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Analysis of Climatic Influences on the Performance of Solar Photovoltaic Systems: A Case Study of Mubi, Nigeria

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Abstract:
Background: Solar photovoltaic (PV) technology plays a critical role in Nigeria's transition to renewable energy, given the country's substantial solar potential. The performance of PV systems is significantly affected by environmental factors, including solar radiation, temperature, humidity, cloud cover, and seasonal variability. This study investigates the influence of climatic conditions on solar PV performance in Mubi, northeastern Nigeria, utilizing published monthly climate data and performance records from four 3.5-kWp grid-connected PV systems: monocrystalline silicon (m-Si), polycrystalline silicon (p-Si), amorphous silicon (a-Si), and copper-indium-diselenide (CIS). The climate variables analyzed include mean daily solar radiation, air temperature, earth temperature, and the clearness index. The methodology incorporates descriptive statistics, seasonal comparisons, correlation analysis, and interpretation of PV performance indicators. Results show that the average daily solar radiation was 5.75 kWh/m²/day, mean air temperature was 26.48°C, and mean earth temperature was 27.38°C. Solar radiation decreased from 6.55 kWh/m²/day in March to 4.75 kWh/m²/day in August, representing a 27.48% difference between the highest and lowest months. The four PV systems exhibited notable differences in annual performance. The a-Si system recorded the highest annual energy output (8,457.0 kWh), with a specific yield of 2,416.3 kWh/kWp, a performance ratio of 90.7%, and a capacity factor of 27.6%. Conversely, the m-Si system produced the lowest output at 6,649.8 kWh and a capacity factor of 21.7%. A strong positive correlation was observed between solar radiation and the clearness index (r = 0.683), while correlations for air temperature (r = 0.396) and earth temperature (r = 0.457) were weaker. These findings demonstrate that both climatic conditions and PV technology type influence system performance. The study recommends selecting PV technology based on local climate, implementing temperature management strategies using site-specific performance models, and utilizing long-term climate data for PV planning in Nigeria.
Keywords: *solar photovoltaic, climatic variability, solar radiation, performance ratio, renewable energy.*

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I. Introduction

Nigeria possesses significant renewable energy resources, yet the provision of reliable electricity remains a persistent challenge. Solar energy is particularly promising due to the country's high solar irradiance. Recent studies consistently identify solar PV as a central component of Nigeria’s renewable energy strategy, despite ongoing technical, economic, and infrastructural barriers.

The capacity rating of a PV system does not accurately reflect its real electricity output, since output is affected by factors such as solar radiation, module temperature, weather conditions, system losses, module type, installation setup, inverter performance, and other environmental variables. In tropical areas, the difference between standard test conditions (STC) and actual conditions is large because module temperatures often exceed the 25°C figure used in laboratory tests. Recent research in Nigeria shows that strong sunlight can raise the surface temperature of PV panels above their optimal operating range.

Nigeria's climate exhibits significant variation across the Sahel, the semi-arid north, the Guinea Savannah, the rainforest, and the coastal regions. Recent modeling studies suggest that future photovoltaic potential will differ by region, underscoring the necessity for site-specific evaluations.

Several studies have examined various aspects of PV performance in Nigeria. For instance, Owolabi et al. (2023) assessed four grid-connected PV technologies in Mubi under the same conditions and found considerable differences in their performance. Other studies have investigated PV systems in Cross River State, PV performance in Jos, solar potential in southeastern cities, and the effect of temperature on PV output in Abuja.

II. Research Problem

A major problem in the literature on photovoltaics in Nigeria is the tendency to examine climate resources and PV performance separately. When studying the solar resource, sunlight availability is usually measured without assessing the actual performance of PV systems, and experimental studies may focus on a single technology at a single location without linking performance to seasonal climate changes. Comprehensive analyses that integrate climate factors and PV performance are essential for advancing the field.

III. Research Gap

This study identifies three principal gaps in the current literature. First, although recent studies have evaluated the solar potential in Nigeria, very few have directly linked monthly climate changes to PV system performance. For example, satellite data show significant variations in solar radiation in northern Nigeria, but these variations do not necessarily lead to the same performance across all PV technologies.

Secondly, previous studies demonstrate that different PV technologies respond variably to identical environmental conditions. Understanding these differences requires analysis of both seasonal radiation and temperature. The Mubi dataset, which includes four technologies, enables such an investigation. Third, although recent climate modeling studies have forecast future changes in Nigeria's PV potential, it is important to first understand the effect of current seasonal climate on system performance before applying these findings to future planning.

Hence, the present study uses Mubi as an example to examine the effects of climate variability on PV system performance.

IV. Aim and Objectives

This study aims to evaluate the effect of climate variability on the performance of solar photovoltaic systems in Mubi, Nigeria. The objectives include:

1. analyze monthly variations in solar radiation in Mubi;
2. examine seasonal variations in air and earth temperatures;
3. Analyze monthly clearness index values;
4. evaluate reported performance indicators for four PV technologies;
5. examine relationships among climatic variables;
6. determine the implications of climatic variability for PV technology selection; and
7. Give suggestions to help boost PV deployment in Nigeria’s climate.

Study Location:
Mubi is located in northeastern Nigeria at a latitude of about 10.28°N and a longitude of 13.29°E, with an elevation of approximately 559 meters above sea level. The region has a clear distinction between its wet and dry seasons and is known for the high amount of solar radiation it receives. The photovoltaic systems examined in this study were installed at the Adamawa State College of Health Technology in Mubi. Mubi is a suitable site for this study since four different PV technologies, all of the same capacity, were tested under similar conditions.

PV Systems Considered:
The four PV technologies were:
• monocrystalline silicon (m-Si);
• polycrystalline silicon (p-Si);
• amorphous silicon (a-Si); and
• copper-indium-diselenide (CIS).

Climatic Variable:

The climatic variables considered were:

- mean daily solar radiation;
- mean air temperature;
- mean earth temperature; and
- clearness index.

The monthly climatic data used in the analysis are presented in Table 1.

Table no 1: Monthly climatic dataset for Mubi

Month	Solar radiation (kWh/m²/day)	Air temperature (°C)	Earth temperature (°C)	Clearness index
January	5.94	23.3	24.4	0.671
February	6.36	25.9	27.2	0.666
March	6.55	29.3	30.8	0.545
April	6.24	31.0	32.8	0.593
May	5.87	30.2	32.0	0.562
June	5.42	28.2	29.5	0.527
July	4.98	25.6	26.2	0.483
August	4.75	24.4	24.6	0.475
September	5.23	25.0	25.0	0.509
October	5.71	26.2	26.4	0.584
November	6.09	25.3	25.5	0.678
December	5.82	23.3	24.1	0.677
Mean	**5.75**	**26.48**	**27.38**	**0.581**

PV performance indicators

Three major indicators were considered:

Specific yield

$$Y_f = \frac{E_{AC}}{P_{rated}}$$

where:

- Y_f = final or specific yield;
- E_{AC} = annual AC energy output;
- P_{rated} = installed PV capacity.

Capacity Factor

$$CF = \frac{E_{annual}}{P_{rated} X 8760} X 100$$

Performance Ratio

The performance ratio quantifies the efficiency with which a photovoltaic system converts available solar energy into usable electricity while accounting for system losses.
The performance indicators discussed in this section are derived from the published Mubi PV-performance study.

V. Results

Seasonal variation in solar radiation

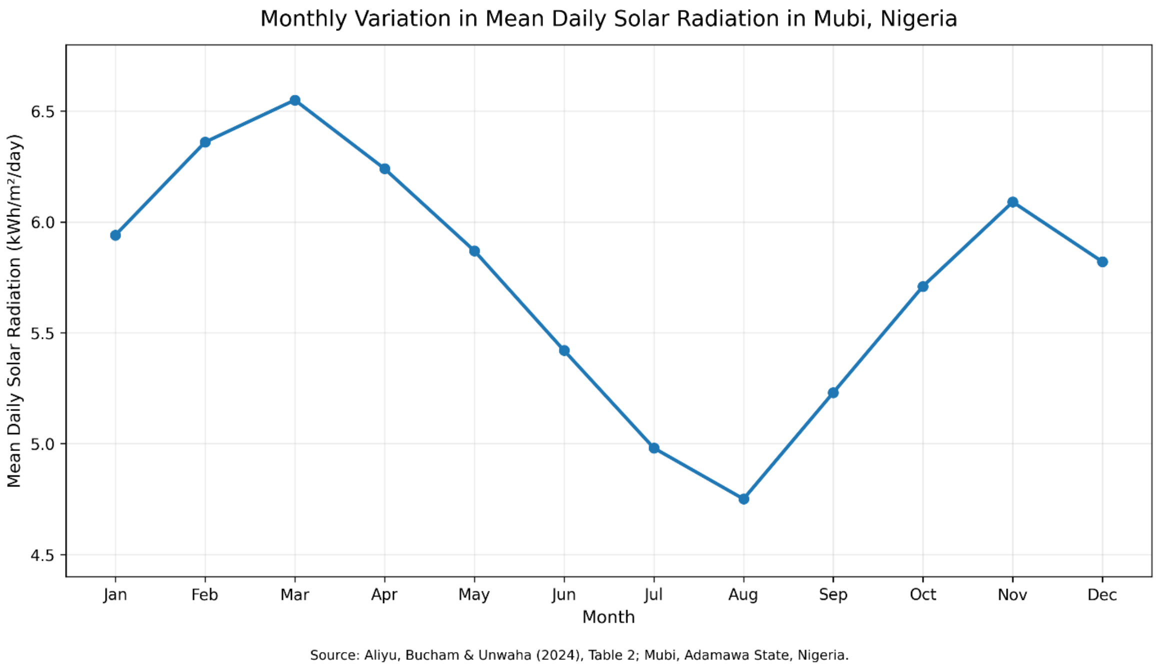

Figure 1. Monthly variation in solar radiation

Solar radiation rose from 5.94 kWh/m²/day in January to 6.55 kWh/m²/day in March, then declined to 4.75 kWh/m²/day in August before increasing again from September to December.

The difference between the highest and lowest values was

6.55 − 4.75 = 1.80 kWh/m²/day

The percentage drop from March to August was:

(6.55 − 4.75) / 6.55 × 100 = 27.48%

In August, the available solar resource was about 27.5 percent lower than the peak in March.

Seasonal changes matter because the electricity produced by photovoltaic systems depends directly on how much solar energy is available.

Air-temperature variation

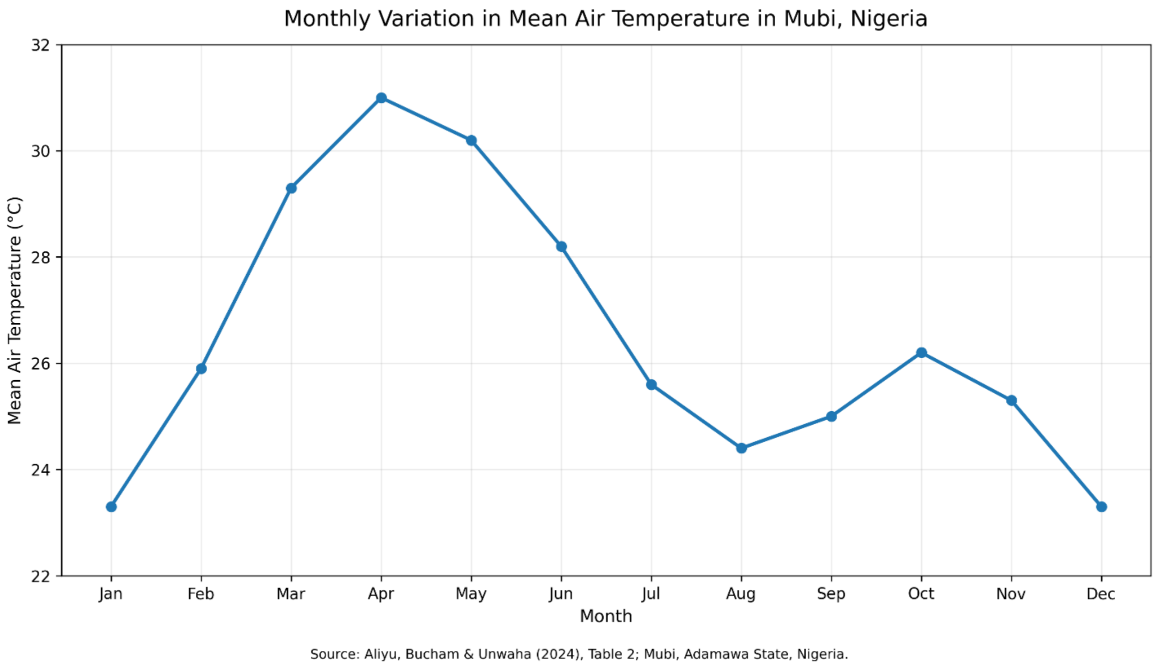

Figure 2. Monthly variation in air temperature

Monthly average temperatures ranged from **23.3°C to 31.0°C**.

The highest temperature was observed in April, whereas the lowest temperatures were recorded in January and December.

The mean annual air temperature was approximately:

26.48°C

This temperature exceeds the 25°C reference value used in standard photovoltaic (PV) test conditions.

The difference between the mean air temperature in Mubi and the 25°C reference is:

$26.48 - 25 = 1.48°C$

This difference does not indicate that each module operated only 1.48°C above standard test conditions (STC), since module temperature is also affected by irradiance, wind, and mounting configuration. Nevertheless, these results demonstrate that the local climate consistently differs from laboratory reference conditions.

Other studies conducted in Nigeria have also reported that PV panel temperatures can exceed 25°C under high solar radiation.

Earth-temperature variation

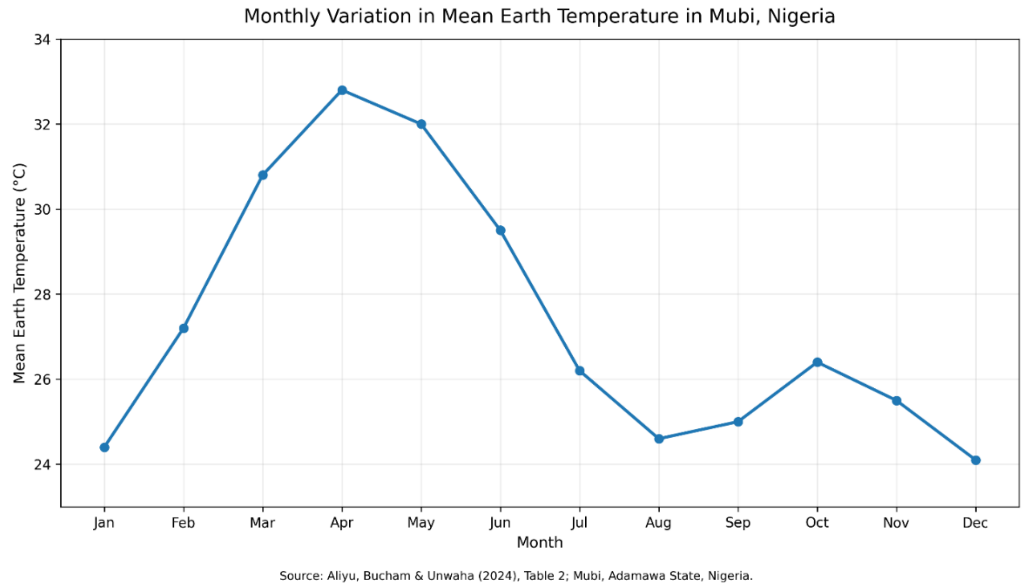

Figure 3. Monthly variation in earth temperature

The recorded temperature on Earth ranged from **24.1°C to 32.8°C**, with the maximum value observed in April.

The mean temperature on Earth during the observation period was as follows:

27.38°C

Earth's temperature generally follows seasonal variations in air temperature; however, differences in thermal storage capacity between the ground and air affect the degree of alignment.

This distinction is significant for photovoltaic (PV) installations, as ground-mounted systems are subject to different environmental conditions compared to rooftop systems, especially in terms of heat exchange and airflow.

Clearness-index variation

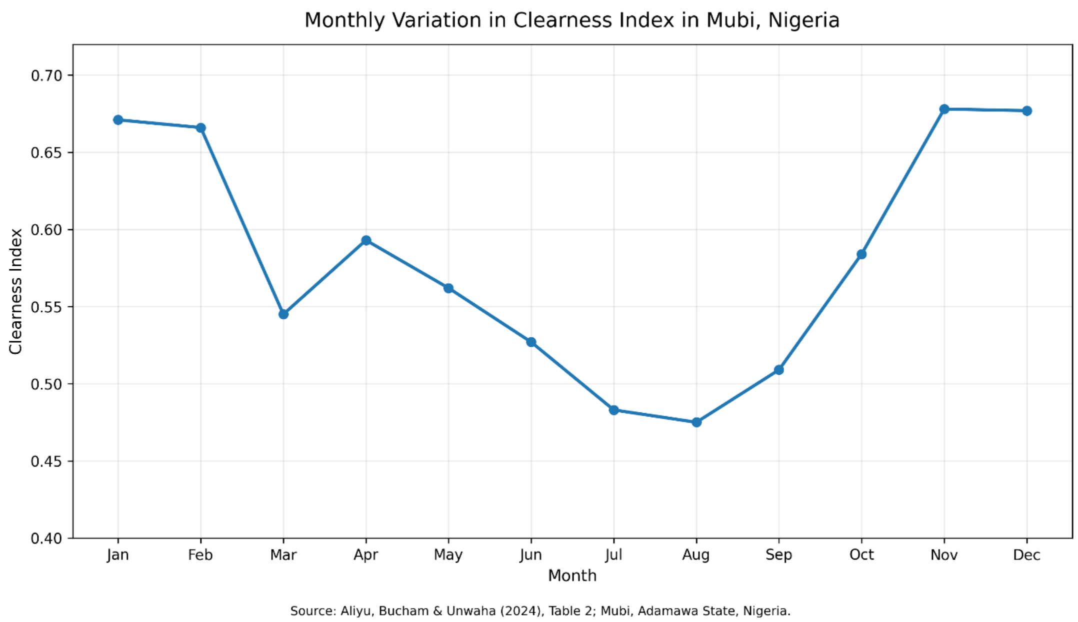

Figure 4. Monthly clearness index

Correlation analysis

Table 2. Pearson correlation coefficients among climatic variables

Variables	**Solar radiation**	**Air temperature**	**Earth temperature**	**Clearness index**
Solar radiation	1.000	0.396	0.457	**0.683**
Air temperature	0.396	1.000	**0.988**	-0.252
Earth temperature	0.457	**0.988**	1.000	-0.177
Clearness index	**0.683**	-0.252	-0.177	1.000

The strongest association involving solar radiation was observed with the clearness index:

$r=0.683$

The results demonstrate a strong positive relationship, indicating that atmospheric clarity has a significant impact on the quantity of solar energy reaching the surface.

A strong correlation was also observed between air temperature and earth temperature.

The correlation coefficient was $r = 0.988$.

This result is consistent with expectations, since both variables are influenced by similar seasonal temperature variations.

Performance of Photovoltaic (PV) Technologies

Each of the four photovoltaic technologies had a nominal capacity of 3.5 kWp; however, their annual electricity generation differed.

Table 3. Annual performance of the four PV technologies

Technology	**Capacity (kWp)**	**Annual energy (kWh)**	**Specific yield (kWh/kWp)**	**PR (%)**	**Capacity factor (%)**
m-Si	3.5	6,649.8	1,899.9	88.8	21.7
p-Si	3.5	8,271.1	2,363.2	85.1	27.0
a-Si	3.5	8,457.0	2,416.3	90.7	27.6
CIS	3.5	7,917.2	2,262.1	84.1	25.9

The data for these values are derived from the Mubi photovoltaic (PV) performance study.

The **amorphous silicon (a-Si) system generated the highest annual electricity output, whereas the monocrystalline silicon (m-Si) system produced the lowest outpu**t.

The difference in annual electricity output between the two systems was calculated as follows:

8457.0 kWh − 6649.8 kWh = 1807.2 kWh

The a-Si system generated the following percentage increase over the m-Si system:

1807.2 kWh ÷ 6649.8 kWh × 100 = 27.18%

Therefore, the a-Si system produced 27.18% more electricity annually than the m-Si system.

Capacity-factor analysis
The capacity factors were:
- m-Si: 21.7%;
- p-Si: 27.0%;
- a-Si: 27.6%;
- CIS: 25.9%.

The mean capacity factor was calculated by summing the individual values (21.7, 27.0, 27.6, and 25.9) and dividing by four, yielding 25.55%.
The a-Si system exceeded the average by approximately the following: The difference between 27.6 and 25.55 is 2.05 percentage points.
The m-Si system was approximately the following: The difference between 25.55 and 21.7 is 3.85 percentage points.
This indicates that the m-Si system was 3.85 percentage points below the average.
These findings demonstrate that nominal capacity alone does not accurately predict actual energy production.

VI. Discussion

The performance of photovoltaic systems in relation to climatic seasonality
The results indicate a pronounced seasonal variation in solar resources. Solar radiation reached its maximum in March and its minimum in August, corresponding to the transition from dry, clear weather to wetter, cloudier conditions.
The 27.5% difference between the highest and lowest monthly solar radiation is significant for photovoltaic system planning. Designing systems based solely on annual averages may overlook these important seasonal variations.
Recent studies conducted in Nigeria have likewise identified considerable regional differences in the availability of solar resources. Thus, Salihu et al. (2024), using a satellite-based analysis, found that the annual solar-radiation potential is higher in northeastern Nigeria than in the north-central and northwestern regions.

Temperature influence:
Temperature is a critical environmental factor affecting photovoltaic performance. Data from Mubi indicate that the highest air temperature occurred in April, coinciding with elevated solar radiation. While high solar radiation enhances PV generation, increased module temperatures can reduce conversion efficiency. Research in Nigeria has demonstrated that as temperature rises, both the power output and efficiency of PV systems decrease. For example, a 2025 study in Kaduna found that PV power output and efficiency declined as ambient temperature increased.
A study conducted in Abuja in 2025 also discovered an inverse relationship between temperature and the power and voltage output of PV systems.
Therefore, the influence of temperature on PV performance requires nuanced interpretation. Temperature often increases concurrently with irradiance. Consequently, even when more solar energy is available, the module's electrical conversion efficiency may decrease. It is important to analyze the effects of temperature and irradiance separately.

The significance of the clearness index
The correlation between solar radiation and the clearness index was higher than the correlation between solar radiation and air temperature.
Atmospheric clarity is a key determinant of the amount of solar energy that a PV system can utilize. Cloud cover, moisture in the air, and aerosols can reduce the amount of solar radiation that reaches the module, even in regions such as southeastern Nigeria, which experience extended rainy seasons and increased cloud cover.

PV technology differences
A key finding is that the four PV technologies produced different results despite having identical nominal capacities.

Among the four technologies, the a-Si system exhibited the highest values for annual output, specific yield, and performance ratio. This finding underscores the importance of considering real operating conditions when selecting a technology, rather than relying solely on the module's listed specifications. This agrees with recent research in Nigeria, which shows that PV technologies can respond differently to environmental conditions. For example, a study in Cross River State found differences between monocrystalline and polycrystalline modules in their current-voltage and maximum-power characteristics under local conditions.

Comparison with Recent Nigerian Studies

Table 4. Selected recent Nigerian PV studies

Study	Location/scope	Main emphasis	Major implication
Owolabi et al. (2023)	Mubi	Four PV technologies	Technology-specific performance differences
Njok et al. (2023)	Ogoja	Diurnal PV performance	Climate variables influence efficiency
Ikemba et al. (2024)	Five southeastern cities	Solar potential and prediction	Strong potential despite cloudiness
Ettah et al. (2024)	Cross River	I–V characteristics	Radiation and temperature affect PV output
Uzer et al. (2024)	Jos	Temperature, humidity and PV output	Local climate affects PV operation
Salihu et al. (2024)	Northern Nigeria	Satellite PV potential	Strong regional solar-resource differences
Ojo et al. (2024)	Four Nigerian climate regions	Climate/PV potential	PV response varies by climatic zone
Awai et al. (2024)	Nigeria	PV temperature	High radiation can increase module temperature
Ojo & Adesemoye (2024)	Nigeria	CMIP6 projections	Future PV potential varies by climate region
Umar & John (2025)	Abuja	Temperature and PV output	Temperature has an inverse effect on output

These studies reinforce the present finding that PV performance cannot be understood independently of climatic conditions.

Limitations of the Study

Several limitations should be acknowledged.

First, the detailed climatic analysis presented here is based on **Mubi**, and therefore the results should not be generalized directly to every Nigerian location.

Second, the climatic dataset is monthly, whereas PV performance is influenced by hourly and sub-hourly variations in irradiance and temperature.

Third, the correlation analysis examines climatic relationships but does not establish causality.

Fourth, the reported annual PV performance indicators were obtained from the published four-technology Mubi study; they should therefore be treated as secondary performance data rather than newly measured observations.

Finally, a stronger national study would combine multiple locations representing the Sahel, Sudan/Sahel transition, Guinea Savannah, rainforest and coastal climatic zones.

VII. Recommendations

Based on the findings, the following recommendations are made:

1. **Location-specific PV assessment:** Solar PV projects should be designed using local climatic data rather than national-average values.
2. **Technology-specific evaluation:** PV technologies should be tested under Nigerian operating conditions before large-scale deployment.
3. **Temperature monitoring:** PV installations should include module-temperature monitoring because temperature can significantly influence electrical efficiency.
4. **Seasonal modelling:** PV feasibility studies should incorporate monthly or preferably hourly climatic data.
5. **Improved ventilation:** Where practical, PV modules should be mounted to permit adequate rear-side airflow.
6. **Long-term monitoring:** Nigerian research institutions should establish long-term PV performance databases covering different climatic regions.
7. **Multi-location research:** Future research should extend this methodology to locations such as Sokoto, Abuja, Jos, Lagos, Enugu and Port Harcourt.
8. **Climate-change modelling:** Future PV projects should consider projected changes in solar radiation and temperature.

VIII. Conclusion

This study analysed climatic influences on PV performance using Mubi, Nigeria, as a case study. The results demonstrate significant seasonal variability in the solar resource and thermal environment.

Mean daily solar radiation was approximately **5.75 kWh/m²/day**, varying between **4.75 and 6.55 kWh/m²/day**. The difference between the maximum and minimum monthly values was approximately **27.5%**, demonstrating that seasonal variability is substantial.

Mean air temperature was **26.48°C**, while mean earth temperature was **27.38°C**. The maximum air temperature of 31.0°C occurred in April, while the minimum of 23.3°C occurred in January and December.

The clearness index averaged approximately **0.581** and showed a relatively strong positive association with solar radiation ($r=0.683$). This indicates that atmospheric conditions are important in determining the solar energy available to PV systems.

The four PV technologies also showed substantial performance differences. The a-Si system recorded the highest annual electricity production of **8,457.0 kWh**, while m-Si recorded the lowest at **6,649.8 kWh**. The difference of **1,807.2 kWh** represents approximately **27.2% more annual energy production by a-Si relative to m-Si**.

Overall, the results demonstrate that PV performance in Nigeria is a function of the interaction between **solar resource, temperature, atmospheric conditions and PV technology**. Consequently, PV deployment should move beyond simple solar-resource assessment toward integrated climate-performance analysis.

The study also demonstrates why Mubi should be regarded as a **case study rather than a proxy for the whole of Nigeria**. A national follow-up study using several climatic zones would provide a stronger basis for generalizing the findings across Nigeria.

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