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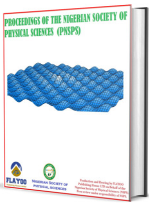

Assessment of solar radiation variability and its impact on estimated photovoltaic electricity output over Kano, Nigeria

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ABSTRACT

This study assessed the variability of solar radiation and its impact on photovoltaic (PV) energy generation in Kano, a Sahelian city in Nigeria located at latitude 12.05°N and longitude 8.20°E. Thirty-one years (1990–2020) of meteorological data obtained from the Nigerian Meteorological Agency (NiMet) were used. Monthly, seasonal, and annual variations in global solar radiation (GSR), sunshine duration, and mean temperature were analysed to evaluate their influence on solar-energy output. The average annual GSR was 17.86 $\mathrm{MJ\,m^{-2}\,day^{-1}}$, the mean sunshine duration was 7.55 $\mathrm{h\,day^{-1}}$, and the mean annual temperature was 26.78°C. Using a 21.9%-efficient monocrystalline panel with an area of 2.58 $\mathrm{m^2}$, the estimated mean monthly energy output was 2721.44 kWh, with peak generation occurring during the rainy season. Correlation analysis showed a strong positive relationship between GSR and energy output. Among the empirical models tested, Garcia's temperature-based model performed best, with $R^2 = 92.2\%$. The findings confirm that solar-radiation variability significantly influences PV generation and that temperature-based models provide superior estimation accuracy in Sahelian climates, supporting large-scale solar deployment in northern Nigeria.

Keywords: Solar radiation, Variability, Photovoltaic energy, Kano, Empirical models.

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1. INTRODUCTION

Solar radiation is the primary energy source that powers photovoltaic (PV) systems; consequently, its assessment is fundamental to solar-energy research. PV technology converts solar irradiance directly into electricity through semiconductor materials. The efficiency of this process depends on the quantity and quality of solar radiation reaching the Earth's surface, which vary across time and space. As global energy demand continues to increase amid concerns about fossil-fuel depletion and climate change, the assessment of solar radiation for PV energy generation has become an important area of scientific inquiry.

Solar energy drives nearly all life-supporting systems on Earth, including climate and weather processes such as atmospheric wind patterns and ocean currents [1]. The Sun also powers the hydrological cycle that replenishes rivers used for hydroelectricity generation [2]. Petroleum resources are derived from ancient plant and animal remains that originally stored solar energy [3]. Mamman *et al.* [4] assessed solar-radiation models and measurement techniques for Nasarawa State, Nigeria, using a pyranometer and nine 12 V, 5 W polycrystalline solar panels. Their mea-

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surements were taken daily between 12:00 and 15:00, and the Angstrom–Prescott model was used to estimate solar radiation, yielding regression constants $a = 0.53$ and $b = 0.052$. They reported the highest radiation value in April (29.86 $\mathrm{MJ\,m^{-2}}$) and the lowest in August (16.68 $\mathrm{MJ\,m^{-2}}$). Their findings indicated a significant potential for harnessing solar energy in Nasarawa State, with consistently high atmospheric transmission coefficients or clearness indices throughout the year.

The aim of this study is to investigate how variations in global solar radiation and temperature affect estimated PV electricity output in Kano, Nigeria.

2. MATERIALS AND METHODS

2.1. DATA COLLECTION

Meteorological parameters, including solar radiation, sunshine duration, and maximum and minimum temperature, were obtained from the Nigerian Meteorological Agency (NiMet) for Kano over a 31-year period (1990–2020). The Gunn–Bellani solar-radiation data were converted to $\mathrm{MJ\,m^{-2}\,day^{-1}}$. A Sunrise Energy SR-72M565HLPro monocrystalline PERC solar-panel datasheet, with a panel efficiency of 21.9% and an area of 2.58 $\mathrm{m^2}$, was used as the reference for PV energy-generation parameters.

In Kano, the rainy season is generally not cold but is characterised by mixed weather, oppressive humidity, and mostly cloudy conditions. The dry season is hot, humid, and partly cloudy. The hot season lasts approximately four months, from February to May, with the hottest days usually occurring in April. The cool season also lasts about four months, from September to December. The rainy period spans seven months, from April to October, with the heaviest rainfall occurring around August. The rainless period lasts about five months, from November to March.

2.2. SOLAR-RADIATION MODELS

The empirical models used in this study are based on sunshine duration and temperature. The models of Bashahu and Ndacayisaba [5] and Ampratwum and Dorvlo [6] represent the sunshine-based models, whereas the models of Akpootu *et al.* [7] and Chen *et al.* [8] represent the temperature-based models:

$$\frac{H}{H_o} = a + b\left(\frac{S}{S_o}\right), \tag{1}$$

$$\frac{H}{H_o} = a + b\ln\left(\frac{S}{S_o}\right), \tag{2}$$

$$\frac{H}{H_o} = a + b\left(\frac{\Delta T}{S_o}\right), \tag{3}$$

$$\frac{H}{H_o} = a + b\ln(\Delta T), \tag{4}$$

where H is the daily global solar radiation on a horizontal surface ($\mathrm{MJ\,m^{-2}}$), H_o is the daily extraterrestrial radiation ($\mathrm{MJ\,m^{-2}}$), ΔT is the temperature difference (°C), S is the day length or sunshine duration (h), S_o is the maximum possible sunshine duration (h), and a and b are empirical coefficients specific to the location.

2.3. PHOTOVOLTAIC POWER-OUTPUT MODELS

The PV power-output model [9] is given by

$$P = G \times A \times \eta, \tag{5}$$

where P is the PV power output (W), G is the solar irradiance ($\mathrm{kW\,m^{-2}}$), A is the area of the PV array ($\mathrm{m^2}$), and η is the PV efficiency (%). The total energy model [9] used to estimate total energy output is

$$E = P \times t, \tag{6}$$

where E is the total energy output (Wh) and t is the time duration (h).

The parameters H_o, δ, ω_s, and S_o were obtained using the following expressions [10]:

$$H_o = \frac{24 \times 3600}{\pi} G_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right] \times\left[\cos\phi\cos\delta\sin\omega_s + \frac{\pi\omega_s}{180}\sin\phi\sin\delta\right], \tag{7}$$

where G_{sc} is the solar constant (1367 $\mathrm{W\,m^{-2}}$), n is the day number, ω_s is the sunrise hour angle, ϕ is the latitude of the site, and δ is the declination angle:

$$\delta = 23.45\sin\left[360\left(\frac{284+n}{365}\right)\right], \tag{8}$$

$$\omega_s = \cos^{-1}(-\tan\phi\tan\delta), \tag{9}$$

$$S_o = \frac{2}{15}\omega_s. \tag{10}$$

If temperature correction is applied to PV efficiency, η_{STC}, τ, T_c, and T_{STC} denote the reference PV efficiency, temperature coefficient of power (%/°C), cell temperature (°C), and reference temperature (25°C), respectively.

2.4. STATISTICAL ANALYSIS

2.4.1. Correlation analysis

The relationship between solar radiation and power output was analysed using Pearson's correlation coefficient [11]:

$$r = \frac{\sum_{i=1}^{N}(H_i - \bar{H})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{N}(H_i - \bar{H})^2 \sum_{i=1}^{N}(P_i - \bar{P})^2}}, \tag{11}$$

where r is Pearson's correlation coefficient, H_i is solar radiation, P_i is power output, $\bar{H}$ is the mean solar radiation, $\bar{P}$ is the mean power output, and N is the number of observations.

2.4.2. Standard deviation and coefficient of variation

Solar-radiation variability was assessed using the standard deviation and coefficient of variation (CV), following Palmer *et al.* [12]:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(H_{\mathrm{obs},i} - H_{\mathrm{est},i})^2}, \tag{12}$$

where N is the number of observations and σ is the standard deviation. The CV was calculated as

$$CV = \frac{\sigma}{H_{\mathrm{est}}} \times 100. \tag{13}$$

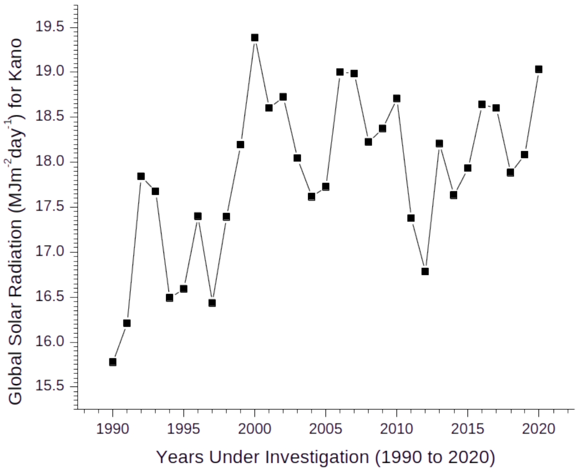

Figure 1. Annual mean variation of global solar radiation for Kano.

2.4.3. Seasonal energy-yield comparison

The seasonal variation in solar-energy output was analysed as [12]

$$\Delta E = \frac{E_{\mathrm{dry}} - E_{\mathrm{wet}}}{E_{\mathrm{wet}}} \times 100, \tag{14}$$

where ΔE is the percentage change in energy output, and E_{wet} and E_{dry} are the energy yields in the rainy and dry seasons, respectively.

2.4.4. Model validation and accuracy assessment

The accuracy of the empirical models was assessed using performance metrics reported by Akpootu *et al.* [7]. The models were ranked according to their performance; the model with the lowest error was considered the best-performing model. The mean bias error (MBE), root mean square error (RMSE), and mean percentage error (MPE) are given by

$$\mathrm{MBE} = \frac{1}{N}\sum_{i=1}^{N}(H_{\mathrm{est},i} - H_{\mathrm{obs},i}), \tag{15}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(H_{\mathrm{est},i} - H_{\mathrm{obs},i})^2}, \tag{16}$$

$$\mathrm{MPE} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{H_{\mathrm{obs},i} - H_{\mathrm{est},i}}{H_{\mathrm{obs},i}} \times 100\right). \tag{17}$$

3. RESULTS AND DISCUSSION

Figure 1 shows the annual variability in solar radiation in Kano over the 31-year study period (1990–2020). The average solar-radiation value for the period was 17.8567 MJ m^{-2} day^{-1}. The maximum value, 19.3833 MJ m^{-2} day^{-1}, was observed in 2000, whereas the minimum value, 15.7750 MJ m^{-2} day^{-1}, was observed in 1990. The results show year-to-year fluctuations in global solar radiation. The higher value recorded in 2000 may be associated with reduced aerosol loading and clearer sky conditions during that year.

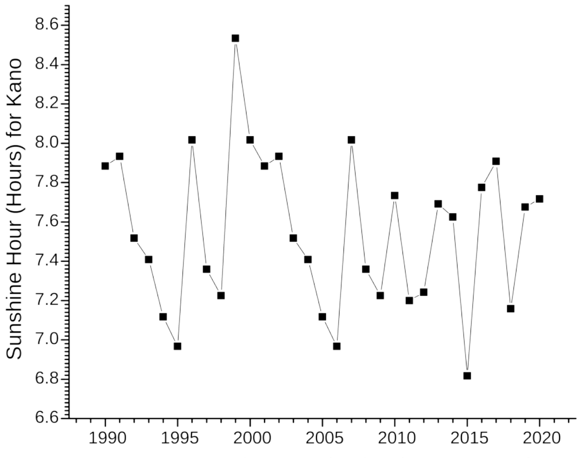

Figure 2. Annual mean variation of sunshine duration for Kano.

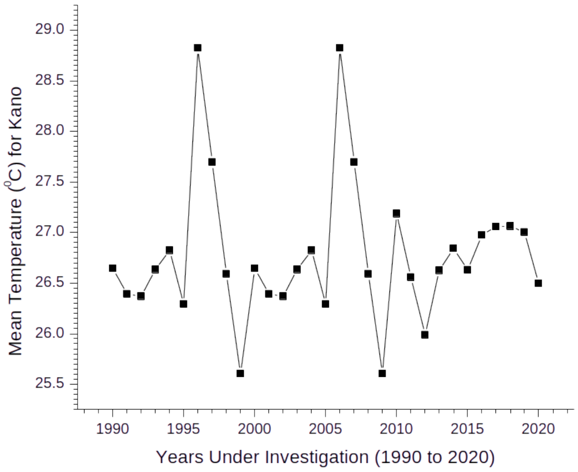

Figure 3. Annual mean variation of temperature for Kano.

Figure 2 shows the annual variability in sunshine duration for 1990–2020. The average sunshine duration was 7.5465 h. The maximum sunshine duration was 8.5333 h in 1999, whereas the minimum was 6.8167 h in 2015.

Figure 3 shows the annual mean temperature variation for 1990–2020. The average mean temperature was 26.7798°C. The maximum annual mean temperature, 27.6958°C, occurred in 1997 and 2007, whereas the minimum, 25.6042°C, occurred in 1999 and 2009. This pattern suggests periodic variability in temperature over the study period.

Figure 4 shows the monthly and seasonal variability in measured solar radiation for 1990–2020. The monthly average measured solar radiation was 22.9637 MJ m^{-2} day^{-1}. The maximum value, 25.3342 MJ m^{-2} day^{-1}, occurred in March, whereas the minimum value, 20.8539 MJ m^{-2} day^{-1}, occurred in December; both months are in the dry season. The results indicate high solar-radiation values at the study location, with lower fluctuations during the rainy season than during the dry season, except in March, when the annual maximum was recorded. Average global solar radiation during the dry and rainy seasons was 22.8244 and 23.0633 MJ m^{-2} day^{-1}, respectively. The slightly higher rainy-season value may be attributed to reduced dust and aerosol con-

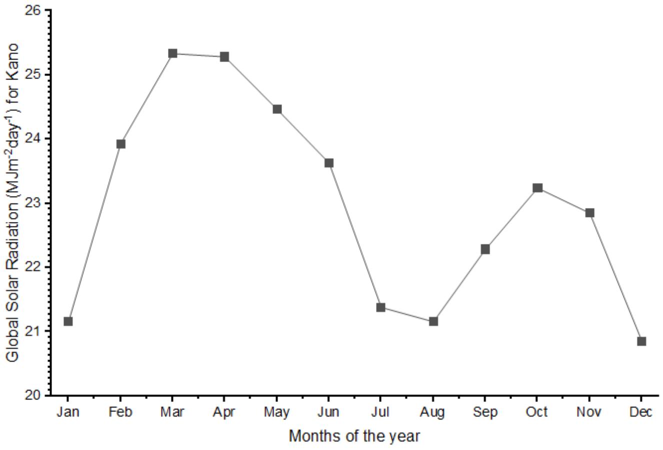

Figure 4. Monthly mean variation of global solar radiation for Kano.

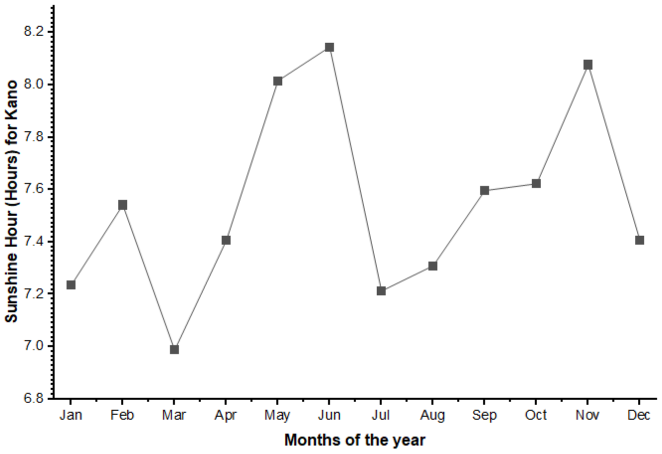

Figure 5. Monthly mean variation of sunshine duration for Kano.

centrations, which generally decrease incoming solar radiation during the dry season [7].

Figure 5 shows the monthly and seasonal variability in measured sunshine duration. The annual monthly average was 7.5465 h. The maximum sunshine duration, 8.1452 h, occurred in June, whereas the minimum, 6.9871 h, occurred in March. The results indicate greater fluctuation and higher sunshine duration during the rainy season, and slightly more stable but lower sunshine duration during the dry season. Average sunshine duration was 7.4497 h during the dry season and 7.6157 h during the rainy season.

Figure 6 shows the monthly and seasonal variability in measured mean temperature. The monthly average mean temperature was 26.7798°C. The maximum mean temperature, 31.6871°C, occurred in April, whereas the minimum, 21.4323°C, occurred in January. The results indicate relatively stable high temperatures during the rainy season and greater fluctuations, with lower temperatures, during the dry season. Mean temperature averaged 24.1590°C during the dry season and 28.6518°C during the rainy season.

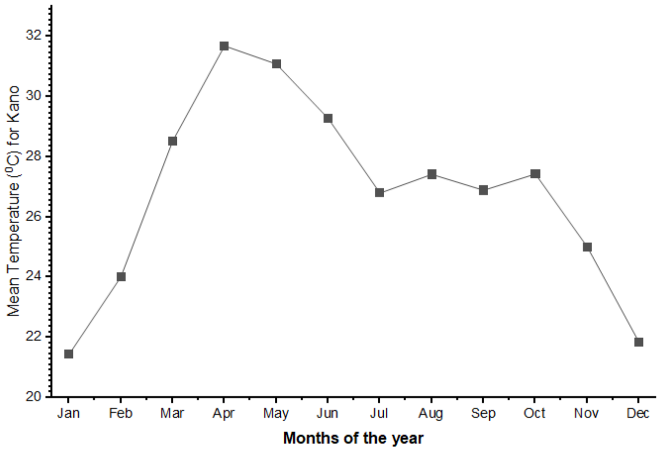

Figure 6. Monthly variation of mean temperature for Kano.

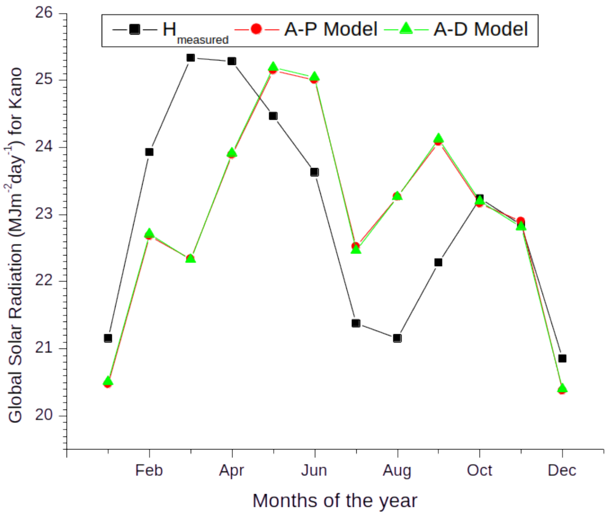

Figure 7. Comparison of estimated sunshine-based models and measured global solar radiation for Kano.

Table 1. Correlation between solar radiation and power output for Kano.

Parameter	CAS1	CAS2	CAT1	CAT2
Correlation	1.00	1.00	1.00	1.00

Table 2. Coefficient of variation for Kano.

Parameter	CV1	CV2	CV3	CV4
Value (%)	4.039348	6.252597	1.319007	7.922727

Table 3. Seasonal energy-yield comparison for Kano.

Parameter	SV	SV1	SV2	SV3	SV4
Value (%)	3.392559	10.87523	10.87978	3.103323	4.062376

Figure 7 compares measured global solar radiation with estimates from the sunshine-based models. The Angstrom–Prescott model underestimated measured global solar radiation from January to April and in December, overestimated it from May to September, and produced comparable values in October and November. The Ampratwum–Dorvlo model showed the same pattern. Thus, there was no major difference in the overestimation or underestimation behaviour of the two sunshine-based models. In general, the measured global solar radiation exceeded

Table 4. Tested performance of each empirical model for Kano.

Model	R^2	MBE	RMSE	MPE
Angstrom–Prescott (H_1)	42.7	0.0215	1.4285	-0.3083
Ampratwum–Dorvlo (H_2)	42.7	0.0333	1.4303	-0.3579
Garcia (H_3)	92.2	0.0070	0.5133	-0.0951
Chen *et al.* (H_4)	87.2	0.0422	0.6702	-0.1845

Table 5. Ranking of the estimated models based on the statistical tests for Kano.

Model	R^2	MBE	RMSE	MPE	Total
Angstrom–Prescott (H_1)	3	2	3	3	11
Ampratwum–Dorvlo (H_2)	3	3	4	4	14
Garcia (H_3)	1	1	1	1	4
Chen *et al.* (H_4)	2	4	2	2	10

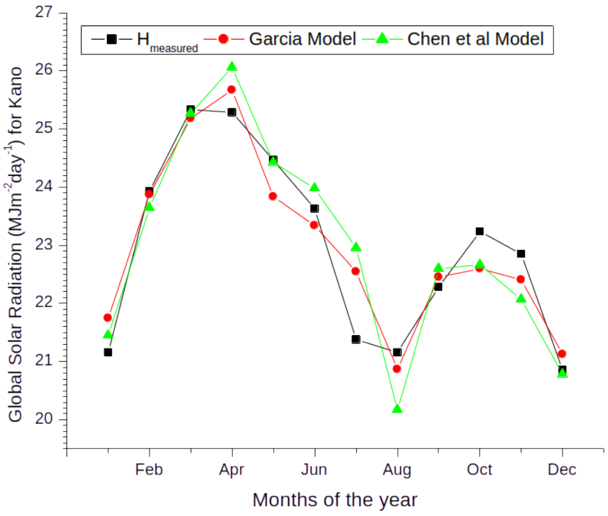

Figure 8. Comparison of estimated temperature-based models and measured global solar radiation for Kano.

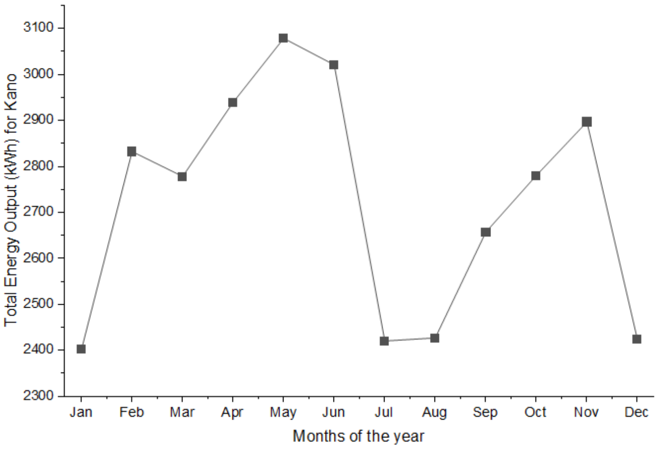

Figure 9. Monthly mean variation of total energy output for Kano.

the estimates during the dry season and was lower than the estimates during the rainy season, except in April, October, and November.

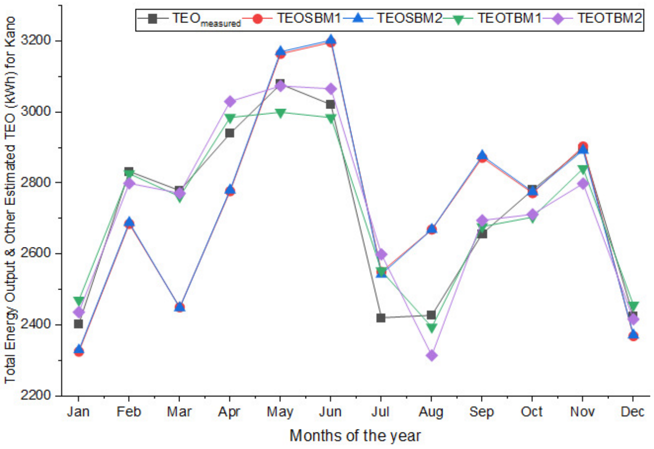

Figure 10. Comparison of total energy output with estimated total energy output from sunshine- and temperature-based models for Kano.

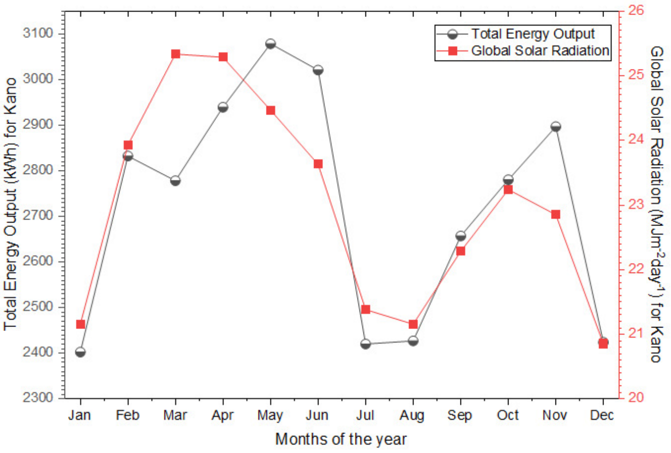

Figure 11. Comparison of total energy output with global solar radiation for Kano.

Figure 8 compares measured global solar radiation with estimates from the temperature-based models. The Garcia model overestimated measured global solar radiation in January, April, July, September, and December, and underestimated it in March, May, June, August, October, and November, with little or no de-

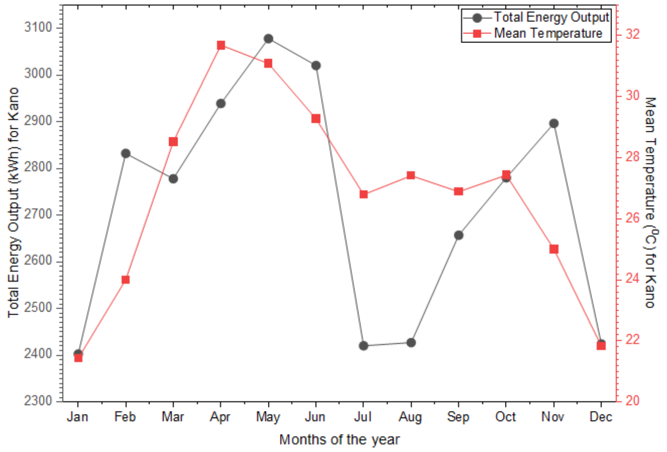

Figure 12. Comparison of total energy output with mean temperature for Kano.

viation in February. The Chen *et al.* model overestimated measured global solar radiation in January, April, June, July, and September, and underestimated it in March, May, and December. Both temperature-based models therefore showed random patterns of overestimation and underestimation across the rainy and dry seasons.

Figure 9 shows the monthly total energy output for Kano. The mean monthly total energy output was 2721.4354 kWh. The highest total energy output occurred in May, with a value of 3078.2938 kWh, as solar irradiance and sunshine duration increased to 6.7964 $\mathrm{kW\,m^{-2}}$ and 8.0161 h, respectively. The minimum output, 2402.5827 kWh, occurred in January, when solar irradiance and sunshine duration decreased to 5.8769 $\mathrm{kW\,m^{-2}}$ and 7.2355 h, respectively.

Figure 10 compares total energy output with the outputs estimated using the sunshine- and temperature-based models. The estimated total energy output from sunshine-based model 1 (TEOSBM1) underestimated the measured total energy output from January to April and in December, overestimated it from May to September, and produced comparable values in October and November. Sunshine-based model 2 (TEOSBM2) showed the same behaviour. Thus, no major difference was observed between TEOSBM1 and TEOSBM2 in terms of overestimation or underestimation. Temperature-based model 1 (TEOTBM1) overestimated measured total energy output in January, April, July, September, and December, and underestimated it in March, May, June, August, October, and November, with little or no deviation in February. Temperature-based model 2 (TEOTBM2) overestimated the measured total energy output in January, April, June, July, and September, and underestimated it in March, May, and December.

Figure 11 shows the effect of monthly solar-radiation variability on energy generation in Kano. As solar radiation increased from 21.1568 $\mathrm{MJ\,m^{-2}\,day^{-1}}$ in January to 23.9279 $\mathrm{MJ\,m^{-2}\,day^{-1}}$ in February, monthly energy generation also increased from 2402.5827 to 2832.3614 kWh. In March, the maximum solar-radiation value of 25.3342 $\mathrm{MJ\,m^{-2}\,day^{-1}}$ coincided with a lower total energy output of 2778.2113 kWh. Similarly, total energy output increased in April, May, and November despite slight decreases in solar radiation. Overall, total energy output increased with increasing solar radiation and decreased when solar radiation declined, although deviations occurred in months affected by aerosols, clear-sky conditions, and variations in sunshine duration.

Figure 12 shows the effect of monthly mean-temperature variability on energy generation. In most months, energy generation corresponded with temperature; however, in March, energy generation decreased despite an increase in temperature. Maximum energy output occurred in May, likely because of clear-sky conditions, whereas output decreased substantially between July and August because of increased cloud cover.

Table 1 shows the correlation between solar radiation and energy output for Kano. The results indicate that all parameters have a strong positive correlation; as solar radiation increases, power output increases proportionally. Table 2 presents the coefficient of variation in solar-energy output. CV3, corresponding to temperature-based model 1, had the lowest variation (1.32%), indicating highly stable solar-energy output, whereas CV4, corresponding to temperature-based model 2, had the highest variation (7.92%), indicating greater fluctuations in energy output.

Table 3 shows the percentage variation in energy output between the dry and rainy seasons. SV1 and SV2, corresponding to sunshine-based models 1 and 2, showed significant seasonal variation of approximately 10.88%. The measured seasonal variation (SV) and SV3 showed low seasonal variation of about 3%, whereas SV4 showed a moderate change of 4%. The significant drops in energy generation for SV1 and SV2 indicate that temperature-based models are more appropriate for the Sahelian region of Nigeria.

Table 4 presents the statistical errors for each empirical model used to estimate global solar radiation in Kano. Based on MBE, RMSE, and MPE, the Garcia model (H_3) had the lowest values, 0.0070, 0.5133, and −0.0951, respectively, with a coefficient of determination of $R^2 = 92.2\%$. Based on the MPE, all models fell within the acceptable range (MPE ≤ ±10%). Table 5 ranks the models according to the validation results. The total ranks ranged from 4 to 14. Overall, the Garcia model (Equation 3) was the best and most suitable model for estimating global solar radiation in Kano.

The following regression equations for the sunshine-based models (Equations 18 and 19) and temperature-based models (Equations 20 and 21) are recommended for estimating global solar radiation in Kano where measured global solar radiation is unavailable. These equations were obtained by regression analysis using Minitab software:

$$\frac{H}{H_o} = 0.059 + 0.945\left(\frac{S}{S_o}\right), \tag{18}$$

$$\frac{H}{H_o} = 0.931 + 0.596\ln\left(\frac{S}{S_o}\right), \tag{19}$$

$$\frac{H}{H_o} = 0.439 + 0.199\left(\frac{\Delta T}{S_o}\right), \tag{20}$$

$$\frac{H}{H_o} = 0.123 + 0.210\ln(\Delta T). \tag{21}$$

4. CONCLUSION

The analysis of solar-radiation variability over Kano demonstrated significant seasonal and inter-annual fluctuations and confirmed the city's strong potential for photovoltaic energy generation. Energy output increased proportionally with solar radiation and sunshine duration, although occasional deviations occurred because of atmospheric conditions such as aerosols and cloud cover. Seasonal analysis indicated slightly higher solar radiation during the rainy season than during the dry season, a pattern attributed to reduced dust and aerosol concentrations. Among the models tested, the Garcia temperature-based model (Equation 3) provided the most accurate estimate of global solar radiation, with the highest coefficient of determination ($R^2 = 92.2\%$). These results indicate that temperature-based models are more reliable for predicting solar radiation in Kano and, by extension, the Sahelian region. The study concludes that Kano possesses abundant and consistent solar resources suitable for large-scale photovoltaic deployment, making it a viable hub for sustainable energy generation. The findings contribute to improved solar-energy forecasting and provide a framework for policymakers, engineers, and energy developers seeking to enhance renewable-energy utilisation in Nigeria.

DATA AVAILABILITY

The meteorological data used in this study were obtained from the Nigerian Meteorological Agency (NiMet), Oshodi, Lagos, Nigeria, and are available from the corresponding author on reasonable request, subject to NiMet data-access policies.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] K. S. Reddy, T. K. Mallick & D. Chemisana, "Solar power generation", International Journal of Photoenergy **2013** (2013) 950564. https://doi.org/10.1155/2013/950564.

[2] S. Mehdizadeh, J. Behmanesh & K. Khalili, "Comparison of artificial intelligence methods and empirical equations to estimate daily solar radiation", Journal of Atmospheric and Solar-Terrestrial Physics **146** (2016) 215. https://doi.org/10.1016/j.jastp.2016.06.006.

[3] O. V. Oluchi, D. L. Kelechi, E. V. Chukwuemeka, O. C. Auselm & E. K. Opara, "Exploring the ideal photovoltaic PV tilt angle across the six geopolitical zones in Nigeria", Journal of Electrical and Electronic Engineering **2** (2024) 25. https://doi.org/10.48001/joeeed.2024.2225-.

[4] A. Mamman, J. Abdullahi & A. A. Abdulhamid, "Assessment of solar radiation models and measurement techniques for Nasarawa State", International Journal of African Development and Sustainable Research **6** (2024) 255. https://nightingalepublications.com/index.php/nijadsr/article/view/214/226.

[5] M. Bashahu & G. Ndacayisaba, "Estimation of daily global solar radiation with different sunshine-based models for some Burundian station", Energy and Power Engineering **16** (2024) 161001. https://doi.org/10.4236/epe.2024.161001.

[6] D. B. Ampratwum & A. S. S. Dorvlo, "Estimation of solar radiation from the number of sunshine hour", Applied Energy **63** (1999) 161. https://doi.org/10.1016/S0306-2619(99)00025-2.

[7] D. O. Akpootu, B. I. Tijjani & U. M. Gana, "Sunshine and temperature dependent models for estimating global solar radiation across the Guinea Savannah climate zone of Nigeria", American Journal of Physics and Applications **7** (2019) 125. https://doi.org/10.11648/j.ajpa.20190705.15.

[8] R. Chen, K. Ersi, J. Yang, S. Lu & W. Zhao, "Validation of five global solar radiation models with measured daily data in China", Energy Conversion and Management **45** (2004) 1759. https://doi.org/10.1016/j.enconman.2003.09.019.

[9] C. Maduabuchi & M. Eke, "Solar electricity generation using a photovoltaic thermoelectric system operating in Nigeria climate", IOP Conference Series: Earth and Environmental Science **730** (2021) 012029. https://doi.org/10.1088/1755-1315/730/1/012029.

[10] A. A. Garba, R. O. Amusat & Y. H. Ngadda, "Estimation of global solar radiation using sunshine-based model in Maiduguri, North East, Nigeria", Applied Research Journal **2** (2016).

[11] A. Gagne, D. Turcotte, N. Goswamy & Y. Poissant, "High resolution characterization of solar variability for two sites in Eastern Canada", Solar Energy **137** (2016) 46. https://doi.org/10.1016/j.solener.2016.07.042.

[12] D. Palmer, E. Koubli, I. Cole, T. Betts & R. Gottschalg, "Comparison of solar radiation and PV generation variability: system dispersion in the UK", IET Renewable Power Generation **11** (2017) 550. https://doi.org/10.1049/iet-rpg.2016.0768.