that 90% of simulated values fall within 8.522 % in situ measured values, which is very close to the 8 %, with which seven cases have been validated in reference studies using SAM. This indicates that the simulated values are very close to the values measured in the reference studies and are within the range of what is expected. This suggests that the simulated values are likely to be accurate and can be trusted. Annual simulations show a reduction in this value, which fits better with the linear of PV cell temperature differs from in situ measurements [12]. This suggests that the model is still inaccurate and needs to be fine-tuned to accurately simulate PV cell temperature. The model database uses the annual average temperature, whereas the in situ data uses point values from one day of measurement since temperatures appear to behave similarly throughout the year at the same radiation levels. This allows for more accurate predictions since annual average temperatures give you a better idea of long-term trends than one-day measurements, which can be affected by short-term weather events.

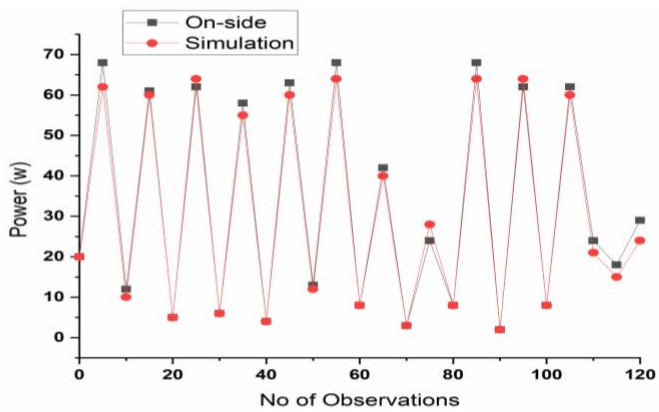

Fig 3. Performance comparison

The average difference from Table 6 is 13.33 C, and the cells without values indicate that, during the day, the radiation values did not fall within these ranges. The model estimates the surface temperature of the cells, whereas the measurements were made on the panel glass, which has a lower temperature than the surface temperature of the cells.

As it is a high-altitude location, there is a variation in the surface temperature of the cells. This variation is also attributed to UV ray intensity. The increase in cell surface temperature should therefore be confirmed by laboratory measurements. The model was found to be valid with the values of these metrics. Due to the availability of the climate file, it is possible to estimate energy production over longer periods. Based on the parameters of and inclination parameters, a yearly simulation of a 100 W module is conducted which is expressed in kWh/year. Table 7 shows the yields obtained [11]. Consequently, the horizontal arrangement generates the most electricity, but it is not suitable for deployment on pitched roofs. Furthermore, it is not a recommended alternative for rainwater harvesting.

Table 6. Comparison of simulated temperature and measured temperature measured temperature

Irradiance (W/m^2)		Average temperature (°C)	Temperature Measured (°C)
From	**To**		
0	200	16.82	-
200	400	22.06	34.6
400	600	25.57	-
600	800	28.03	41
800	1000	31.34	44
1000	1200	35.09	48.34

Table 7. Annual energy production (kWh/year)

Angle	North	South	East	West
0°	120.17	-	-	-
14°	117.6	117.95	118.22	117.25
18.26°	115.67	116.25	116.64	115.36
26.6°	110.77	111.65	112.36	110.6

According to Table 7, PV orientation and slope in the context of the study exhibit an interesting particularity. In this study, horizontal deployment was shown to effectively yield maximum production, but in terms of annual generation, it was only 8.8% above the minimum production (west orientation, 26.56 slope) due to the limitations mentioned above, horizontal deployment was not recommended. According to the comparison of inclined and oriented cases, the lower the slope, the better the average production, with 5.8 % of annual production [22]. Point yield analysis shows that the maximum production occurs with an east orientation and 14° of inclination, and the minimum with a west orientation and 26° of inclination, being more efficient with the first arrangement in 7.0% and being intermediate in all other yields. This study measures lower losses than in previous studies that have estimated PV yields under a seasonal moderate climate condition (36° latitude), where an improper orientation by 90° leads to a reduction of 17 % in PV yields.

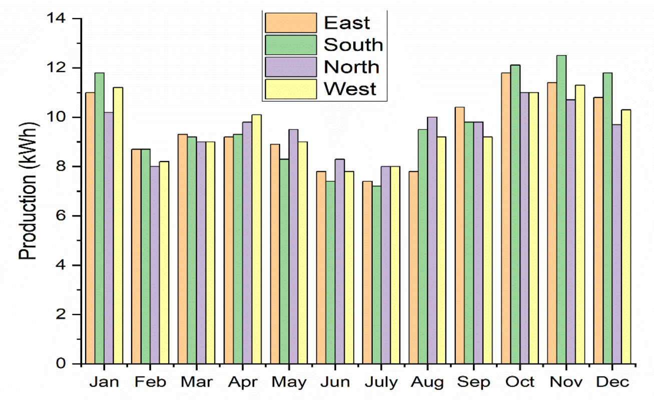

Fig 4. Simulation-estimated monthly production in SAM

A PV system oriented opposite the solar path and located at a latitude far from the equator would likely produce much less power. This is because the sun's rays would be weaker and the angle of incidence from the sun would be less, resulting in less energy being converted to electricity. Easterly orientations tend to have less cloudy mornings, which is why they produce higher yields [9]. However, PV systems oriented eastward are also more likely to suffer from shading from trees and other structures, which can reduce energy production significantly. There is a more pronounced difference in monthly values, with 7.33 kWh/month in July (month of minimum irradiation) and 12.19 kWh/month in November (month of maximum irradiation) (Figure 4). This is likely because solar energy is most abundant during the summer months when the sun is higher in the sky. It is least abundant during winter when the sun is lower in the sky. The results demonstrate the stability of existing PV production in moderate seasonal climates (38 South latitudes), where summer generation can triple from winter. This suggests that PV plants in this region will be a reliable source of energy, providing a consistent level of electricity throughout the year. At extreme latitudes (60 degrees north latitude) in climates with marked seasonality, such as Helsinki (Finland), summer production is three times greater than winter production; at extreme latitudes (60 degrees north latitude), summer production is three times greater than winter production in climates with marked seasonality, such as Helsinki (Finland). It is ten times hotter in summer than in winter [13]. The equatorial zone has the obvious advantage of being more adaptable to urban and building demands.

4. Conclusions

An important step in developing a city's renewable energy potential is to validate tools for reducing uncertainties in estimations and simulations. SAM can be used to project PV electricity generation at Mount Ararat with low uncertainty when parameter adjustments are made. In this study, calibration was used for other locations and the model was validated using in-situ performance measurements. Many results were obtained, including the average loss of efficiency due to dirt accumulation, which is less than 2.78 %. This is not significant and would allow the PV panels to be cleaned recurrently since the continuity of local precipitation would suffice to recover efficiency without recurrent cleaning. The temperature-induced losses, on the other hand, are measured as high values in the presence of high irradiation, which can be explained either by the cell construction conditions or by how much UV radiation is exposed to the cells, which is why this parameter was considered during model calibration. Model versus on-site readings showed a R2 = 0.987, NRMSE = 8.147 and NMBE = -1.627%, which suggests it can be used to predict future scenarios in annual simulations, despite being expected to be underestimated, since it exhibits a marked linear relationship within situ data. In this study, a methodology is developed and a validated tool is developed for estimating electricity production from monocrystalline solar panels. Based on yields detected in the specific context, PV systems facing east with a slope close to horizontal have a higher annual generation, though there are no significant differences between them and other orientations with similar slopes; this is due to the area's geographic location, which has a stable level of irradiance all year round. There is expected to be a 40% reduction in electricity production between June and July (the month of minimum irradiation) and November (the month of maximum irradiation). The annual balance of production would be much more stable as compared to other latitudes, and therefore could be more easily connected to a smart grid or a smart grid for self-consumption.

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