Assessment of Performance of 80W Monocrystalline Photovoltaic (PV) Module in Abuja FCT

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Abstract: Solar PV modules are rated by manufacturers under Standard Test Conditions (STCs), which often differ from real outdoor operating conditions. Therefore, evaluating field performance is essential for accurate module selection and power prediction. In this study, a one-year performance assessment of an 80 W solar PV module manufactured by NSENI Solar Energy Limited was conducted in Abuja-FCT, Nigeria, using real-time measurements and simulation. Key electrical parameters (Pmax, VMP, and IMP), solar radiation, and module temperature were continuously monitored using calibrated instruments. In parallel, empirically based PV models incorporating manufacturer datasheet values and local climatic data were used for simulation.

The results show significant deviations between STC ratings and outdoor performance. At certain periods, the module voltage and efficiency dropped below 12 V and 11%, compared to the rated 17.35 V and 18%. While VMP and efficiency decreased at high solar radiation, Pmax, IMP, and module temperature increased, with opposite trends observed under lower radiation levels. A strong agreement between measured and simulated maximum power outputs was obtained, with a correlation coefficient of 0.98 and an average error of about 5%. These findings confirm the reliability of the applied PV models and demonstrate that the developed testbed can be used as a practical PV module performance validation facility suitable for replication across Nigeria.

Keywords Solar PV module, STC, Outdoor condition, Maximum Power, Module Temperature.

1. Introduction

In order to reduce global warming, the adoption of renewable energy is becoming more popular, with solar photovoltaic (PV) power systems most favoured because they are easier, consume less time, and are less complex to deploy for electricity generation (IEA, 2022; Iheanetu, 2022). In fact, IEA (2022) stated that the estimated solar PV electricity generation from 2019 to 2020 increased to 23% and has contributed a record high of 156 TWh, and their prediction is that it will reach 7000 TWh by 2050.

Solar PV technology converts solar energy directly to electricity using PV cells (connected together to form a solar PV module), and the PV modules are exposed to capture the energy from the sun (solar energy) by installing them outdoors. The generation of electricity using a solar PV power system is highly dependent on uncontrolled weather and environmental conditions, such as PV module temperature, solar radiation, wind speed, and other climatic parameters (Iheanetu, 2022). Due to the variability of these climatic factors, the output power of a solar PV system dynamically changes with time and season (Geravandi and Moradi, 2022). The use of battery backup is currently adopted to mitigate the challenges encountered due to the variable weather conditions. This is because the battery backup system makes sure that the desired level of power supply, irrespective of the actual weather condition, is available. However, battery backup increases cost. Therefore, there is a need for accurate yield prediction with respect to operating climatic conditions.

The inability to predict PV module/array electrical outputs accurately significantly affects the stability, dependability, and scheduling of the power system operation and its economic benefit (Woyte et al., 2006; Strzalka et al., 2012; Das et al., 2019). According to Bücher (1997), the manufacturers of solar PV modules rate them at controlled conditions called Standard Test Conditions (STCs) of 25°C Module Temperature (Tm) and 1000 W/m² Solar Radiation. Unfortunately, the manufacturer's ratings are used by solar power system designers to make decisions on the choice of solar PV module (solar panel) and array design. However, Zhou et al. (2007) stated that the outdoor performance of PV modules is influenced majorly by ambient conditions such as solar radiation and location-based module temperature (Tm). Consequently, Iheanetu (2022) concluded that solar PV power forecasting or prediction provides a means by which a reliable estimate of the power from the solar PV modules/arrays is obtained after considering the existing weather conditions and system losses. These have led many researchers to carry out solar PV module performance assessments (Kurnik et al., 2011; Kozak et al., 2009; Buday, 2011; Meral & Dinçer, 2011; Abdelkader et al., 2010; Bahaidarah et al., 2015). Wahidullah, Safiullah, and Sayed (2024) evaluated and compared the energy output of mono-crystalline and poly-crystalline solar photovoltaic (PV) technologies under the same climatic conditions and concluded that mono-crystalline technology performed better.

Zhou et al. (2007) suggested that having reliable knowledge and understanding of the performance of a solar PV module under the actual climatic conditions (outdoor) is necessary for correct module selection criteria and accurate prediction of their energy performance. Liomnis *et al.* (2022), in their study comparing 10 module temperature estimation models, concluded that of King et al. (2004) is the most accurate.

Nduka and Mohamed (2018) simulated city-based PV-module temperature (Tm) in eight cities of Nigeria, using the empirical thermal model developed by King et al. (2004) to predict the expected voltage (V), power, and efficiency of a 100 W PV module. They discovered that the outdoor conditions are different from Standard Test Conditions (STCs), and cities with high Tm and solar radiation produced lower voltage and efficiencies and higher power. Osagie-Bolaji and Osadebamwen (2025) carried out a performance analysis of 250W monocrystalline and 250W polycrystalline photovoltaic (PV) modules under varying solar irradiance conditions in Nigeria and discovered that the monocrystalline module consistently outperformed the polycrystalline module under the same irradiance condition with a drop in efficiency at the highest irradiance for both of them. The climatic condition of Nigeria varies from location to location and season to season (Nduka and Mohamed, 2018). In this study, a performance assessment is being carried out on an 80W solar PV module produced by NSENI Solar Energy Limited through real-time measurements and simulation in Abuja-FCT, Nigeria, to ascertain the validity of some empirically based PV models in the prediction of solar module power yield.

2. Materials

The 80W Solar PV Module is the sample whose outdoor performance is being monitored. The Elejoy 400W Solar PV Panel Multimeter was the instrument used for real-time monitoring of the electrical output (maximum power, voltage at maximum power, and current at maximum power) of the 80W PV module; the

BGT-HJX-TFI Portable Pyranometer with Data Logger was used for real-time monitoring of the solar radiation of Karshi FCT; and the Temp U 07B Digital Temperature Data Logger was used for real-time monitoring of the module temperature of the 80W solar panel. The cables are used to connect the Solar Panel Multimeter and Temperature Data Logger to the 80W Solar Panel, the clips were used to clip cables, the metallic platform served as the bed upon which the solar PV module and the attached devices were installed/mounted, and the bolts and nuts were used to firmly fix the testbed and the devices. The materials and instruments that were used in this study are presented in Table 1.

Table 1 Materials and their specifications

Materials	Quantity	Specification
Solar PV Panel Multimeter	1	Elejoy 400W: Range 0-400W, 0-30V, 0-15A.
BGT-HJX-TFI Portable Pyranometer with Data Logger	1	Range 0-2500 W/m²
Temp U07B Digital Temperature Sensor with Data Logger	1	Range 0.1-1000°C
PV Module	1	Power: 80W, Voc = 20.15V, Isc = 5.44 A, Vmp =17.35V, Imp = 5.3A, Eff =18%. Temp. Coeff. of Pmax = -0.5629%/°C, Temp. Coeff. of Vpmax = -0.79914%/°C, FF = 0.78.
Flexible cable	5m	Silver plated, 6mm thick
Flexible cable	8m	Copper, 1.5mm thick
Metallic platform	1	2m high
Aluminum clips	1pck	6063-T6 aluminum alloy, 2 inch length, 1/4 inch holes.
Bolts and Nuts	8nos	Bolt & Nun-11

3. Methods

3.1 Study Location

Abuja FCT is the capital of Nigeria. It has 6 Area Councils, namely Abaji, Abuja Municipal (AMAC), Bwari, Gwagwalada, Kuje, and Kwali. Abuja is located just north of the confluence of the Niger River and the Benue River (FCTA, 2008). It is geographically located at the center of the country and is bordered in the west by Niger State, in the north by Kaduna State, in the northeast by Nasarawa State, and in the southwest by Kogi State. The FCT lies between latitudes 8.25 and 9.20 north of the equator and longitudes 6.45 and 7.39 east of the Greenwich Meridian (FCTA, 2008). It has a landmass of approximately 7.315 km², and it is situated within the savannah region with moderate climatic conditions (FCTA, 2008). Abuja has an average daily maximum temperature that is above 30°C or 86°F (FCTA, 2008). Abuja is located within the Guinea Savannah climatic zone of Nigeria, and it receives a global horizontal irradiation (GHI) of about 2.04 MWh/m²/year (232.88 W/m²) (Ohajianya, 2023). Abuja has an average monthly wind speed of 2.4m/s (Ani *et al.,* 2012). The map of FCT-Abuja showing the study location is shown in Figure 1.

3.2 In-Situ Measurement

A real-time field/physical measurements setup using a testbed containing the 80W solar panels and all devices monitoring the electrical output and module temperature was mounted close to a pyranometer for monitoring solar radiation in Karshi, Abuja-FCT. The Elejoy 400W Solar PV Panel Multimeter was used for real-time monitoring of the electrical outputs Maximum Power (Pmax) in watts (W), Voltage at Maximum Power (VMP) in volts (V), and Current at Maximum Power (IMP) in amperes (A) of the 80W PV module. The BGT-HJX-TFI Portable Pyranometer with Data Logger was used for real-time monitoring of the solar radiation in W/m², and the Temp U 07B Digital Temperature Sensor with in-built Data Logger was used to measure the Module temperature MDT measured in °C. The calibration process for all the instruments used was carried out by comparing the Solar Panel Multimeter voltage values with that of a UNI-T UT-33D Digital Multimeter (range: 0V – 1000V), the Portable Pyranometer values with that of the SM 206 Hand-held Mobile Solar Radiation Meter (range: 0W/m² - 1500W/m²), and the digital temperature sensor values

with that of the DT8018 Body Infrared Thermometer (range: 0°C - 100°C). All these parameters were measured simultaneously from 7am to 6pm daily for 1 year (January to December, 2024). The measured efficiency output was calculated from the measured solar radiation and Pmax. Figure 2 shows the experimental setup for the data collection procedure.
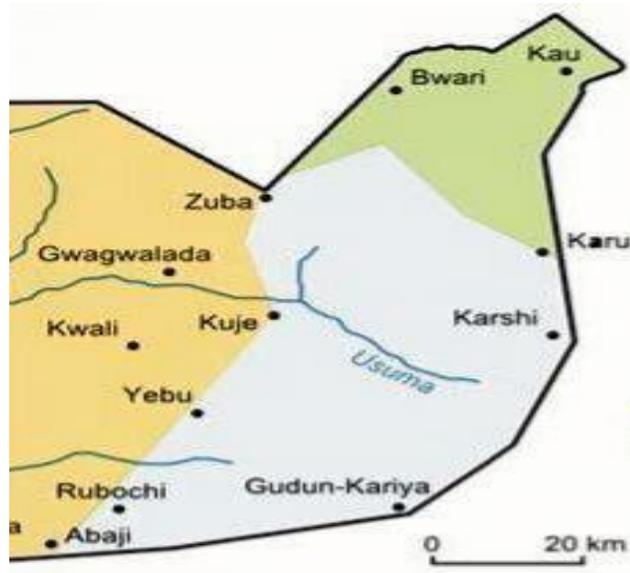

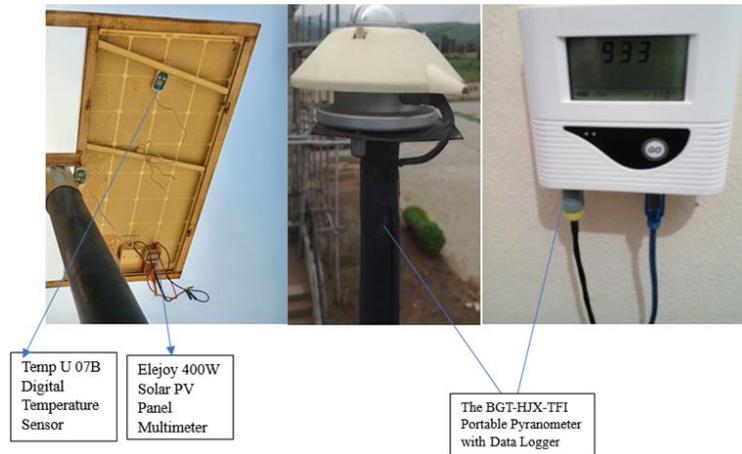**Figure 1** Map of FCT-Abuja showing Karshi town, the study location (Akubue *et al.*, 2025)

Figure 2 Experimental Set-up for data collection

3.3 Method of Data Analysis

Daily and Monthly Average: The daily and monthly average of the hourly measured values of solar radiation and module temperature at Karshi were calculated. Also, the daily and monthly averages of the hourly measured values for maximum power, voltage at maximum power, current at maximum power, and efficiency of the 80W PV Module were calculated as follows:

$$Daily\ Ave. = \frac{Total\ hourly\ value}{12} \tag{1}$$

$$Monthly\ Ave. = \frac{Total\ daily\ value}{Days\ of\ the\ month} \tag{2}$$

Simulation: The manufacturer's datasheet values of the current, voltage, and temperature coefficient of the 80W Solar PV Module and the daily NIMET climatic data were used to simulate/estimate the 80W PV

Module's actual outdoor module temperature (MDT), maximum power (Pmax), voltage (V) at MDT (VMP), current (I) at Solar Radiation (G) (IMP), and efficiency (η) by implementing the following equations in a Microsoft Excel spreadsheet:

Module Temperature MDT: The module temperature is given as follows:

$$MDT = T_a + G\,e^{(-3.473-0.0594*WS)} \tag{3}$$

where, MDT is the module temperature, T_a is the ambient temperature, E is the solar radiation, W is the wind speed, and a = -3.473 and b = -0.594 are empirical constants.

Maximum Power (Pmax): The module power is given as follows:

$$Pmax = IMP \times VPM \tag{4}$$

where, IMP is the current at maximum power at the actual operating solar radiation, VPM is the voltage at maximum power at actual module temperature.

VPM, the voltage at maximum power at actual module temperature is given as follows:

$$VPM = [V_{oc}(STC) - Tem\ coeff\,(MDT - 25)]FF \tag{5}$$

where, V_{oc} (STC) is the open circuit voltage at standard test conditions, Temp coeff. is the temperature coefficient of V_{oc}, MDT is the module temperature, and FF is the fill factor of the solar panel.

IMP, Current at maximum power at the actual operating solar radiation: The module current is given as follows:

$$IMP = I_{sc}(STC)\,\frac{G}{1000} \tag{6}$$

where, I_{sc} (STC) is the short circuit current at standard test conditions, and G is the actual operating solar radiation.

The Efficiency (η): The efficiency of the solar panel is given as follows:

$$\eta = \frac{P_{out}}{P_{in}} \tag{7}$$

where, Pout is the output power of the solar panel/unit area of the solar panel, Pin is the solar radiation in W/m².

Correlation: The correlation between the measured values and the simulated values of the total average maximum power output is calculated as follows:

$$r_{XY} = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum(X_i - \bar{X})^2 \sum(Y_i - \bar{Y})^2}} \tag{8}$$

where r_{XY} is the correlation coefficient of the linear relationship between the measured and simulated monthly average P_{max}, X_i is the values of the measured monthly average P_{max}, $\bar{X}$ is the mean of the measured monthly average P_{max}, Y_i is the values of the simulated monthly average P_{max}, and $\bar{Y}$ is the mean of the simulated monthly average P_{max}.

Root Mean Square Error: The root mean square error was obtained as follows:

$$RSME = \sqrt{\frac{\sum(Y_i - \hat{Y}_i)^2}{N - P}} \tag{9}$$

where Y_i is the actual value for the ith observation, $\hat{Y}_i$ is the predicted value for the ith observation, N is the number of observations, and P is the number of parameter estimates, including the constant.

Percentage Error: The root means square error percentage was calculated as follows:

$$Percentage\ Error = \frac{RMSE\ Value}{(The\ highest\ value - the\ lowest\ value)\ of\ all\ the\ variable} \ x\ 100 \quad (10)$$

However, the assumption in this study is that if a considerable positive correlation coefficient value is obtained and the root mean square error percentage is approximately equal to or less than ±5%, then the validity of the empirically based models used is established.

4. Results and Discussion

The measured and simulated data of the 80W Solar PV Module parameters were obtained, and Tables 2 and 3 and Figures 3 and 4 show the monthly average representation of data for both real-time monitoring and simulation.

Table 2 Monthly Measured Average for the 12 Months in Year 2024

| MONTHS	PMAX (W)	VMP (V)	IMP(A)	Eff (%)	MDT (⁰C)
January	27.48425629	13.71905914	2.003951613	12.70047811	39.02096774
February	31.22038836	14.33341954	2.179022989	13.80518058	39.92270115
March	32.20248531	13.82789315	2.330564516	13.06305524	40.98604839
April	31.33563609	13.63819444	2.305027778	12.85469514	40.60794444
May	31.52279348	14.0175	2.259489247	13.40497099	40.48494624
June	27.72155576	14.16733333	1.970583333	13.78058147	38.95158333
July	24.85213371	14.45758065	1.730376344	13.99101571	37.6786828
August	20.6794321	14.6138172	1.4150602691	14.52501047	32.46080645
September	26.805134	13.62711111	1.978527778	12.1836766	37.69057906
October	28.4383698	13.27252688	2.150860215	12.60932864	39.96912826
November	34.24725789	13.72702778	2.49475	12.98335395	41.38483333
December	31.23995453	14.38053763	2.173198925	13.93517225	39.30432796
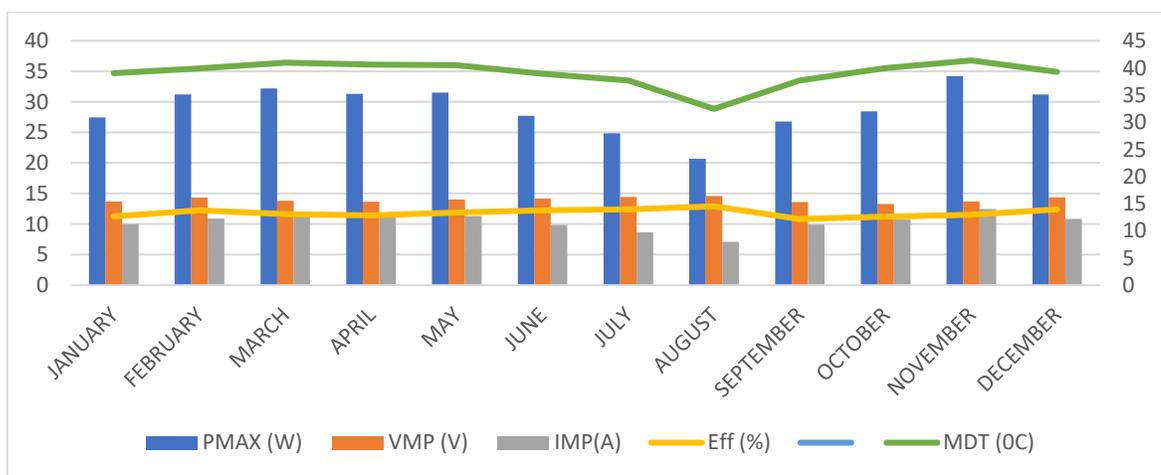
Figure 3 Measured Monthly Average Data for the 12 Months in Year 2024

Table 2 and Figure 3 show that in the year 2024, the highest four (4) measured monthly average Maximum Power (Pmax) outputs were recorded in November (34.24725789 W), March (32.20248531 W), May (31.52279348 W), and April (31.33563609 W). However, the lowest four (4) monthly average Maximum

Power (Pmax) outputs were recorded in January (27.48425629 W), September (26.805134 W), July (24.85213371 W), and August (20.6794321 W). The highest monthly average voltage at maximum power (VMP) outputs were recorded in August (14.6138172 V), July (14.45758065 V), December (14.38053763 V), and February (14.33341954 V), while the lowest 4 outputs were recorded in January (13.71905914 V), April (13.63819444 V), September (13.62711111 V), and October (13.27252688 V). The highest four (4) monthly average current at maximum power (IMP) outputs were recorded in November (2.49475A), March (2.330564516A), April (2.305027778A), and May (2.259489247A), and the lowest recorded were in September (1.978527778A), June (1.970583333A), July (1.730376344A), and August (1.4150602691A). The highest four (4) conversion efficiencies (Eff.) recorded were in August (14.52501047%), July (13.99101571%), December (13.93517225), and February (13.80518058%), while the lowest recorded were in April (12.85469514%), January (12.70047811%), October (12.60932864%), and September (12.1836766%). Finally, the four highest Monthly Average Module Temperatures (MDT) were recorded in November (41.38483333°C), March (40.98604839°C), April (40.60794444°C), and May (40.48494624°C). However, the lowest values were recorded in June (38.95158333°C), September (37.69057906°C), July (37.6786828°C), and August (32.46080645°C).

Table 3 Monthly Simulated Average for the 12 Months in Year 2024

| MONTHS	IMP (A)	VMP (V)	PMAX (W)	Eff (%)	MDT (⁰C)
January	1.96575254	14.04288614	27.6059344	13.94075606	40.56963463
February	2.369083545	13.55026658	32.0486284	13.45171919	45.15110703
March	2.422786107	13.34950401	32.32767275	13.2524167	47.01824406
April	2.341225433	13.44238186	31.3889567	13.34461908	46.15445919
May	2.331786689	13.56220717	31.57245558	13.46357294	45.04005688
June	1.996148058	14.01442539	27.83214453	13.91250229	40.83432599
July	1.743592873	14.36378453	24.91673073	14.25932065	37.58520752
August	1.6039140301	14.38101226	22.8639531	14.27642308	37.42498585
September	1.881147544	14.25509893	26.68442143	14.15142548	38.59600806
October	2.02161811	14.11161585	28.35017153	14.00898592	39.93043285
November	2.494331953	13.78393913	34.37943661	13.6836923	42.97789987
December	2.336043114	13.81779657	32.28025253	13.71730351	42.66301809
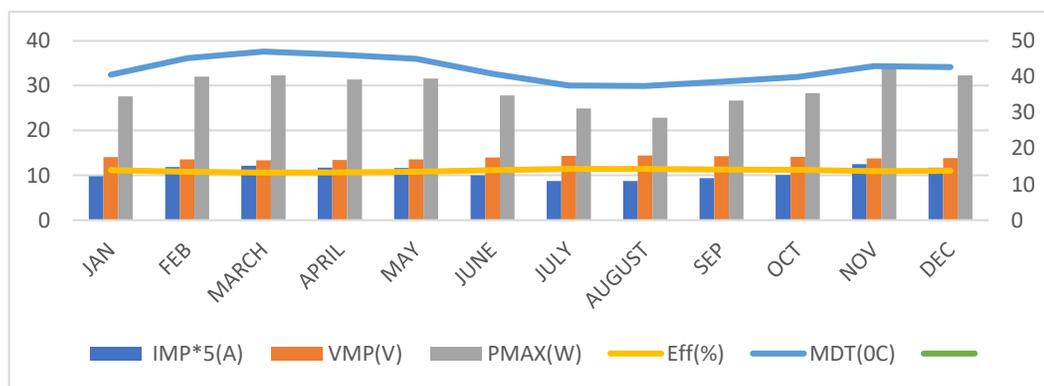
Figure 4 Simulated Monthly Average Data for 12 the Months in Year 2024

Table 3 and Figure 4 show that in the year 2024, the highest four (4) simulated monthly average Maximum Power (Pmax) outputs were recorded in November (34.37943661 W), March (32.32767275 W), December (32.28025253 W), and February (32.0486284 W). However, the lowest four (4) simulated monthly average Maximum Power (Pmax) outputs were recorded in January (27.6059344 W), September (26.68442143 W), July (24.91673073 W), and August (22.863953175 W). The highest simulated monthly average voltage at

maximum power (VMP) outputs were recorded in August (14.38101226 V), July (14.36378453 V), September (14.25509893 V), and October (14.11161585 V), while the lowest 4 outputs were recorded in May (13.56220717 V), February (13.55026658 V), April (13.44238186 V), and March (13.34950401 V). The highest four (4) simulated monthly average Current at Maximum Power (IMP) outputs were recorded in November (2.494331953A), March (2.422786107A), February (2.369083545A), and April (2.341225433A), while the lowest recorded were in January (1.96575254A), September (1.881147544A), August (1.744987219A), and July (1.743592873A). The highest simulated four (4) monthly conversion efficiencies (Eff.) recorded were in August (14.27642308%), July (14.25932065%), September (14.15142548%), and October (14.00898592%), while the lowest recorded were in May (13.46357294%), February (13.45171919%), April (13.34461908%), and March (13.2524167%). The highest simulated Four (4) Monthly Average Solar Radiation (Sol. Rad.) values were recorded in November (456.837354 W/m²), March (443.7337192 W/m²), February (433.8980851 W/m²), and April (428.7958668 W/m²), while the lowest values were in January (360.0279377 W/m²), September (344.5325172 W/m²), August (319.5947288 W/m²), and July (319.3393541 W/m²). Finally, the highest simulated four (4) monthly average module temperatures (MDT) were recorded in March (47.018244060°C), April (46.154459190°C), February (45.151107030°C), and May (45.040056880°C). However, the lowest values were recorded in October (39.930432850°C), September (38.596008060°C), July (37.585207520°C), and August (37.424985850C). A comparison of the measured and simulated maximum power results is presented in Table 4.

Table 4 Comparison of the Measured and Simulated Monthly Pmax of the 80W Solar Panel

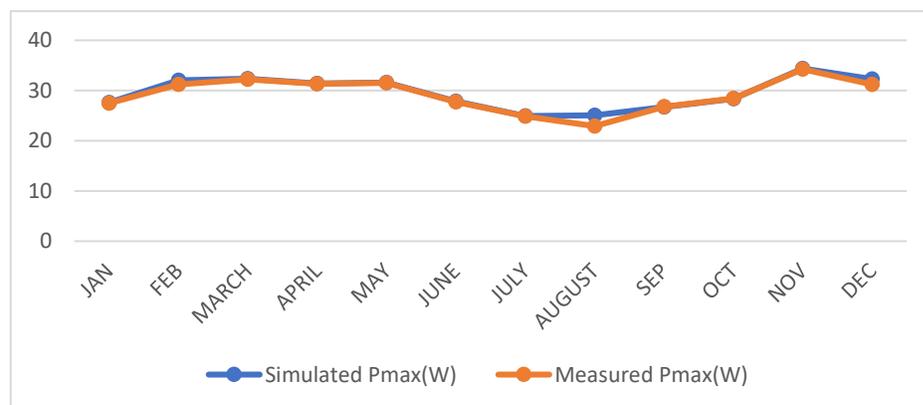| Months	Simulated Pmax(W)	Measured Pmax(W)
January	27.6059344	27.48425629
February	32.0486284	31.22038836
March	32.32767275	32.20248531
April	31.3889567	31.33563609
May	31.57245558	31.52279348
June	27.83214453	27.72155576
July	24.91673073	24.85213371
August	22.863953175	20.6794321
September	26.68442143	26.805134
October	28.35017153	28.4383698
November	34.37943661	34.24725789
December	32.28025253	31.23995453

Figure 5 Comparison of Monthly Measured and Simulated Pmax Output

Findings from this study have revealed that both measured and simulated values of the 80W solar panel parameters followed majorly the same pattern in all the months, and the outdoor conditions in Abuja-FCT

in 2024 were different from the Standard Test Conditions (1000 W/m² and 25°C) used for the rating of solar panels by manufacturers, which is in line with the findings of Kim et al. (2011) and Bahaidarah et al. (2015).

Findings have also shown that, in the same location and year, both the measured and simulated Pmax, VMP, IMP, Eff., and MDT increased as the solar radiation increased, but however, as the MDT was increasing beyond 25°C, the VMP and Eff. decreased. During the period of low solar radiation in Abuja in 2024, both the measured and simulated values showed that the 80 W solar panel generated lower Pmax and IMP, and its MDT was also low. However, the 80W generated higher VMP and Eff. during this period, while the reverse was the case during the period of high solar radiation. This is in line with the findings of Kurnik et al. (2011), Kozak et al. (2009), Buday (2011), and Meral and Dinçer (2011).

However, in the same period, with high solar radiation at reduced MDT, the 80W solar panel generated a better Pmax due to increased VMP. Sometimes during the daytime in the year 2024 at the FCT, the hourly VMP and Eff. of the 80W solar panel dropped to less than 12 volts and to less than 11%, respectively.

A number of the months in the year 2024 recorded approximately the same values for some of the parameters, and some months recorded their highest and lowest values on the same day for both measured and simulated. The calculation of the correlation coefficient between the measured and simulated monthly maximum power (Pmax) of the 80W solar panel based on the year 2024 climatic conditions of Abuja FCT was achieved from the values presented in Table 4 using Equation 8. The CORREL function in Microsoft Excel was used to estimate the correlation coefficient r, and r = 0.980194 was obtained. It means that the association/relationship between the measured and simulated monthly maximum power outputs of the 80 W solar panel is positive, and the strength is very strong, in line with the findings of Bahaidarah et al. (2015).

To calculate the Root Mean Square Error (RMSE), we used Equation 9. The differences between the simulated and measured values for every point were obtained, then the squares of these differences were calculated, then the average of these squared errors (mean squared errors) was obtained, and finally, the square root of the average was taken to get the RMSE value, and this was easily implemented in Microsoft Excel based on the values in Table 4 to obtain RMSE (e) = 0.743435393. Therefore, the typical or average prediction error of the models used for the simulation of the monthly Maximum Power (Pmax) of the 80 W solar panel based on the year 2024 climatic condition in the FCT is 0.743435393. This is also a measure of the average difference between the measured and simulated values: However, the percentage error was calculated using Equation 10 as follows:

$$Percentage\ Error = \frac{0.743435393}{(34.37943661 - 20.6794321)}\ x\ 100 = 0.0542653393\ x\ 100\ =\ \textbf{5.43\%}$$

The percentage error of 5.43% indicates that the accuracy of the models used to simulate the final monthly maximum power (Pmax) of the 80W solar panel, based on the year 2024 NIMET FCT climatic data used, is established in line with the findings of Bahaidarah et al. (2015). Based on this value obtained, the models used in this study can be used to accurately predict the power yield of solar PV modules. The existence of about 5% error could be due to numerical errors (rounding-off errors).

5. Conclusions

This study assessed the performance of an 80 W monocrystalline photovoltaic (PV) module in Abuja FCT, Nigeria, over a year (January - December, 2024). The results have shown that the general performance of a solar PV module or solar panel depends mainly on the actual operating condition of the location where it is installed. Also, the (outdoor) conditions of locations where a solar panel is installed are not the same as the Standard Test Conditions (1000 W/m² and 25°C, STCs) used by the solar panel manufacturers for the rating of their products. In fact, the above results showed that the solar radiation can rise beyond 1200 W/m² and the module temperature beyond 57°C at some points. As a result of the difference between the STCs and the actual operating conditions, a solar panel cannot generate the same output specifications stated by its

manufacturer. The 80 W solar panel generated at some periods VMP less than 12 volts from the 17.35-volt manufacturer's rating and Eff less than 12% from the 18% manufacturer's rating. This simply means that the 80 W solar panel will not be able to charge any 12-volt battery (with a maximum terminal voltage of 14 volts) during peak solar radiation despite high current generation. In fact, during these periods, current is expected to flow from the battery to the solar panel, since electric current flows from the point of higher potential (higher voltage) to the point of lower potential (lower voltage). The correlation coefficient, r, between measured and simulated monthly Pmax was obtained as r = 0.980194, showing that the correlation between these value sets is positive and their relationship is very strong. Also, the percentage error, e = 5.43% ≈ 5%, shows that the empirically based PV models used for simulation in this work have a high level of accuracy. However, the existence of about 5% error could be due to numerical errors (rounding-off errors). This means that these models used in this work can be implemented to predict the power yield of solar PV modules at different locations in Nigeria. The real-time measurements setup (testbed) can serve as a solar PV module performance validation facility, which can be duplicated at regional locations to serve as validation centers in Nigeria. Using these empirically based PV models for accurate performance prediction and the establishment of solar PV module validation centers will foster better and more reliable solar power system design, deployment, and management in Nigeria.

Declaration of Ethical Standards
As the authors of this study, we declare that we comply with all ethical standards.

Credit Authorship Contribution Statement
S.D.Yusuf: Investigation, Methodology, Writing, Review & Editing, Supervision.
A.O.Nduka: Software, Validation, Formal analysis, Writing -Original Draft, Visualization.
I.Umar: Validation, Visualization, Supervision.

Declaration of Competing Interest
The authors declared that they have no conflict of interest.

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